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Blockchain Technology Applications in the Supply Chain: A Critical Analysis

By

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Abstract

Blockchain is a combination of technologies comprising a digital chain of records that are time-stamped, uniquely identified, and stored in chronological order. It has been recognised as a potentially disruptive technology due to its core characteristics, including decentralisation, immutability, security, transparency, and traceability. Blockchain has captured the interest of many organisations that are increasingly experimenting with the technology in various applications ranging from financial services to healthcare and logistics and supply chain management. Supply chain academics and professionals have acknowledged the potential of blockchain to transform supply chains and operations management. However, the academic literature on blockchain applications in the supply chain lags behind its applications in practice and is mostly conceptual with limited empirical research. Many blockchain implementations in practice do not go beyond the pilot stage. Industry professionals lack evidence-based guidance on blockchain capabilities and potential applications in the supply chain. Thus, it is crucial to conduct empirical research to provide an in-depth analysis of blockchain's capabilities and its potential implications for supply chains to provide guidance on the main considerations related to its adoption, application and scalability.

This research investigates empirically the main motivations behind blockchain adoption and the main pre-requisites, inhibitors and factors influencing blockchain adoption and scalability within different supply network configurations. It also examines the influence of sectoral characteristics on blockchain adoption and applications in the different industries. The study uses mixed research methods, including multiple case studies of leading organisations at different stages of blockchain adoption and across different industries, an analysis of secondary data sources for reported blockchain use cases, and an executive workshop that debated blockchain-enabled supply chain traceability.

The research findings provide comprehensive guidelines for blockchain adoption in the supply chain from the pre-adoption stage to the scaling of blockchain across supply networks. The research identifies the main industry motivations, main application areas and specific sectoral characteristics influencing blockchain adoption and application in the supply chain. The research also studies the decision-making process for blockchain adoption and application in the supply chain. The study also provides specific guidance for one of the most critical application areas for blockchain - supply chain traceability.

This research has significant theoretical and practical contributions for this emerging and prominent field. It provides new empirical evidence to the main motivations behind blockchain adoption in the supply chain, highlighting the importance of new considerations not discussed in the literature, including customer service, risk management and quality assurance. The research also develops three important frameworks: First, it proposes the first cross-sectoral framework that captures the main motivations, application areas and industry characteristics that influence blockchain adoption and application in the supply chain. This framework can lay the foundation for future research that can further investigate the different associations identified in the framework between the motivations, application areas and industry characteristics. Second, the research proposes the first decision model that provides guidance to the selection of blockchain technology and its application area in the supply chain. Third, the research proposes a framework for theory that identifies different combinations of theoretical perspectives to further study and contribute to theory development in the blockchain-SCM research. The research findings and developed frameworks provide detailed guidance to practitioners interested in investigating and adopting blockchain in their supply chain.

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List of Abbreviations

AL	Aluminium
API	Application Programming Interface
BRWB	Battery Raw Material Buyer
BOL	Bill of Lading
CTS	Cattle Tracing System
Co	Cobalt
DPoS	Delegated Proof of Stake
DRC	Democratic Republic of Congo
DNA	Deoxyribonucleic Acid
DLT	Distributed Ledger Technology
DSCSA	Drug Supply Chain Security Act
EV	Electric Vehicle
EDI	Electronic Direct Interface
ERP	Enterprise Resource Planning
ECM	Environmental Compliance Manager
EU	European Union
FSC	Food Supply Chain
FSC	Forest Stewardship Council
GIGO	Garbage In Garbage Out
GDPR	General data protection regulations
GBA	Global Battery Alliance
C	Graphite
ID	Identification Number
ISS	Information Systems Success
IP&C	Instrument Panel and Console
IP	Intellectual Property
ISO	International Organisation for Standardisation
IPCSA	International Port Community Systems Association
IoT	Internet of Things
ITD	IT Director
JIT	Just-in-time
LSC	Leather Supply Chain
LoC	Letter of Credit
Li	Lithium
LIB	Lithium-ion Battery
LSP	Logistic Service Providers
MRO	Maintenance, Repair and Overhaul
Mn	Manganese
MSC	Mediterranean Shipping Company
MOBI	Mobility Open Blockchain Initiative

NFC	Near-field Communication
Ni	Nickel
NGO	Non-government Organizations
NPT	Normalisation process theory
OEM	Origin Equipment Manufacturer
PBFT	Practical Byzantine Fault Tolerance
PAT	Principal Agent Theory
PEFC	Programme for the Endorsement of Forest Certification
PoS	Proof-of-Stake
PoW	Proof-of-Work
PM	Purchasing Manager
PSM	Purchasing Senior Manager
QR	Quick Response
RFID	Radio Frequency Indentification
RQ	Research Question
RDT	Resource Dependency Theory
RBV	Resource-based View
ROI	Return-on-investment
SPM	Senior Project Manager
SSE	Senior Sustainability Engineer
SME	Small and Medium Enterprise
SaaS	Software-as-as-service
SWOT	Strength, Weakness, Opportunity and Threat
SC	Supply Chain
SCDM	Supply Chain Design Manager
SCM	Supply Chain Management
TTF	Task-Technology Fit
TOE	Technological, Organisational, and Environmental Framework
TAM	Technology Acceptance Model
TRI	Technology Readiness Index
TSC	Textile Supply Chain
TPB	Theory of Planned Behaviour
3PL	Third-party Logistics Partner
TQM	Total Quality Management
TCA	Transaction Cost Analysis
UKFT	UK Fashion and Textile Association
UTAUT	Unified Theory of Acceptance and Use of Technology
VIN	Vehicle Identification Number
WEF	World Economic Forum

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Chapter 1: Introduction

1.1 Problem Background

The supply chain management (SCM) field has always been influenced by changes in technology, consumer behaviour, regulations, and the economy. Globalisation of business has brought increasing complexity, uncertainty, risks, and opacity to supply networks. In addition, the increasing pressure from customers and regulators to ensure sustainable practices has forced organisations to engage with and be responsible for their extended supply chains (Saberi *et al.*, 2019). However, many organisations lack detailed knowledge about their supply chains, limiting their ability to address many supply chain challenges and manage uncertainties effectively. The recent Covid-19 pandemic is a living example of disruptions affecting many organisations' operations and supply chains, addressing the necessity to understand supply chain (SC) configurations to better manage risks and uncertainties.

SCM researchers and practitioners have been investigating new ways to improve SC transparency, visibility, and information sharing capabilities. The development of communication technologies and the advancement and refinement of information systems have significantly improved information flows across supply chains over the last three decades. Several technologies have emerged, including Enterprise Resource Planning (ERP), Radio Frequency Identification (RFID) and Cloud Manufacturing that facilitate the collection, storage, and analysis of relevant SC data (Davies and Wang, 2021; Fazlollahi and Franke, 2018; Peng and Gala, 2014). However, most existing information systems operate in isolation and are fragmented across the supply chain. Many systems are centralised and can be tampered with, which increases the risk of corruption or leakage of information (Arora, Gera, *et al.*, 2021; Kshetri, 2018; Li, Wang, *et al.*, 2018; Peng and Gala, 2014; Toyoda *et al.*, 2017). Therefore, there is a continuing need for technologies that make supply networks more connected, secure, and transparent.

1.2 Why Blockchain?

Blockchain has emerged as a potential technology for applications in the supply chain (Glaser, 2017; Wamba and Queiroz, 2020; Xu *et al.*, 2019). Blockchain was first introduced by Satoshi Nakamoto in 2008 in proposing the Bitcoin concept (Nakamoto, 2008). A blockchain is a

decentralised and distributed ledger shared in a peer-to-peer network, consisting of blocks of transactions that are time-stamped, cryptographically identified and linked in a chain-like structure (Crosby *et al.*, 2016). Transactions recorded in a blockchain are validated based on a consensus mechanism, establishing an agreement on the ledger status and history to provide a shared truth among the participating nodes in the network (Treiblmaier, 2020). Blockchain core characteristics are the creation of immutable, traceable, and shared digital records of time-stamped transactions. Blockchain concepts and technologies have developed rapidly, including numerous data structures from decentralised public cryptocurrencies to permissioned and private blockchains (Zhou, Huang, *et al.*, 2020). The functionality of blockchain has been greatly expanded with the development of 'smart contracts' - self-executing codes stored in the blockchain, triggered by predetermined events (Christidis and Devetsikiotis, 2016; Crosby *et al.*, 2016).

Blockchain's core characteristics provide several opportunities for its applications in the supply chain (Mann *et al.*, 2018; Papathanasiou *et al.*, 2020). Blockchain can provide a secure medium for instant information sharing among distributed SC partners, facilitating secure information sharing across the fragmented structures of global supply networks (Wamba and Queiroz, 2020). Blockchain may help tackle some major SCM challenges, including visibility, traceability and transparency (Jardim *et al.*, 2021; Verhoeven *et al.*, 2018; Wamba and Queiroz, 2020).The immutable chronological record of blockchain transactions supports verifiable traceability and auditability. Consequently, blockchain has been increasingly trialed to enable product traceability within different supply network configurations (Garrard and Fielke, 2020; Malik *et al.*, 2018; Mann *et al.*, 2018; dos Santos *et al.*, 2019). The autonomous capabilities provided by smart contracts may foster the automation and digitalisation of business processes with the potential to transform many business models (Christidis and Devetsikiotis, 2016; Dolgui *et al.*, 2020; Wamba and Queiroz, 2020). Smart contracts may support network governance, transaction validation, as well as quality, environmental and sustainability data management and verification (Chohan, 2021; Kummer *et al.*, 2020; Philipp *et al.*, 2019; dos Santos *et al.*, 2019; Xu *et al.*, 2018). We introduce the blockchain technology and its core characteristics in Section 2.1.

Despite the manifold potentials of blockchain, the technology is still in its developmental stage. It is unclear how it will modify or be incorporated into the existing landscape of digital operations, processes, services, and infrastructures. The academic body of knowledge on

blockchain is immature in its understanding of the technology and its capabilities in SCM (Glaser, 2017; Lacity and Van Hoek, 2021; Wong *et al.*, 2020). However, there is strong interest in investigating the potential of blockchain across various SC and enterprise applications (Jardim *et al.*, 2021; Queiroz and Wamba, 2019).

SCM practitioners are ahead of the research community in experimenting with blockchain (Kshetri, 2018; Lim *et al.*, 2021). Many organisations are increasingly experimenting with blockchain in various SC application areas e.g., (Carrefour, 2018; Everledger, 2020). Blockchain has already captured the interest of many start-ups and consortia (Ahmed and MacCarthy, 2022; Lacity and Van Hoek, 2021; Lacity, 2018a), with a growing body of practice literature (Vadgama and Tasca, 2021). A study by MarketsAndMarkets indicated that blockchain SC market (based on offerings (service Vs platforms), blockchain network type, application area, industry and region) is expected to grow from USD 253 million in 2020 to USD 3,272 million in 2026 (MarketsAndMarkets, 2021). The Mordor Intelligence (2020) report predicts a strong compound rate of growth of 81.7% between 2021 to 2026. Numerous recent studies underscore the relevance and potential of blockchain for transforming supply chains with respect to business intelligence, transparency and traceability, end-to-end visibility and resolving multi-party disputes (Cognizant, 2018; Deloitte, 2018; IBM, 2018, 2020; WEF, 2020).

1.3 Overview of Major Literature Gaps

Despite its emergence in 2008, academic literature on blockchain applications in the supply chain did not emerge until 2016 (Casino *et al.*, 2019; Gurtu and Johny, 2019; Queiroz *et al.*, 2019), resulting in a big time lag between research and practice (Treiblmaier, 2020). Industry professionals lack academic guidance on blockchain capabilities, adoption, and scalability in the supply chain, contributing to the limited number of blockchain implementations beyond the pilot stage. Thus, it is crucial to conduct more evidence-based research to enable an in-depth understanding and analysis of blockchain's capabilities and implications and provide comprehensive guidance on its adoption and scalability for SC applications.

Many researchers have anticipated the potential benefits of blockchain in the supply chain (Kamble *et al.*, 2019; Kshetri, 2018; Queiroz and Wamba, 2019; Rejeb, Keogh, *et al.*, 2021). Maull *et al.* (2017) argued that blockchain could significantly improve SC visibility and enable

traceability for complex supply networks. Many researchers have followed this path and investigated blockchain adoption to enable traceability in the supply chain across various sectors (Agrawal *et al.*, 2021; Baralla *et al.*, 2021; Bullón Pérez *et al.*, 2020; Ho *et al.*, 2021; Kuhn *et al.*, 2021; Mann *et al.*, 2018; Tian, 2017; Xu *et al.*, 2019).

Viriyasitavat and Hoonsopon (2019) anticipated that blockchain could enable the automation and digitalisation of business processes to overcome SCM challenges resulting from increased globalisation and SC complexity. The immutable distributed ledger of blockchain may provide SC partners with access to information to track shipments, deliveries, and progress, resulting in increased transparency and trust, the elimination of some intermediaries, improvements in performance, and reduced costs (Jović *et al.*, 2019; Pournader *et al.*, 2020). Blockchain may also be used to secure the storage and transmission of digitally signed documents, improving the efficiency, lead time and costs of the shipping processes (Li and Zhou, 2020; Papathanasiou *et al.*, 2020), verification and auditing processes (Chang *et al.*, 2019; Loklindt *et al.*, 2018), product recall processes (Miehle *et al.*, 2019; Saberi *et al.*, 2019), and certifications processes (dos Santos *et al.*, 2019).

However, despite the increasing interest, most of the growing literature in the area is conceptual (van Hoek, 2019a, 2019b; Sternberg *et al.*, 2021; Wamba and Queiroz, 2020), anticipating the potential benefits and barriers for blockchain adoption (Cole *et al.*, 2019; Grover *et al.*, 2018; Hughes *et al.*, 2019; Jardim *et al.*, 2021; Rejeb, Keogh, *et al.*, 2021; Wang, Han, *et al.*, 2019). The increasing number of research reviews of the limited literature has resulted in a recurrence of the same themes of claimed benefits, applications, and anticipated challenges for blockchain applications but with a lack of supportive empirical evidence.

The sole use of the academic literature can provide only limited insights into how blockchain can be applied in practice (Wang, Han, *et al.*, 2019). There is limited empirical research that investigates real blockchain use cases. Kshetri (2018) analysed a variety of practical blockchain use cases to investigate how blockchain can address essential SCM objectives, including speed, quality, cost, flexibility, dependability, risk reduction and sustainability. Lacity (2018) studied three different practical applications for blockchain to identify the main challenges for adoption. van Hoek (2019a, 2019b) also conducted three case studies to better understand the drivers and key considerations for blockchain adoption and compared it to RFID development. Li and Zhou (2020) analysed seven blockchain applications in the maritime industry to identify the potential application areas. Most blockchain applications in practice are still in the early

stages of adoption and have yet to become commercial or be implemented at scale (Wamba and Queiroz, 2020). Moreover, limited information about these projects is available in the public domain, hindering further analysis or obtaining insights from these implementations. The immaturity of blockchain technology and its limited adoption at scale also limit the insights that can be gathered using empirical data collection methods such as questionnaires and surveys (van Hoek, 2019b).

Some researchers adopted other empirical research methods such as conducting workshops and in-depth interviews to gain in-depth insights into the drivers, challenges, and key considerations regarding blockchain adoption in the supply chain e.g., (van Hoek, 2019c; Kayikci *et al.*, 2020; Lopes *et al.*, 2021). However, despite the detailed information that can be gathered using these methods, they have limitations e.g., the number of participants and their knowledge and awareness of blockchain and its capabilities, their level of expertise and the design and length of the workshop. As noted by van Hoek (2019b), surveys and workshops can be useful to identify an initial framework and important themes but need to be investigated further by in-depth case research.

Several researchers recommended the use of case studies to investigate blockchain applications in practice to transfer industry knowledge and experience into further developing blockchain research for theory testing and development (van Hoek, 2019a; Sternberg *et al.*, 2021; Treiblmaier, 2020). Although still small, an increasing number of case studies have been conducted across different industries (Dede *et al.*, 2021). However, most conducted case studies are sector specific. There is limited research that investigates case studies in different sectors (Aich *et al.*, 2019; Danese *et al.*, 2021; van Hoek, 2019a; Lacity, 2018a), but none have applied a cross-industry lens to understand whether the sectoral characteristics influence blockchain adoption and application areas in the supply chain. There is a notable lack of research investigating how blockchain may be applied in different SC contexts taking account of the different supply network configurations and complexity, products, and business processes characteristics, and the various forms of ownership, relationships, and power structures that differ substantially across industries (Demirel *et al.*, 2019; MacCarthy *et al.*, 2016). Given the wide diversity of supply chains, there is a need to better understand the factors that influence blockchain applications in different contexts to guide future applications.

The growing literature dispersedly highlighted several potential factors influencing blockchain adoption in the supply chain. These factors include blockchain scalability and interoperability,

organisation size, and existing regulations and standards (Clohessy *et al.*, 2019; Janssen *et al.*, 2020), perceived benefits of blockchain and technology readiness and maturity (Queiroz *et al.*, 2021), availability of funds (Sternberg *et al.*, 2021), clearly defined vision and value proposition (Wang, 2020), data accessibility and information sharing (Lopes *et al.*, 2021) . Other factors influencing blockchain adoption broadly discussed in the literature, include management involvement and support (Chen *et al.*, 2018; van Hoek, 2019a; Mendling *et al.*, 2018), awareness about blockchain and its capabilities (Caldarelli *et al.*, 2021), and trust issues (Batwa and Norrman, 2021). However, there is a strong need for investigation of empirical case studies to enable an in-depth understanding and analysis of the main factors influencing blockchain adoption and deployment in the supply chain.

The immaturity of blockchain technology and its adoption in the supply chain have contributed to the lack of its theory development. The nature of blockchain applications and their potential implications call for multidisciplinary theoretical perspectives to develop a better understanding of the technology, its capabilities, and its impact at this early stage of development (Saberi *et al.*, 2019). However, given the limited amount of adoption in practice, we argue that industry data is needed to assess and further develop theory-driven research. It is crucial to first examine and analyse in-depth real applications of blockchain in the supply chain to better understand why organisations are seeking to apply the technology, where they are seeking to use it, and the factors influencing its adoption and deployment. This evidence can then be interpreted using relevant theoretical perspectives to further develop and refine existing theory. The use of grounded theory when studying blockchain applications can provide opportunities to develop new theoretical perspectives that advance the emerging body of knowledge (Glaser and Strauss, 2017; Saberi *et al.*, 2019).

1.4 Research Aim, Questions and Objectives

This research aims to critically analyse the use of blockchain technology in the supply chain. We apply grounded theory to study and analyse the use of blockchain and its applications in the SCM field using mixed research methods to enable a rigorous investigation and provide comprehensive insights that address major literature gaps. We seek to answer the following research questions (RQs):

RQ1: How do industry characteristics influence blockchain applications in the supply chain?

RQ2: What are the main motivations for blockchain adoption and application in the supply chain?

RQ3: What are the key pre-requisites and inhibitors for blockchain adoption and deployment in the supply chain?

RQ4: What factors influence the decision-making and scalability of blockchain-enabled solutions in supply chain applications?

To achieve the research's aim and answer the research questions, this research has the following objectives:

1. Conduct multiple case studies across different industries and at different stages of blockchain deployment.
2. Investigate and analyse blockchain practical applications in the supply chain across diverse industries.
3. Identify and provide in-depth analysis of the main motivations, pre-requisites and inhibitors, and factors influencing blockchain adoption and scalability within different supply network configurations.

1.5 Research Methodology

This research uses multiple case studies, complemented with secondary data analysis of a large sample of blockchain use cases reported in practice and an executive workshop, to provide new empirical evidence that is validated and triangulated using multiple methods.

The multiple case studies comprise of four cross-sectoral case studies at different stages of blockchain adoption- pre-adoption, development of a blockchain use case, a pilot application, and a commercial application. The case study industries are the automotive, textiles, and international shipping and maritime logistics. The use of cross-sectoral case studies aims at bridging the literature gap by investigating the sectoral characteristics and their influence on blockchain adoption and deployment. The different stages of blockchain adoption across the case studies provide in-depth insights into the main pre-requisites, inhibitors and factors influencing the decision-making, adoption and scalability of blockchain in the supply chain beyond the commonly investigated pilot stage.

The analysis of blockchain use cases covered 50 cases reported across six sectors: Automotive, Aerospace, Food and Beverages, International Shipping and Logistics, Pharmaceutical and Textile and Apparel. It enabled the generation of rich insights into the variety of blockchain applications in practice across other sectors and SC characteristics not addressed in the case studies. It provides complementary findings to the influence of industry characteristics on blockchain applications in the supply chain (RQ1) and the main motivations for blockchain adoption in the supply chain (RQ2).

The executive workshop aimed at discussing the drivers, challenges, and requirements for blockchain adoption for SC traceability, a major blockchain application area (addressing RQ2, RQ3, and RQ4). The workshop included 22 participants from five organisations. The workshop participants were divided into groups and were given different sets of questions to discuss and answer. The workshop provided in-depth insights about the motivations, factors and challenges influencing blockchain application for SC traceability.

The research methodology has generated comprehensive data that were analysed using a variety of techniques, including content analysis, within-case and cross-case analysis, pattern match logic and framework analysis. The research findings from the different studies were compared, validated, and triangulated, providing comprehensive answers to the four research questions.

1.6 Summary of Research Contribution

The research contributions have significant theoretical and practical implications. The use of grounded theory enabled the collection of comprehensive data and the consideration of many aspects that could potentially influence blockchain adoption and deployment. The research findings confirmed the multidisciplinary nature of blockchain research and the variety of theoretical perspectives that can provide insights into different aspects of this prominent phenomenon. We summarise the main research contributions below:

- Identification of the main motivations, application areas and industry characteristics influencing blockchain adoption and application areas in the supply chain. This has led to the development of an evidence-based conceptual framework that takes a cross-industry perspective and captures the principal industry motivations, the main application areas, and the key industry characteristics influencing blockchain adoption and application. The framework

provides a strong foundation for future research that can adopt different theoretical perspectives to investigate the different associations captured in the framework.

- Identification of the main pre-requisites and inhibitors for blockchain adoption and deployment in the supply chain based on empirical cross-sectoral evidence of real blockchain application at different stages of adoption. The identified pre-requisites and inhibitors have strong theoretical and practical implications by identifying new dimensions not considered previously in the blockchain-SCM literature, including the consideration of supply chain configuration characteristics, knowledge about the supply chain, ability to create a supply chain digit twin.
- Identification of the main factors that influence the decision-making, adoption and scalability of blockchain in the supply chain based on empirical cross-sectoral evidence of real blockchain application at different stages of adoption. This has helped in the development of an empirically based decision framework that guides the decision-making process regarding blockchain adoption and the selection of application area in the supply chain. The framework is the first to provide guidance to where to apply blockchain in the supply chain. Furthermore, by focusing on blockchain application to enable SC traceability, the research develops a novel framework that defines the different scopes of SC traceability that can be targeted by the different organisations.
- The research provides a structured approach and guidance into the use of multiple theoretical perspectives to further investigating different aspects of blockchain-SCM research. It presents a framework for theory that proposes different combinations of multidisciplinary theoretical perspectives to be used in blockchain-SCM research to contribute to its theory development.

1.7 Dissemination of Results

The research findings were presented in a number of international conferences and were published as book chapters and journal papers, including:

1.7.1 Conference papers

Ahmed, WA.H. and MacCarthy, B. (2022) "Blockchain-enabled Supply Chain Traceability: How Deep? How Wide?" *International Working Seminar on Production Economics (Online),* February 21-25, 2022.

Ahmed, WA.H. and MacCarthy, B. (2021) "Blockchain Technology in the Supply Chain: Why, Where and When?" *European Decision Science Conference (Online)*, May 29- June 1, 2021.

Ahmed, WA.H. and MacCarthy, B. (2021) "How do industry characteristics influence blockchain applications in the supply chain? Insights from Practice. *Production and Operations Management Society Conference (Online)*, April 30- May 5, 2021.

Ahmed, WA.H. and MacCarthy, B. (2020) "Blockchain Technology in the Supply Chain: A Decision Model". *Decision Science Conference (Online)*, Nov 21-23, 2020.

Ahmed, WA.H., MacCarthy, B., Petrovic, S (2019) "Use of secondary data sources to investigate supply chains" *Production and Operations Management Society Conference*, Brighton, UK, Sep 2-4, 2019.

Ahmed, WA.H., MacCarthy, B., Petrovic, S (2019) Supply Chain Visualisation – How should we do it? *European Decision Science Conference*, Nottingham, UK, June 2-5, 2019.

1.7.2 Journal papers

Ahmed, WA.H., MacCarthy, B. and Treiblmaier, H (2022). Why, Where, and How are Organizations Using Blockchain in their Supply Chains? Motivations, Application areas, and Contingency Factors. *International Journal of Operations and Production Management*, in press.

Ahmed, W.A. and MacCarthy, B.L. (2022). Blockchain in the Supply Chain -A comprehensive framework for theory-driven research. *Digital Business*, p.100043.

Ahmed, W.A. and MacCarthy, B.L. (2021). Blockchain-Enabled Supply Chain Traceability in the Textile and Apparel Supply Chain: A Case Study of the Fiber Producer, Lenzing. *Sustainability*, 13(19), p.10496.

1.7.3 Book chapters

Ahmed, W.A.H. and MacCarthy, B.L. (2022) Blockchain Technology in the Supply Chain: Learning from Emerging Ecosystems and Industry Consortia. *Handbook on Digital Business Ecosystems: Strategies, Platforms, Technologies, Governance and Societal Challenges*, edited by Sabine Bauman, Edward Elgar: Cheltenham (UK), 2022, 800.

Ahmed, W.A.H. and Rios, A. (2022) Digitalisation of the International shipping and maritime logistics: A case study of Tradelens. *The Digital Supply Chain*, Edited by Bart MacCarthy and Dmitry Ivanov, Elsevier, 2022, 320.

Treiblmaier, H. Rejeb, A, and Ahmed, W.A.H. (2022) Introduction to the blockchain technology. *The Digital Supply Chain*, Edited by Bart MacCarthy and Dmitry Ivanov, Elsevier, 2022, 320.

This thesis is structured as follows: Chapter 2 provides an introduction to blockchain technology and an overview of the current literature on blockchain applications in the supply chain to identify the main literature gaps and pose relevant research questions. Chapter 3 explains the research methodology. Chapters 4, 5, 6 and 7 present four case studies in the automotive battery, automotive leather, textile fibre, and international shipping and maritime logistics industries, respectively. Chapter 8 provides a cross-case studies analysis guided by the research questions. Chapter 9 presents two complementary studies, including analysis of blockchain reported used cases and an executive workshop. Chapter 10 discusses the research findings in-depth and proposes the developed conceptual and decision frameworks. Chapter 11 summarises the research's theoretical and practical contributions, including research limitations and directions for future research.

Chapter 2: Literature Review

This chapter provides an overview of the literature on blockchain technology and its applications in the SCM field. We review the growing body of academic literature up to June 2021, including journal articles, conference papers, and some book chapters. We also refer to blockchain applications in practice, white papers, and industry reports where relevant. The chapter is structured as follows: Section 2.1 provides an introduction to blockchain technology, Section 2.2 provides an overview on blockchain adoption and applications in the supply chain, Section 2.3 analyses the variety of theoretical perspectives adopted in blockchain-SCM research, and finally, Section 2.4 concludes with a summary of the literature gaps and introduces the research questions.

2.1 Introduction to Blockchain Technology

A blockchain is a type of distributed ledger technology (DLT) comprising a digital chain of blocks stored in a distributed ledger and linked through cryptographic keys called hashes. Lacity (2018) defined blockchain as *"a distributed, peer-to-peer system for validating, time-stamping, and permanently storing transactions on a distributed ledger that uses cryptography to authenticate digital asset ownership and asset authenticity, and consensus algorithms to add validated transactions to the ledger and to ensure the ongoing integrity of the ledger's complete history."* Smart contracts also play an important role in blockchain development as they add further capabilities (Wang, Han, *et al.*, 2019; Xu *et al.*, 2019).

Blockchain is a combination of technologies that were in existence for a long time, but their unique combination was proposed by Satoshi Nakamoto in 2008 (Narayanan and Clark, 2017; Treiblmaier, 2020). In a simple way, blockchain is a digital technology that stores data in a chain of blocks where each block contains several transactions that are time-stamped and refers to the block that preceded it in the chain by the block hash (Figure 1). The blockchain ledger is distributed and shared across all the nodes in the blockchain network, and all nodes have access to the exact version of the ledger. Transactions in the blockchain are validated and added to the network based on the consensus mechanism employed, which ensures agreement on the recorded transactions and that all the nodes have access to the latest blockchain ledger (Christidis and Devetsikiotis, 2016; Crosby *et al.*, 2016; Zheng *et al.*, 2018). More information

on how blockchain works can be found in Pilkington (2016), Morkunas *et al.* (2019), and Treiblmaier (2020).

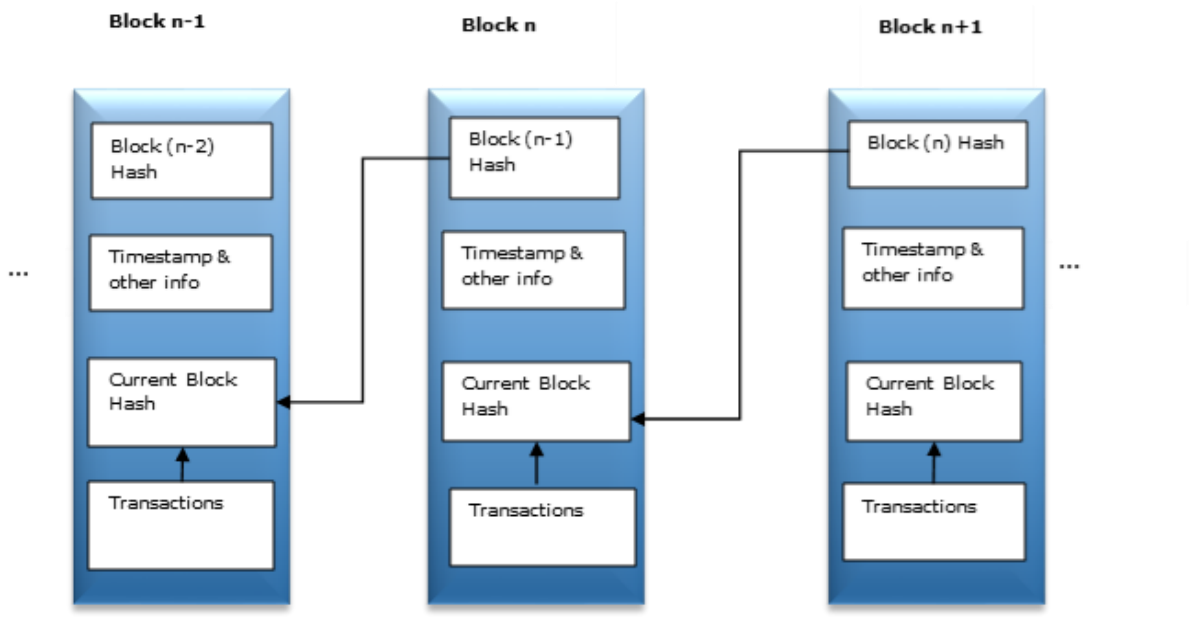


Figure 1. Illustration of blockchain architecture

We briefly explain several blockchain concepts to better understand its core characteristics (Section 2.2.1 discusses these concepts in the contexts of supply chains):

- **Block:** A block is a group of transactions containing any type of data, e.g., in the context of SCM, it can be financial, product, process or SC partner related data. Each block has a unique identification (i.e., hash), is timestamped, and contains information about the block that precedes it in the network (Wang, Hoang, *et al.*, 2019).
- **Distributed Ledger Technology:** Distributed ledgers are digital databases that are shared, validated, updated and synchronised by participants in a network, eliminating the need for a central authority (Lashkari and Musilek, 2021). Blockchain is a type of DLT that exhibits a chain-like structure.
- **Decentralisation:** Decentralisation is a form of organisational structure where decision-making and control are transferred from a central authority to a distributed network (Bhalla, 2021). The blockchain network is decentralised in terms of storage where all the nodes can share, access and have a copy of the distributed ledger, and of decision-making and governance where transactions are validated based on an agreement in the network rather than being dictated by a centralised authority (Treiblmaier, 2020). The

degree of decentralisation in blockchain varies across the different network types (Section 2.1.1).

- **Cryptography:** Cryptography is a method that prevents a third party from accessing and knowing the content of a message in a communication process (Singh, 2021). In the blockchain, two types of cryptography are used – (1) asymmetric-key cryptographic where an encryption public key, and decryption private key are used and are generated using the cryptographic algorithm, and (2) hash functions that use a cryptographic algorithm to generate a hash value of fixed length from the input data and is sensitive to any changes in the original data (Singh, 2021; Wang, Hoang, *et al.*, 2019). With asymmetric-key cryptography, nodes in the blockchain can interact using private keys to sign off transactions created by the specific node, and public keys to address the block in the network for validation. Hash functions do not include keys and create a unique hash representing the data where any change in the input data will lead to a new hash value. The same input will always generate the same hash value using the same function. Furthermore, it cannot regenerate the input data, and regardless of the length of the input data, the hash function's output is generated almost instantly[1] (Singh, 2021; Wang, Hoang, *et al.*, 2019). Some of the common cryptographic algorithms used in blockchain are SHA-256 and RIPEMD-160 (Singh, 2021; Wang, Hoang, *et al.*, 2019).
- **Blockchain Immutability:** The use of cryptography in blockchain help identify blocks and their data. With hash functions, each transaction is uniquely identified by a hash, that is generated from all the transactions in the block (Farah, 2018). The use of Merkle roots (Merkle, 1987) as a data structure of a block's transactions help ensure data immutability, optimise the on-chain storage, and help to identify and verify the transactions within blocks without the need to review the entire ledger or all transactions within blocks (Farah, 2018; Wang, Hoang, *et al.*, 2019).
- **Linked timestamping:** Digital timestamps were first proposed by Haber and Stornetta (1991) for documents that are signed by the creator. Nakamoto (2008) proposed the same data structure where each block is timestamped at the time of its creation and the information is stored in the block, and each block refers to past transactions (Narayanan

[1] https://andersbrownworth.com/blockchain for a visual demo on how the hash value changes with blockchain data

and Clark, 2017), creating a chronological immutable record of transactions (Treiblmaier, 2018).

- **Consensus mechanisms:** Consensus mechanisms ensure agreement on the ledger status and the transactions to be recorded on the blockchain (Treiblmaier, 2020). They allow distributed networks of computers to interact and work together in a secure way while ensuring information consistency. They vary in computational complexity, performance, scalability and fault-tolerance (Zhu, 2019). Some common consensus mechanisms include Proof-of-Work (PoW), Proof-of-Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT). PoW is the current consensus mechanism governing Bitcoin and Ethereum, in which all nodes try to solve a cryptographic puzzle (called a mining process). The node that solves it first adds and validates the new block and gains a reward, while in PoS, the possible selection of any node to mine the next block is proportional to its stake or balance and therefore, it requires less computations for mining (Aras and Kulkarni, 2017; Christidis and Devetsikiotis, 2016; Farah, 2018). PBFT is used when there is an expected number of faulty nodes in the network. It is based on having selected nodes that act as leaders for other nodes. These nodes are responsible for ordering transactions to their correspondent group and wait until over 1/3 responses are received within a given interval for a transaction to be valid. This mechanism is currently used by Hyperledger Fabric (Aras and Kulkarni, 2017; Zhu, 2019), an important platform for SC applications. More information on consensus mechanisms is provided in Zhu (2019) and Lashkari and Musilek (2021).
- **Smart contracts:** Smart contracts are "*computerized transaction protocols that execute the terms of a contract*" (Szabo, 1994). Smart contracts can be stored in the blockchain, and once triggered by another transaction, they are executed autonomously in the network according to the code commands it entails (Christidis and Devetsikiotis, 2016). Smart contracts improve blockchain's programmability and makes transaction processing more efficient through automatic execution (Hughes *et al.*, 2019; Treiblmaier, 2020)

The combination of the attributes derived from the above is what makes blockchain a unique, powerful and attractive technology (Casino *et al.*, 2019). They collectively constitute the core characteristics of blockchain, including: (1) the distributed nature of blockchain ledger that supports blockchain transparency (Lashkari and Musilek, 2021;

Treiblmaier, 2020), (2) blockchain data immutability since the data can only be added but not changed or erased (Crosby *et al.*, 2016), (3) blockchain decentralisation in terms of data storage and processing, governance and decision-making through decentralised consensus mechanisms, all of which support the elimination of central authorities and intermediaries (Christidis and Devetsikiotis, 2016; Treiblmaier, 2020), (4) blockchain consensus mechanisms that ensure agreement on transaction validation and the current status of the ledger (Aras and Kulkarni, 2017; Christidis and Devetsikiotis, 2016; Lashkari and Musilek, 2021; Treiblmaier, 2020), (5) Blockchain security with cryptography and timestamped transactions supporting data immutability and security (Glaser, 2017; Wang, Hoang, *et al.*, 2019), (6) blockchain inherited traceability supported by the chronological order of blockchain transactions and storage of all historical transactions (Glaser, 2017), and (7) smart contracts, which bring further capabilities to the blockchain ledger, making it a computational platform rather than just a storage database (Xu *et al.*, 2019).

2.1.1 Types of blockchain networks

There are different types of blockchain networks (Table 1). The well-publicised blockchain network for the crypto-currency, Bitcoin, is only one type. Blockchain networks can be classified based on three aspects: accessibility to network data, ability to transact, and validation of transactions. In public or 'permissionless' networks, anyone can access the network, post transactions, and participate in the validation process (Aras and Kulkarni, 2017; Buterin, 2015; Farah, 2018). Private or permissioned blockchain networks provide access to selected participants in which every permissioned node in the network can transact and engage in the validation process (Buterin, 2015; Farah, 2018). A further type of network is the consortium blockchain network, in which the transaction validation is controlled by selected participants and the access to the information in the network can be public or private (Buterin, 2015). As organisations will be concerned about, and will wish to control access to commercial data and restrict information sharing, permissioned blockchain networks are the common type used in SCM applications (Wang, Han, *et al.*, 2019).

There is a growing number of blockchain networks and platform providers ranging from start-ups to well-established consortia. Several configurations for blockchain networks have been developed and can be adopted depending on the application. Some of the top blockchain

network platforms include Hyperledger (https://www.hyperledger.org/), Ethereum (https://ethereum.org/), and R3 (https://www.r3.com/).

Table 1. Types of blockchain networks. Source: (Buterin, 2015)

Type of Network	Transaction Validation	Ability to Transact	Ability to read/ access information
Public/Permission-less Blockchain Network	Anyone/Public	Anyone/Public	Anyone/Public
Private/Permissioned Blockchain Network	All Permissioned Participants	All Permissioned Participants	All Permissioned Participants
Consortium Blockchain Network	Only selected Participants in the network	Public or Private (permissioned participants)	Public or Private (permissioned participants)

2.1.2 Blockchain challenges and limitations

Despite the potential of blockchain, it has significant limitations and challenges that are important to address, including:

- **Immaturity of the technology:** Blockchain was initially used for finance and quickly reached its development stage. Many prototypes and proof-of-concepts have been and continue to be developed by different organisations in various industries (Lacity and Van Hoek, 2021; Lacity, 2018b). However, the technology and its applications are still immature (Farah, 2018; Glaser, 2017; Lacity, 2018a), hindering its mass scale adoption (Lacity and Van Hoek, 2021; Queiroz *et al.*, 2019; Wamba and Queiroz, 2020). Organisations interested in experimenting with blockchain need to be agile for its deployment and be ready to upgrade or replace solutions as it develops (WEF, 2020).
- **Blockchain scalability issues:** Blockchain has developed rapidly from the first decentralised cryptocurrency, Bitcoin, to Ethereum with smart contracts and permissioned blockchains like Hyperledger Fabric (Zhou, Huang, *et al.*, 2020). The increase in the number of blockchain users has revealed the issue of blockchain scalability, particularly for public blockchain networks (Eklund and Beck, 2019; Zhou, Huang, *et al.*, 2020). Gartner (2021) defined scalability as "*the measure of a system's ability to increase or decrease in performance and cost in response to changes in application and system*

processing demands." Two inherent characteristics of blockchain contribute to its limited scalability. First, the blockchain distributed ledger shared in a decentralised peer-to-peer network imposes storage and latency costs for all participant nodes. Second, consensus mechanisms like PoW may require all nodes to be involved in each transaction validation process before it gets published in the chain. These characteristics are the underlying principles for blockchain transparency and security. However, blockchain scalability decreases with increased network size and transactions (Chauhan *et al.*, 2018; Eklund and Beck, 2019; Zhou, Huang, *et al.*, 2020).

Zhou *et al.* (2020) and Hafid *et al.* (2020) classified the emerging blockchain scalability solutions as on-chain (Layer 1) and off-chain (Layer 2). On-chain solutions improve the blockchain architecture and throughput and reduce transaction latency by increasing block size and using improved consensus mechanisms (Altarawneh *et al.*, 2020). For example, sharding techniques divide the blockchain network into multiple smaller network "shards" where transactions are validated within the shards in parallel to improve overall network throughput (Chauhan *et al.*, 2018). Off-chain blockchain scalability solutions include lighting network techniques that create separate payment channels to handle multiple transactions away from the main chain and the final state is updated in the chain (Poon and Dryja, 2016). Further solutions include cross-chain techniques that enable interoperability between multiple blockchain platforms (Zhou, Huang, *et al.*, 2020).

Most emerging scalability solutions compromise on decentralisation, leading to the blockchain 'scalability trilemma' described by Vitalik Buterin, the founder of Ethereum (Viswanathan and Shah, 2019), indicating that blockchain security, decentralisation, and scalability cannot perfectly co-exist (Altarawneh *et al.*, 2020; Viswanathan and Shah, 2019; Zhou, Huang, *et al.*, 2020). Buterin (2021) explains the scalability trilemma in the current blockchain networks as: (1) Traditional public blockchains like Bitcoin require every node to verify every transaction. Hence, they are secure and decentralised but not scalable, (2) High transactions-per-second chains, e.g., delegated PoS-based solutions include small number of trusted participants verifying the network transactions and can be considered secure and scalable, but not decentralised, and (3) multi-chain ecosystems where several blockchain systems interact are decentralised and scalable but not entirely secure since any attack on any chain can also breach the other chains. Buterin (2021) anticipated that sharding techniques with improved security models can help overcome blockchain scalability issues while maintaining decentralisation and security.

- **Lack of blockchain governance mechanisms:** There is still limited understanding of the governance aspects of blockchain systems. Beck *et al.* (2018) anticipated that governance in the blockchain economy will transform from traditional governance models. With blockchain, the decision rights are decentralised, and accountability is more enforced through the technical infrastructure (i.e., smart contracts and consensus mechanisms) rather than through institutions. However, incentives remain crucial in the blockchain economy to ensure the functionality of the system since it leads to consensus. Despite the potential use of smart contracts to enforce governance in the system, there will always be risks associated with the autonomous mechanisms that could lead to unwanted consequences due to coding errors or changing conditions (Beck *et al.*, 2018). This particularly if the smart contracts are stored on the blockchain since it cannot be changed in case of any error in the the smart contract code or changes in the conditions that it was based on initially.
- **Blockchain interoperability:** Blockchain has the potential to create an electronic interoperable system considering its decentralised structure, inherited cryptography, chronological records, and use of smart contracts, which enable dispersed parties to securely interact with each other without the need for a centralised authority. However, the interoperability of blockchain systems with each other and with other information systems, particularly legacy systems that support existing business functions, remains a big challenge (Casino *et al.*, 2019; Feng *et al.*, 2020; Jović *et al.*, 2019; Kamble *et al.*, 2020; Kayikci *et al.*, 2020).
- **Regulations and standards compliance:** Blockchain systems face many challenges to fit within the complex, regulatory, economic, social and physical systems (Lacity, 2018a). The rate at which technological developments occur exceeds regulations development (Aras and Kulkarni, 2017). It is still unclear how the existing standards and regulations globally and within countries will impact blockchain adoption across different industries (Janssen *et al.*, 2020; Wang *et al.*, 2016). Several regulations restrict blockchain potential and/or limit its use for commercial and enterprise applications. Organisations have to either design solutions that comply with the existing regulations or actively lobby to change them (Lacity, 2018a). General data protection regulations (GDPR), for example, may have a significant impact on decision-making regarding what data can be stored on the blockchain platform and how to manage users' permissions (Truong *et al.*, 2019).
- **Lack of knowledge, experience and expertise:** Terms like blockchain, smart contracts, cryptography, and decentralisation are not simple to grasp (Glaser, 2017). There is limited

understanding of blockchain, its characteristics, and challenges by the majority of SCM professionals, academics, and the wider community. There is an acknowledged gap in the talent pool and human resources with sufficient knowledge about the technology and how it works (Glaser, 2017). Lack of knowledge, experience and expertise can potentially hinder blockchain adoption and scalability in the supply chain domain (Caldarelli *et al.*, 2021; Kamble *et al.*, 2020; Saberi *et al.*, 2019; Wong *et al.*, 2020).

2.2 Blockchain Adoption and Application in the Supply Chain

Blockchain research is multidisciplinary (Casino *et al.*, 2019; Saberi *et al.*, 2019; da Silva and Moro, 2021). The technical features of blockchain makes the technology attractive to a wide range of applications underlying a variety of disciplines. Tama *et al.* (2017) reviewed the literature to identify current blockchain applications areas including financial services, healthcare, business and industry. Two years later, Casino *et al.* (2019) did the same and their research indicated the growth in blockchain application areas across the different sectors, including financial applications, integrity verification, governance, internet of things, healthcare, education, privacy and security, data management and finally business and industry.

Although blockchain for cryptocurrencies emerged in 2008 (and distributed ledger concepts pre-dates that), the academic literature on blockchain applications in the supply chain started to emerge only in 2016 (Casino *et al.*, 2019; Gurtu and Johny, 2019; Queiroz *et al.*, 2019). In their bibliometric review for selected databases on blockchain research in SCM and logistics, Rejeb *et al*. (2021) revealed a dramatic increase from one publication in 2016 to 379 publications in 2020. Other studies have shown a similar increase (Gurtu and Johny, 2019; Lim *et al.*, 2021; Rejeb, Treiblmaier, *et al.*, 2021), showing the growing interest in investigating blockchain within the SCM field.

Wang *et al.* (2019) , Kamble *et al*. (2020), and Jardim et al. (2021) conducted a literature review to identify the main motivations behind blockchain adoption in the supply chain. Other reviews investigated blockchain adoption and IoT (Conoscenti *et al.*, 2016; Ye *et al.*, 2020), blockchain and trust (da Silva and Moro, 2021), blockchain in healthcare (Mazlan *et al.*, 2020; Rejeb, Treiblmaier, *et al.*, 2021), blockchain in automotive (Fraga-Lamas and Fernández-Caramés, 2019), blockchain in manufacturing (Khanfar *et al.*, 2021), blockchain and SC integration (Queiroz *et al.*, 2019), blockchain in shipping and logistics (Jović *et al.*, 2019; Pournader *et*

al., 2020; Tsiulin *et al.*, 2020), and blockchain in operations and SCM (Cole *et al.*, 2019; Grover *et al.*, 2018; Gurtu and Johny, 2019; Hughes *et al.*, 2019; Lim *et al.*, 2021).

In this research, we are concerned with blockchain applications in the SCM field. However, we appreciate the need to take a holistic and multidisciplinary view of the technology's capabilities and the factors influencing its adoption and deployment. We categorise the literature review of blockchain-SCM research into four sections, in which we review: (1) blockchain capabilities and implications in the SCM, (2) blockchain applications across the different industries, (3) the main factors and barriers noted in the literature influencing blockchain adoption in the supply chain, and (4) blockchain decision models developed in the literature.

2.2.1 Blockchain capabilities and potential implications on the supply chain

The core characteristics of blockchain make the technology transformative to existing business models and supply chains (Baiyere *et al.*, 2020; Casino *et al.*, 2019; Janssen *et al.*, 2020; Xu *et al.*, 2019). When assessed individually, each blockchain characteristic is not unique, and many have existed previously. However, the power of blockchain comes from combining these different features to support a wide range of applications (Casino et al., 2019). Many researchers investigated the technical capabilities of blockchain to anticipate its potential applications in the supply chain (Crosby *et al.*, 2016; Fraga-Lamas and Fernández-Caramés, 2019; Kamble *et al.*, 2020; Swan, 2015; Wang, Han, *et al.*, 2019). Cole et al. (2019) investigated the different blockchain characteristics and its relevance to Operations and SCM. We discuss the core characteristics of blockchain and their potential implications on SCM:

(1) **Blockchain decentralisation and distributed ledger:** The transparency enabled by blockchain's decentralised and distributed ledger is one of its core capabilities that can improve SC transparency and visibility (Aras and Kulkarni, 2017; Kamble *et al.*, 2020; Kshetri, 2018). Globalisation has increased the complexity of SC configurations and their management (Saberi *et al.*, 2019), contributing to SC visibility issues, one of the most challenging issues noted by SCM researchers and practitioners (Francis, 2008). Furthermore, most organisations operate with siloed systems and use different, often incompatible information systems (Tan and Sundarakani, 2020). Information may get distorted, manipulated, delayed or lost as it is transmitted across the supply chain (Yusuf *et al.*, 2019), which contributes to the risks of

bullwhip effects that hit the upstream suppliers the most, leading to imbalanced, disrupted and poorly coordinated supply (Wang and Disney, 2016).

The lack of a trustworthy information system that enables secure SC information sharing is another major challenge (Kamble *et al.*, 2020; Wang, Han, *et al.*, 2019). Blockchain decentralised and distributed ledger enables the different SC partners to have access to information in real-time, which help improve SC transparency (Cole *et al.*, 2019), eliminate the need for a centralised authority and help tackle trust issues in the supply chain (Kamble *et al.*, 2019; Saberi *et al.*, 2019; Wamba and Queiroz, 2020; Wong *et al.*, 2020). Moreover, the resulting redundancy improves system's reliability and ensures information availability (Christidis and Devetsikiotis, 2016; Kummer *et al.*, 2020; Sternberg *et al.*, 2021), which can potentially inform and improve SC planning and management processes

(2) **Blockchain immutability:** Blockchain immutability has made the technology appealing to a wide range of SC applications(Fernández-Caramés *et al.*, 2017; Kamble *et al.*, 2020; Loklindt *et al.*, 2018). Blockchain provides a reliable immutable system that facilitates secure information sharing, and a digital tracking record across the supply chain that cannot be questioned for accuracy and authenticity (Cole et al., 2019; Kamble et al., 2020; Kshetri, 2018; Mettler, 2016). The use of cryptography enables blockchain data auditability and verifiability, which is very important for SCM applications as it ensures shared data validity and enables the identification of responsible parties in the case of dispute or corruption (Chen *et al.*, 2020; Cole *et al.*, 2019; Eryilmaz *et al.*, 2020; Kamble *et al.*, 2020).

(3) **Blockchain traceability:** The chronological record of blockchain has the potential to significantly improve traceability across complex supply networks (Maull et al., 2017). Traceability is becoming an increasing requirement in many supply chains across different industries (Aich *et al.*, 2019; Eryilmaz *et al.*, 2020; Miehle *et al.*, 2019; Saberi *et al.*, 2019). Blockchain can enable the collection and analysis of traceability information related to product transformation and transportation data across the supply chain, as well as environmental impact (Kshetri, 2018; Saberi et al., 2019). Through blockchain-enabled traceability, product quality can be monitored and verified to ensure authenticity and prevent counterfeit and fraud (Singh *et al.*, 2020; Sylim *et al.*, 2018; Tseng *et al.*, 2018). Blockchain can also be used to facilitate and improve product recall processes when non-conformance is detected by identifying and tracing back non-conformed products in an effective way, which may significantly reduce time and effort to contain the problem (Kshetri, 2018; Miehle *et al*., 2019; Saberi *et al*., 2019).

Blockchain-enabled traceability can also promote and enforce sustainable practices (Agrawal *et al.*, 2021; Saberi *et al.*, 2019).

(4) **Blockchain consensus mechanisms:** For SC applications, different consensus mechanisms can be used, including Delegated Proof of Stake (DPoS) (Sylim *et al.*, 2018), PBFT (Abbade *et al.*, 2020; Schyga *et al.*, 2019; Sylim *et al.*, 2018), and proof of authority (Kuhn *et al.*, 2021). Blockchain consensus mechanisms enable having different rules for the participants in the blockchain network (Casino *et al.*, 2019; Pedersen *et al.*, 2019). This flexibility is important for enabling information sharing across the supply chain as it ensures only authorised participants have access to certain information.

(5) **Blockchain and smart contracts:** Smart contracts can represent business logic and implement different business processes, marketing mechanisms, payment methods and sophisticated services autonomously (Christidis and Devetsikiotis, 2016; da Cruz *et al.*, 2020; Dolgui *et al.*, 2020; Glaser, 2017; Xu *et al.*, 2019). They may be used for different purposes in blockchain solutions to support process automation, network governance, transaction validation, as well as quality, environmental and sustainability management (Chohan, 2021; Kummer *et al.*, 2020; Philipp *et al.*, 2019; dos Santos *et al.*, 2019; Xu *et al.*, 2018).

Seebacher and Schüritz (2017) and Choi *et al*. (2020) have investigated the potential use of blockchain in service systems by facilitating information sharing and collaborative value creation in a trusted and transparent environment. Blockchain also has the potential to be integrated to SC planning and management processes. van Engelenburg *et al*. (2018) and Wang *et al.* (2020) investigated the potential of blockchain in reducing the bullwhip effect through increased transparency and information sharing among the SC partners. Dolgui *et al*. (2020) suggested using blockchain-enabled smart contracts to track and monitor the operations fulfilment processes against planned schedules and identify any deviations. Their work indicates the potential opportunities of incorporating existing operations and SC planning and management methodologies in the design and development of blockchain solutions to transform and digitalise SC processes. Xu *et al.* (2019) applied blockchain and smart contracts in a traceability system called originChain and compared the use of DLTs to centralised databases. Their research indicated that reading from blockchain is more efficient than from centralised databases, but writing takes longer time, and that smart contracts can improve the adaptability of the whole system. To overcome blockchain limitations, they used on-chain/off-chain concept to store only required data for traceability on-chain and private data off-chain.

Based on literature reviews, several reseaarchers identified the main motivations behind blockchain adoption in the supply chain. Wang *et al.* (2019) identified improving trust, information security and reliability, SC disconnections and complexity, product safety and authenticity, and public safety and anticorruption, while Jardim *et al.* (2021) identified process automation, cost benefits, transparency, product traceability, data variability, and having a single source of data as the main motivations for blockchain adoption in the supply chain.

Gurtu and Johny (2019) and Hughes *et al.* (2019) identified blockchain potential in improving SC efficiencies and eliminating intermediaries as a key driver for its application in the supply chain. Saberi *et al.* (2019) classified the potential benefits of blockchain in promoting sustainable supply chains into economical social and environmental. Economically, by reducing costs and lead times resulted from elimination of intermediaries, improved transparency, real-time information sharing, and data immutability. Blockchain also enables organisations improve their transparency with customers and gain a competitive advantage by positively increase customers' trust and retention (Saberi *et al.*, 2019). Socially, by ensuring only authorised parties have access to the blockchain data and enabling the identification of any corrupted party and attempt to manipulate the data. Finally, environmentally, blockchain-enabled traceability can help track products and their subcomponents to improve product recall and rework processes. Blockchain can also supports green products verification and can provide a standard way to accurately measure carbon footprints and improve product recyclability through downstream product traceability (Saberi *et al.*, 2019).

2.2.2 Blockchain-SCM research across different industries

Blockchain applications are growing across the different sectors (Gurtu and Johny, 2019; Hughes *et al.*, 2019). According to Lim *et al.* (2021) recent review, the agriculture, forestry, fishing and animal husbandry are the most involved industries with blockchain adoption followed by manufacturing, construction, mining, logistics, and retail. We review the academic and practice literature to investigate blockchain research and application in various industries.

2.2.2.1 Blockchain in the food industry

In the food sector, consumers are increasingly demanding transparency in how food products are produced and sourced (Kayikci *et al.*, 2020; Malik *et al.*, 2018). Food safety is a major concern forcing the continuous development of traceability systems (Kayikci *et al.*, 2020; Tian,

2017). Most existing traceability systems are centralised systems, facing many inefficiencies and security concerns, including having a single point of failure, corruption and fraud (Bechtsis *et al.*, 2019; Dasaklis *et al.*, 2019).

Several researchers have anticipated the potential for blockchain application in the food sector (Baralla *et al.*, 2021; Bodkhe *et al.*, 2020; Danese *et al.*, 2021; Fu *et al.*, 2020; Park and Li, 2021; Rogerson and Parry, 2020; dos Santos *et al.*, 2019). Most academic research investigated blockchain in the agri-food supply chain (Fu *et al.*, 2020; Kamble *et al.*, 2020; Lim *et al.*, 2021; Niknejad *et al.*, 2021; Patelli and Mandrioli, 2020; Stranieri *et al.*, 2021). In their review, Feng *et al*. (2020) identified potential benefits for blockchain use in the agri-food sector, including information security, improved collaboration and trust, reduced economic loss and product waste, and improved sustainability and transparency. Similarly, Kayikci *et al*. (2020) identified measuring food loss, gaining regulatory acceptance, re-distribution of food, and ERP complementarity as potential opportunities for blockchain in the food sector.

Tian (2017) is one of the early studies aimed at developing a blockchain-based traceability system in the food supply chain (FSC) with the use of IoT followed by Haroon *et al*. (2019), Aich *et al*. (2019), and Baralla *et al*. (2021). Malik *et al*. (2018) proposed a permissioned blockchain framework for food traceability across the supply chain that includes SC partners and regulatory bodies. To tackle blockchain scalability issues, they proposed the use of sharding technique to manage transaction load and enable consumers to access provenance data while limiting competitors from accessing the data. Wu *et al*. (2019) investigated the technical challenges of blockchain, including scalability, access control, throughput and data retrieval for the design of food traceability solutions. Casino *et al*. (2021) developed a blockchain-based traceability solution for a local dairy supply chain and indicated the realised benefits in terms of SC process management improvement, security and resilience. Shingh *et al.* (2020) investigated how blockchain can improve the dairy supply chain by improving food safety, preventing product counterfeiting, and establishing trust in the dairy sector. Kamble *et al*. (2020) identifies traceability, auditability, immutability and provenance as the main motivations behind blockchain adoption in the agri-FSC.

Many researchers have developed and tested the use of blockchain in the FSC (Feng *et al.*, 2020; Niknejad *et al.*, 2021). Using Hyperledger Fabric, Bechtsis *et al*. (2019) developed a traceability system for containerised FSC, and Yusuf *et al*. (2019) developed a multi-channel blockchain platform promoting real-time information sharing among vegetable suppliers and

clients. Maity *et al*. (2021) used stochastic models and blockchain to investigate their use to improve traceability in FSCs. Stochastic models were used to study and analyze batch dispersion across the entire supply chain of sausages (i.e., two stochastic optimization models were used, one to optimize raw material usage at each SC stage and the second to optimize material flow across the supply chain) while blockchain was used to store traceability data of sausage batches across five SC stages and to verify blockchain data immutability and ability to identify attackers. Other interesting studies on blockchain in the FSC include its use to develop ingredient certification scheme (dos Santos *et al.*, 2019) and to improve precise irrigation systems (Bodkhe *et al.*, 2020) and SC financing (Rijanto, 2020).

The motivations behind blockchain applications in the FSC vary across countries, products and SC characteristics. Fu *et al*. (2020) investigated blockchain use in the Chinese agri-FSC to overcome inefficiencies in existing traceability systems and SC transparency. Garrard and Fielke (2020) investigated blockchain use to enable traceability and identify provenance in the Australian prawn industry. Their research indicates that the industry would benefit more from digitalisation in general rather than from explicitly adopting blockchain. Danese *et al*. (2021) conducted multiple case studies in the Italian wine sector to investigate how blockchain systems can be designed to prevent counterfeiting depending on the SC partners desired protection level.

Patelli and Mandrioli (2020) indicated that different SC traceability requirements affect the structure of blockchain. For instance, the sole requirement of identifying meat provenance and its SC linearity has different blockchain adoption requirements compared to other products that involve multiple ingredients mixing where blockchain is implemented at the last stages of the supply chain.

Blockchain is being increasingly applied in practice in the food sector to enable SC traceability and identify product origin. The French wine producer Chateau Marguax recorded the first certification of 2001 bottle using blockchain in 2016 (Zimmerman, 2017). Similarly, Birra Peroni has partnered with Ernst & Young (EY) to enable beer traceability to ensure its authenticity and improve SC visibility (EY Global, 2021). Other retailers include Alibaba who have worked on developing food traceability systems based on blockchain (The Maritime Executive, 2018), Walmart whose first pilots include traceability for Pork in China and mango in the US (Hyperledger, 2019), HEMA who started using blockchain for coffee beans traceability across the supply chain (World Coffee Portal, 2021), and Carrefour who

collaborated with IBM to use blockchain to implement food traceability standards across their supply chain (Carrefour, 2018). Carrefour has reported an increase in sales as a result of using blockchain and informing customers about products' origin and harvesting and packaging processes (Thomasson, 2019).

Blockchain has also been applied in the animal husbandry and meat supply chains. E-Livestock Global used blockchain to enhance SC visibility and transparency in the cattle industry in Zimbabwe by capturing cattle health records and origin information (Light, 2021). JBS, the Brazilian largest beef producer, has started to use blockchain to enable traceability across the beef production value chain (Kamel, 2021). Considering industry-wide blockchain solutions, IBM has developed Food Trust, one of the largest blockchain platforms for food traceability that has been applied in many food and beverage supply chains, including seafood, coffee, olives and crops (IBM Food Trust, 2020).

2.2.2.2 Blockchain in the automotive industry

The automotive industry is one of the most complex and technologically advanced industries (Fraga-Lamas and Fernández-Caramés, 2019; Kuhn *et al.*, 2021). The automotive supply chain is complex, with large number of participants across multiple tiers that are geographically dispersed (Kuhn *et al.*, 2021; Miehle *et al.*, 2019). The automotive market is highly competitive, resulting in high concerns related to information sharing (Miehle *et al.*, 2019). Since many automotive parts are considered safety critical products (Kuhn *et al.*, 2021), parts traceability across the supply chain is a major legal requirement in some countries such as the USA and Germany (Miehle *et al.*, 2019). It is also important in managing the costly and lengthy product recalls processes, and in identifying counterfeit parts in the after-sales market (Miehle *et al.*, 2019).

Miehle *et al*. (2019) developed PartChain, an automotive part blockchain-based SC traceability system that digitally identify and tokenise each part on the permissioned blockchain ledger. A mobile app is used to capture product data and transfer of product ownership across the supply chain. PartChain registered 1000 parts with 0.5 second average transaction time, enabling data sharing across the supply chain in near real-time. Similar work was conducted by Kuhn *et al*. (2021).

Aich *et al*. (2019) identified the potential benefits from implementing blockchain and IoT in automotive inbound and outbound logistics by improving inventory management, informing

production schedules, and supporting just-in-time operations. In their review, Fraga-Lamas and Fernández-Caramés (2019) indicated the potential use of blockchain to improve data management, gain operational benefits through real-time information sharing and reduced costs from eliminating intermediaries, and facilitate financial management in cross-border export and import, letters of credit, leasing and financing.

The automotive supply chain expands across multiple industries (Kuhn *et al.*, 2021), including the mining and metal industries at the beginning of the automotive value chain. Using blockchain can help in tackling several issues in the mining industry, including ethical sourcing, risks management and disruption, and improving operational productivity and efficiency. Mann *et al*. (2018) investigated the use of blockchain in the mining industry to identify data provenance and enable asset tracking across the supply chain. Similarly, Chohan (2021) investigated the use of blockchain for cobalt traceability from mining and across the supply chain, as it is one of the main components used in automotive batteries (Chung *et al.*, 2015; Mayyas *et al.*, 2019; Sharma and Manthiram, 2020).

Vehicle data management is another prominent area for blockchain applications in the automotive industry to fight counterfeiting and improve efficiencies. Singh and Kim (2018) investigated the use of blockchain for secure intelligent vehicles communication - self-driving vehicles that support 'vehicle-to-everything communications' through the internet. Researchers also investigated blockchain application to fight vehicle odometer fraud (Abbade *et al.*, 2020) and counterfeit issues in the used car market (Chen *et al.*, 2020), and to secure and maintain vehicle insurance records (Demir *et al.*, 2019).

IBM (2018) identified the top three areas that will be highly impacted by blockchain in the automotive industry as finance, supply chain, and mobility services. Blockchain can enable secure and transparent transactions, which is important for managing payments across the supply chain. With the use of IoT, blockchain can significantly improve mobility services, such as car insurance by developing a secure and transparent platform where drivers incur insurance charges based on their vehicle usage and conditions (Deloitte, 2018).

Some of the automotive blockchain projects in practice include Hyundai project that uses Hyperledger Fabric to automate manual processes, reduce lead time and costs, and improve SC finance and customers' financial services (Torres, 2019). To manage the lengthy and costly certification processes, luxury vehicle OEM Lamborghini started to experiment with

blockchain to streamline its authentication processes, improve customer service and fight counterfeit (Wood, 2019). Mercedes-Benz and Icertis have teamed up to use blockchain to digitalise contracts management across their supply chain to leverage transparency and ensure compliance to standards and contractual obligations set by the company (Rombach, 2019). BMW Group has experimented with blockchain to enable products traceability across their complex global supply chains starting with front lights supply chain and aiming to extend to other SCs (Essbauer, 2020). Similarly, Porsche has piloted blockchain to enable plastics SC traceability and tracking of CO_2 emissions (Adsale Plastics Network, 2020).

Several OEMs have engaged in blockchain pilots to ensure the responsible sourcing and sustainability of Cobalt including Ford Motors (Wolfson, 2019), Volkswagen (Wolfsburg, 2019a) and Volvo (Volvo Cars, 2019). Mercedes-Benz is also using blockchain to tackle transparency issues on carbon emissions in the cobalt supply chain (Ledger Insights, 2020a). The US department of Energy has funded two pilot projects that aimed at tracing the life cycle of lithium-ion batteries and ensure end-of-life responsible recovery and to provide information about battery recycling and reward customers when recycling their batteries (Everledger, 2020).

Hyundai used blockchain as part of its innovative 'smartphone-vehicle pairing based performance adjustment technology' to enable users to securely choose and upload their performance preferences through a smartphone application (Hyundai Motor and Kia, 2019). It is also working on a 'blockchain-as-a-service' platform to capture vehicle information from purchase and re-sale to prevent vehicle history counterfeiting (Hyundai Auto Ever, 2019). Volkswagen has experimented with blockchain to collect vehicle usage data to prevent odometer fraud (Akilo, 2018). Other OEMs such as Jaguar Land Rover (JLR, 2019) and Daimler AG (Smith, 2018) are also using blockchain to reward drivers with cryptocurrency when sharing their vehicle data and road conditions.

The Mobility Open Blockchain Initiative (MOBI) is an automotive industry consortium that focuses on using blockchain to improve mobility services and SC sustainability, efficiency, and affordability. MOBI works with OEMs (e.g., Ford, BMW, GM), automotive suppliers and non-profit organisations on the development of blockchain standards to accelerate its adoption. MOBI believe in the potential benefits of blockchain in improving efficiency and reducing costs and the necessity of industry collaboration to realise these benefits (MOBI, 2022).

2.2.2.3 Blockchain in the textile and apparel industry

The textile and apparel industry is globally dispersed, with complex supply network configurations and material flows (Agrawal, Sharma, *et al.*, 2018; MacCarthy and Jayarathne, 2013). The sector is fast-paced requiring quick responses to changing customer demands, while maintaining quality and controlling costs (Fulton and Lee, 2013). This industry has serious sustainability concerns regarding sourcing practices and the social and environmental impact of apparel production (Cognizant, 2018; UNECE, 2021). Many consumers have become aware of the social and environmental impacts of textile and apparel production, including those related to child labour, health and safety, water consumption, discharge of toxic chemicals, and deforestation (Rana and Allen, 2021). Hence, consumers are increasingly demanding ethically produced garments made from sustainable materials using environmentally friendly manufacturing processes (Agrawal *et al.*, 2021; Cognizant, 2018).

Blockchain technology can help in tackling many existing challenges in the textile and apparel supply chain by improving the transparency, traceability, and sustainability of apparel products (Lam and Zhibin, 2019; UNECE, 2021). The fragmented structure of the industry can benefit from the decentralised blockchain architecture that promotes transparency and information sharing (ElMessiry and ElMessiry, 2018; Pal and Yasar, 2020). With the provision of a chronological record of transactions, blockchain can enable materials tracking across the multi-tier apparel supply networks. The use of smart contracts may help enforcing sustainable practices and identifying non-conformance, which can potentially encourage and support ethical practices (Agrawal *et al.*, 2021).

Many researchers investigated the use of blockchain to enable traceability and improve transparency in the textile and apparel supply chain (Agrawal *et al.*, 2021; Bullón Pérez *et al.*, 2020; ElMessiry and ElMessiry, 2018). Agrawal *et al.* (2018) highlighted the importance of having a traceability system to improve SC transparency, ensure product quality and manage recalls effectively, and improve marketing and boost consumer confidence and trust in the products.

Blockchain use with IoT can help in ensuring the quality of the textile products to enable the identification of defective batches in a timely manner. However, there is a need to use modern textile machines with sensors to enable direct communication with the blockchain platform (ElMessiry and ElMessiry, 2018). Pal and Yasar (2020) proposed the use of blockchain for IoT

applications to provide a secure distributed platform for data and transactions management within the globally dispersed and complex apparel networks.

Choi and Luo (2019) analysed the issue of data quality on the profitability and social welfare of sustainable fashion supply chains in emerging markets using the newsvendor model. Their analysis showed that poor quality data could negatively affect social welfare and profitability. However, blockchain can help improve social welfare but not profitability due to required investment costs. They addressed the importance of government sponsorship and environmental tax waiving schemes to support blockchain adoption. Choi (2020) also used the newsvendor model to investigate blockchain use in SC finance to facilitate the selling of fashion products.

Blockchain use to promote sustainability in the textile and apparel supply chain is another prominent area in the literature. Fu *et al.* (2018), Lam and Zhibin (2019), Guo *et al.* (2020), Manupati *et al.* (2020), and Chan et al. (2020) investigated the use of blockchain to disclose environmental performance information to improve trust and sustainability performance among the SC partners and consumers. Researchers have also investigated the use of blockchain to promote a circular economy in this industry e.g., Wang *et al.* (2020) and Alves *et al.* (2021) .

Many major brands and retailers have been experimenting with blockchain to tackle several issues. Fighting fraud and ensuring product authenticity have been the driver for many blockchain pilots. Luxury brands such as the French luxury brand conglomerate LVMH has experimented with blockchain to provide proof of authenticity to its customers and to track and trace its products from raw materials origin to point of sale (ConsenSys, 2019). HUGO BOSS has collaborated with ASTRATUM to develop Tracey, a blockchain platform that tracks products across the supply chain and ensures their authenticity (Hackling, 2019). Fibre producers, Chargeurs Luxury Materials, a world leading wool supplier, has developed a label named Organica Precious Fibres based on blockchain to ensure fibre quality and enable their traceability from sheep-to-retail (Chargeurs, 2018).

Due to the high sustainability concerns related to apparel sourcing and production, many brand retailers and fibre producers started to use blockchain to ensure garment sustainability through verification of garment origin and involvement of certified suppliers across the supply chain. The first garment piece to be tracked by blockchain was a jumper by Martine Jarlgaard who

partnered with Provenance and A Transparency company to collect and record product information as it moves across the supply chain in Provenance blockchain application (FIA, 2020). Another blockchain pilot led by Bext360 has tracked organic cotton from farm to the ginning process with a plan to extend it to the consumers (C&A Foundation, 2019).

Using the Textile Genesis blockchain platform, three sustainability pioneers have partnered to enable fibre-to-retail traceability: Lenzing, a leading wood fibre producer, Schneider top wool producer, and the brand retailer ArmedAngels (Lenzing, 2020a). The US Cotton Trust Protocol has also partnered with Textile Genesis to track and verify the SC transactions at the article level alongside the movements of cotton across the entire supply chain (US Cotton Trust Protocol, 2021). The UK fashion and textile association (UKFT) has partnered with IBM, Tech Data and other retailers, including H&M and New Look in an Innovate UK project to pilot blockchain to enhance SC transparency and sustainability and improve profitability (UKFT, 2021). The Arianee consortium is an industry-wide collaboration that aims at developing standards for the digital certification of valuable assets using the Arianee protocol based on blockchain technology (Arianee, 2022).

2.2.2.4 Blockchain in the shipping and logistics industry

Digitalisation in the shipping industry has been introduced at a slower pace compared to its counterparts (Sanchez-Gonzalez *et al.*, 2019), and varies across the shipping ecosystem (Pradi and Rios, 2020). The majority of entities in the maritime ecosystem work independently and only interact closely at certain times to achieve individual aims (Feibert *et al.*, 2017; Lind *et al.*, 2015; Tan and Sundarakani, 2020). The shipping industry also lacks standards for data sharing across the supply chain (Tönnissen and Teuteberg, 2020; Yang, 2019), and information is scattered across multiple systems (Philipp *et al.*, 2019).

Trust is a main concern in the shipping industry (Kummer *et al.*, 2020; Tönnissen and Teuteberg, 2020). The industry has been subject to fraud, especially in customs clearance processes and to several cyberattacks hitting its top players (Cimpanu, 2020). This has raised concerns related to the security of currently used digital technologies for shipping data sharing and documents exchange and maintained the use of manual processes (Li and Zhou, 2020; Papathanasiou *et al.*, 2020). The emergence of blockchain technology is providing opportunities to address some of these issues (Irannezhad, 2020; Li and Zhou, 2020; Philipp *et al.*, 2019; Wang and Sarkis, 2021).

Blockchain security and transparency have great potential to tackle the outstanding challenges in the industry (Kummer *et al.*, 2020). Smart contracts can enable the automation and digitalisation of shipping processes (Lambrou *et al.*, 2019; Philipp, 2020; Philipp *et al.*, 2019). Li and Zhou (2020) analysed seven blockchain applications in the maritime industry indicating the potential of blockchain in overcoming cybersecurity issues, improving transparency and facilitating shipping processes. Zhou *et al.* (2020) identified managing shipping operations and cargo movement, facilitating marine insurance, and managing ship registry processes as the main blockchain application areas in the maritime industry. Tsiulin et al. (2020) identified document workflow management, device connectivity, and financial processes as the three main blockchain application areas in the shipping industry. Other researchers including Papathanasiou et al. (2020), Jović et al. (2019), and Gausdal et al. (2018) also investigated the potential opportunities and challenges for blockchain application in the shipping industry.

Many researchers investigated the use of blockchain in the digitalisation of shipping documents, particularly bills of lading and letters of credit to ensure data integrity and security, improve inefficiencies, and reduce costs (Irannezhad and Faroqi, 2021; Kummer *et al.*, 2020; Loklindt *et al.*, 2018; Peronja *et al.*, 2020). Chang *et al*. (2019) investigated blockchain applicability in international trade processes by designing a blockchain-based re-engineering process to automate the workflow. Prause (2019) investigated the use of blockchain and smart contracts to facilitate collaborative cross-organisational business processes in the context of autonomous delivery robots and industry 4.0 solutions. Calle *et al*. (2019) investigated blockchain use in reducing uncertainty and trade disruption in the case of Brexit through improved transparency and real-time information sharing. Philipp (2020) proposed a new business model for the use of liquefied biogas to reduce emissions in the maritime industry, indicating that blockchain and smart contracts can support its implementation and optimise the operations across the value chain.

Limited research investigates the implications of adopting blockchain on the shipping ecosystem. Yang (2019) identified customs clearance and management processes, digitisation of paperwork, and enabled standardisation as key factors that positively influence blockchain adoption intention based on a survey of logistics companies. Philipp *et al*. (2019) investigated the implication of blockchain and smart contract adoption on cross-organisational logistics collaboration and integration with small and medium enterprises (SME), highlighting their potential benefits for freight market and for improving ports performance. Tan and Sundarakani

(2020) investigated blockchain adoption to facilitate freight booking operations, improve efficiencies and ensure security and transparency at critical points across the shipment route, especially storage, customs, transporters, carriers, and consignee stages. They suggested coding the Incoterms and letter of credit terms into the smart contracts to enable process automation. Tönnissen and Teuteberg (2020) identified six value propositions for blockchain applications in logistics: transparency, traceability, efficiency, cost reduction, real-time processing, and process safety. They also indicated that intermediation takes a new form in blockchain applications with the introduction of a new service provider (e.g., blockchain provider). Similar views were highlighted in Tseng and Shang (2021)

The shipping industry have been increasingly investigating blockchain in practice. Many blockchain-based solutions have been developed, including Insurwave, CargoX and TradeLens (Lambrou *et al.*, 2019). TradeLens, is one of the prominent solutions in the industry, developed by Maersk A.P Moller and IBM to provide entities in global trade with digital tools to securely exchange information using blockchain (Tradelens, 2021). CargoSmart (2018) is another industry-wide solution that uses blockchain to improve shipment documentation management.

Alibaba and China Merchants Ports, the biggest port operator in China, have started a blockchain project to digitalise import and export transactions and integrate the logistics value chain (The Maritime Executive, 2020). Alibaba also joined the International Port Community Systems Association's (IPCSA) initiative that aims at using blockchain to standardise the bill of lading document (Ledger Insights, 2020b). The giant Mediterranean Shipping Company (MSC) also engaged in a blockchain project to digitalise the issuance and exchange of electronic bill of lading (MSC, 2021). The Port of Rotterdam is engaged in several collaborative projects, including Deliver, a blockchain-based solution that tracks and manages orders, shipments, and financial transactions (Douwstra, 2019). Some of the industry specific logistics blockchain solutions include Vinturas collaboration initiative in the automotive industry that aims at streamlining the logistics processes for finished vehicles using blockchain (www.vinturas.com).

2.2.2.5 Blockchain in the aerospace industry

The aerospace industry is an important industry that could also benefit from blockchain. The nature of the industry's supply network and the complexity of its products and manufacturing processes make blockchain characteristics very attractive. The Aerospace Industries Association has identified the potential use of blockchain in the traceability of aircraft parts

location and availability, parts authenticity, lease return to services, contracts execution and payments, and certification of quality and maintenance (Aerospace Industries Association, 2019).

In the aerospace industry, the provenance and SC path for every aircraft part has to be identified and recorded by a certified SC partner, presenting tremendous opportunities for blockchain adoption (Eryilmaz *et al.*, 2020). Wang and Li (2019), Eryilmaz *et al*. (2020) and Ho *et al*. (2021) investigated blockchain use for aircraft parts traceability across the supply chain. Blockchain can potentially transform aerospace traceability systems by improving inefficiencies, reducing documentation verification costs, and fighting spare parts counterfeiting by ensuring data validity and integrity. Blockchain can also help in dispute resolution by providing all parties with access to the distributed ledger and traceability records (Eryilmaz *et al.*, 2020; Schyga *et al.*, 2019).

Aircraft maintenance data management is another prominent blockchain application area in the aerospace industry. Aleshi *et al*. (2019) proposed using blockchain for aircraft maintenance records to maintain an immutable record that relevant parties can access in real-time. Schyga *et al*. (2019) developed a prototype for blockchain application in the aircraft maintenance, repair and overhaul (MRO) process to manage aircraft maintenance documentation using Hyperledger Fabric. In the airline industry, Lopes *et al*. (2021) anticipated the potential disruption of blockchain to the centralised airline ticketing platforms, and removal of intermediaries and the potential application in customer loyalty programs.

In practice, some major manufacturers have experimented with blockchain, including Airbus and Roll-Royce for parts tracking and data management (Bryan, 2018). Rolls Royce also launched a blockchain challenge in Singapore for developing a solution to manage aircraft engine maintenance data (Ledger Insights, 2019). Block Aero (2019) partnered with Sanad Aerotech and Etihad Airways to develop a blockchain solution that enhances engine overhaul times by digitalising asset data and management. Boeing is taking the lead in making proof-of-concept for blockchain, partnering with Sparkcognition to establish SKYGRID company to develop technical solutions for urban aerial mobility, including blockchain (SkyGrid, 2020).

The Aerospace Industries Association has partnered with Authenticity and Capgemini to develop a blockchain-based solution that digitalises the Department of Defence form 250 process related to material inspection and receiving between government and prime contractors

(Authenticiti Inc, 2021). Emerging from the Global SITA alliance, the consortium that focuses on IT and communication in air transport, the MRO alliance, was launched by major aerospace industry partners in February 2020, to investigate and experiment with blockchain for aircraft parts traceability (SITA, 2020).

2.2.2.6 Blockchain in the pharmaceutical and healthcare industry

Similar to the food industry, governments are intensively involved in the pharmaceutical industry and are expected to monitor every step of the supply chain (Eryilmaz *et al.*, 2020; Tseng *et al.*, 2018). Drug temperature monitoring and product counterfeit are main challenges in the pharmaceutical industry (Singh *et al.*, 2020; Sylim *et al.*, 2018). There are also restricted conditions for drug storage and transportation, including humidity, temperature, and light exposure (Kshetri, 2018). To overcome such issues, technologies such as RFID are increasingly applied to track drugs in their supply chain. However, counterfeit still happens as collected data can be tampered with (Tseng *et al.*, 2018).

Like the pharma industry, healthcare faces some outstanding challenges in terms of inefficient data management, high security concerns regarding information sharing, and data privacy challenges (Dutta *et al.*, 2020). Blockchain can potentially address all of these issues (Aich *et al.*, 2019; Arora *et al.*, 2021; Bocek *et al.*, 2017).

Many researchers investigated the use of blockchain and IoT to enable the identification, monitoring and traceability of drugs across the supply chain (Aich *et al.*, 2019; Bocek *et al.*, 2017; Singh *et al.*, 2020). Blockchain can also help governments improve their regulatory enforcement. Sylim et al. (2018) developed a blockchain-based pharmacy surveillance system that ensures drugs distribution through official channels to fight counterfeit and ensure regulatory compliance. The solution enables authorities to monitor drug distribution and provides consumers with a traced record of the drug distribution history. Similar work was proposed by Tseng *et al.* (2018) and Uddin (2021) in their development of Gcoin and Medledger respectively, to tackle the counterfeit problem.

In healthcare, blockchain can enhance data management capabilities by improving healthcare data usage, security and privacy, lowering costs and lead to better patient outcomes (Dutta *et al.*, 2020; Mattke *et al.*, 2019). Many functions in healthcare can benefit from blockchain, including neuroscience, biomedicine, electronic health records, and vaccine and drugs traceability (Dutta *et al.*, 2020; Jayaraman *et al.*, 2019; Radanović and Likić, 2018).

Modum, the Swiss start-up, conducted a blockchain pilot project to monitor the ambient temperature of medicines during transportation (Campbell, 2016; Rohr, 2019). Several organisations aimed at developing blockchain solutions to meet regulations, including Merck, who collaborated with IBM, KPMG and Walmart to pilot blockchain for drugs SC traceability and verification in correspondence to the FDA drug supply chain security act (DSCSA) (Merck, 2020). Blockchain healthcare applications in practice has been mainly to secure data exchange and to protect patients' privacy (Mettler, 2016). Some pilot projects in the USA includes IBM's Watson Health artificial intelligence unit (Tseng *et al.*, 2018), and Chronicled Company (Kshetri, 2018; Tseng *et al.*, 2018).

There are two prominent industry-wide blockchain collaborations: Pharmaledger and Mediledger. Pharmaledger is a public-private partnership that aims at developing industry-wide blockchain-enabled healthcare solutions, leveraging the benefits for the entire ecosystem, including enabling drug SC traceability and verifications and the development of blockchain secured drug e-leaflet (IMI, 2020). Mediledger, initially led by Chronicled, focuses on developing solutions for drugs traceability across the supply chain to meet the requirement of FDA DSCSA (Kshetri, 2018; Mediledger, 2019).

2.2.2.7 Blockchain in other industries

Researchers have investigated blockchain in other industries. In the manufacturing industry, blockchain can help overcome the limitations of existing technologies. With IoT and analytics capabilities, manufacturers have become more capable of sharing and exchanging information across online platforms (Li, Wang, *et al.*, 2018). Concepts of "*Cloud Manufacturing*" and "*Social Manufacturing*" have emerged to manage the manufacturing processes and to strengthen the connectivity of manufacturers and consumers (Li, Wang, *et al.*, 2018). However, many challenges are associated with these platforms, including centralisation around small parties, lack of workforce knowledge to plan, maintain and execute these systems, lack of standards and interoperability to enable the full adoption of these integrated systems, and issues related to the security of using such shared and open platforms (Li, Wang, *et al.*, 2018). Li *et al.* (2018) suggested the use of blockchain and edge computing to overcome these challenges. Blockchain provides the means to support information and knowledge exchange in a secure, transparent and decentralised way, while edge computing supports the computing and storage of the knowledge and information in the distributed network (Li, Wang, *et al.*, 2018).

Blockchain presents opportunities in improving additive manufacturing by authenticating the manufacturing instructions for 3D printed parts (Lacity, 2018a), managing intellectual properties rights, monitoring printed parts across their lifecycle, ensuring data security and enabling process improvements (Kurpjuweit *et al.*, 2021). Abeyratne and Monfared (2016) developed a blockchain prototype for cardboard boxes production processes, indicating that the different organisations can use the collected data to improve their operations and better understand the product lifecycle while end consumers can access information about how the product is manufactured. Westerkamp *et al.* (2020) proposed a method based on blockchain to enable products' traceability across the manufacturing processes with the use of non-fungible tokens. Khanfar *et al.* (2021), Gunasekaran *et al.* (2019), and Ko *et al.* (2018) investigated the potential contributions of blockchain in enhancing manufacturers' economic, environmental, and social performance through improved transparency, traceability, and security of blockchain.

Blockchain has gained a prominent presence in the energy sector compared to other industries (Queiroz *et al.*, 2019). Blockchain has the potential to transform traditional energy utilities business models and operational roles (Andoni *et al.*, 2019). One of the early blockchain applications in this sector is the peer-to-peer energy market platform developed by the New York Startup TransActiveGrid in the USA in 2016 (Lacity, 2018a). With the use of blockchain, smart contracts and IoT, the company developed a microgrid platform connected to the existing grid infrastructure where local communities can sell or buy renewable energy (Lacity, 2018a). Hou *et al.* (2018) investigated the integration of blockchain to transform the centralised distribution system of photovoltaic energy systems in China by enabling a decentralised marketing platform for photovoltaic energy that improves efficiency and facilitates energy trading. Further investigation about blockchain use for the development of smart grids is conducted in Mengelkamp *et al.* (2018), Andoni *et al.* (2019), and Hasankhani *et al.* (2021).

Considering the word limitations of the literature review, we cannot cover blockchain applications in all the sectors. Thereby, we only refer to additional literature on blockchain applications in the humanitarian industry (Dubey *et al.*, 2020; Ozdemir *et al.*, 2020; Zwitter and Boisse-Despiaux, 2018) and construction industry (Dakhli *et al.*, 2019; Li *et al.*, 2019; Perera *et al.*, 2020; Turk and Klinc, 2017; Wang *et al.*, 2017).

2.2.2.8 Major literature gaps in blockchain-SCM research

The academic literature shows the growing interest in blockchain adoption and application in different industries (Casino *et al.*, 2019; Cole *et al.*, 2019). Table 2 summarises the main identified motivations and application areas for blockchain across the different sectors. A significant portion of blockchain-SCM research is in the food sector, and an increasing interest is shown in the shipping and maritime logistics industry. There are various blockchain application areas in the automotive industry investigated in the academic literature and in practice. Most research in the other industries, such as the textile and apparel, aerospace and pharmaceutical, anticipate the potential benefits and application areas from using blockchain with limited prototypes or pilots conducted.

The literature review identified two major literature gaps. First, most research is conceptual, highlighting the motivations of blockchain adoption with limited research based on empirical evidence. There is also significant proportion of the literature investigating the technical aspects of blockchain by developing prototypes for specific use cases. Despite the importance of this type of research to better understand the technology, it does not consider or reflect the actual complexities of SC processes and operations nor the perceptions and motivations of the different SC partners regarding blockchain adoption. Furthermore, most developed blockchain solutions in the supply chain are at the pilot stage, and very few projects are implemented at scale (Aich *et al.*, 2019; van Hoek, 2019a; Wamba and Queiroz, 2020). All these factors stress the need for research that empirically investigates the organisatons' motivations of blockchain adoption and application in the supply chain.

Literature Gap No 1: Lack of empirical research that investigates organisations' motivations of blockchain adoption and application in the supply chain in the different industries

Second, most published academic research consists of isolated studies focusing on a particular sector or industry. Researchers have vaguely pointed out certain industry characteristics influencing blockchain adoption and application area in the supply chain. Kshetri (2018) indicated that industries with high risk in counterfeiting are more likely to adopt blockchain in their supply chain. Saberi *et al*. (2019) proposed the potential use of blockchain to identify the provenance of luxury and high-end products that require significant paper-work and certification to eliminate fraud. Eryilmaz *et al*. (2020) highlighted blockchain adoption in heavily regulated industries such as the automotive, aerospace, pharmaceutical and food, where manufacturing processes are tightly controlled and there are high considerations of product

safety. Patelli and Mandrioli (2020) indicated the impact of the manufacturing processes and product composition, including the degree of mixing on blockchain-enabled traceability requirements. Alazab et al. (2021) conducted a cross-sectoral survey to analyse the key factors influencing blockchain adoption in the supply chain without considering the differences between sectors or the sectoral characteristics. Thus, there is a clear lack of research that applies a cross-industry lens to analyse the different industry motivations for blockchain adoption and the influence of the specific industry characteristics on blockchain adoption and application area in the supply chain.

Literature Gap No 2: Lack of empirical research that investigates the influence of the industry characteristics on blockchain adoption and application in the supply chain

Table 2. The main motivations and application areas for blockchain adoption in the supply chain identified in the literature

Industry	**Main Motivations**	**Main Application Areas**	**Relevant References**
Food	Traceability and provenance Sustainability Security Authenticity and fight counterfeiting Improving trust and inefficiencies	Product SC traceability Ingredient certification schemes Integration with precise irrigation systems SC finance processes	(Baralla *et al.*, 2021; Bodkhe *et al.*, 2020; Casino *et al.*, 2021; Danese *et al.*, 2021; Feng *et al.*, 2020; Fu *et al.*, 2020; Garrard and Fielke, 2020; Haroon *et al.*, 2019, 2019; Kayikci *et al.*, 2020; Maity *et al.*, 2021; Malik *et al.*, 2018; Park and Li, 2021; Patelli and Mandrioli, 2020; Rijanto, 2020; dos Santos *et al.*, 2019; Stranieri *et al.*, 2021; Tian, 2017; Yusuf *et al.*, 2019)
Automotive	Traceability and provenance Security Improving inefficiencies Sustainability Authenticity and fight counterfeiting	Product SC traceability Vehicle data security and management SC finance	(Abbade *et al.*, 2020; Aich *et al.*, 2019; Chen *et al.*, 2020; Chohan, 2021; Demir *et al.*, 2019; Fraga-Lamas and Fernández-Caramés, 2019; Kuhn *et al.*, 2021; Mann *et al.*, 2018; Miehle *et al.*, 2019; Singh and Kim, 2018)
Textile and Apparel	Transparency Traceability and provenance	Product SC traceability Data management SC finance	(Bullón Pérez *et al.*, 2020; Chan *et al.*, 2020; Choi, 2020; Choi and Luo, 2019; Fu *et al.*, 2018; Guo *et al.*, 2020; Lam and Zhibin, 2019; Pal and Yasar, 2020)

	Product quality, Sustainability Cost reduction and improved profitability		
Shipping and Logistics	Transparency Traceability Efficiency Security Decentralisation Cost reduction Improved collaboration Sustainability	Document digitalisation, exchange, and management Vessel records keeping Shipping operations workflow digitalisation and automation	(Chang *et al.*, 2019; Irannezhad and Faroqi, 2021; Kummer *et al.*, 2020; Li and Zhou, 2020; Papathanasiou *et al.*, 2020; Peronja *et al.*, 2020; Philipp, 2020; Tönnissen and Teuteberg, 2020; Tsiulin *et al.*, 2020)
Aerospace	Traceability and provenance Efficiency Security, Immutability Cost reduction Fight counterfeiting	Product SC traceability Product certification and documents management Aircraft engine data management	(Aleshi *et al.*, 2019; Eryilmaz *et al.*, 2020; Ho *et al.*, 2021; Schyga *et al.*, 2019; Wang and Li, 2019)
Pharmaceutical and Healthcare	Traceability Product quality Efficiencies Fighting counterfeiting Regulatory compliance	Product SC traceability Data management Business process improvements	(Aich *et al.*, 2019; Arora, Sachdeva, *et al.*, 2021; Bocek *et al.*, 2017; Dutta *et al.*, 2020; Jayaraman *et al.*, 2019; Kshetri, 2018; Radanović and Likić, 2018; Singh *et al.*, 2020; Sylim *et al.*, 2018; Tseng *et al.*, 2018; Uddin, 2021)
Manufacturing	Transparency Traceability Efficiency Cost reduction Sustainability Quality	Integration with other manufacturing systems Additive manufacturing processes and data management.	(Gunasekaran *et al.*, 2019; Khanfar *et al.*, 2021; Ko *et al.*, 2018; Kurpjuweit *et al.*, 2021; Li, Wang, *et al.*, 2018)
Energy	Decentralisation Transparency Security Automation Efficiency	Development of energy marketing platform Data management Financial services and trading.	(Andoni *et al.*, 2019; Hasankhani *et al.*, 2021; Hou *et al.*, 2018; Lacity, 2018a; Mengelkamp *et al.*, 2018)

2.2.3 The main factors and challenges influencing blockchain adoption and application in the supply chain

Most of the available literature on blockchain focuses on the technicalities of the technology with limited research investigating the organisational complexities of blockchain adoption (Janssen *et al.*, 2020; da Silva and Moro, 2021). Studies based on literature reviews have identified reoccurring themes due to the limited literature. These largely discuss blockchain technical aspects, including blockchain maturity, design, scalability, block size, governance and interoperability (Casino *et al.*, 2019; Clohessy *et al.*, 2019; Crosby *et al.*, 2016; Janssen *et al.*, 2020; Jović *et al.*, 2019; Lopes *et al.*, 2021; Mendling *et al.*, 2018; Swan, 2015; Wang *et al.*, 2016; Wang, 2020; Wong *et al.*, 2020).

Limited empirical studies have investigated blockchain adoption in the SC context. van Hoek (2019) investigated the drivers and barriers for blockchain adoption in the supply chain in an executive workshop. The main identified drivers include improved visibility, transparency and reduced costs, while the main barriers include lack of understanding of costs and perceived benefits of blockchain. Wang (2020) conducted multiple workshops to investigate the key factors considered by senior executives when implementing blockchain in the supply chain. Her research identified business viability, ecosystem management, technical feasibility, and user desirability as the key success factors for blockchain adoption.

van Hoek (2019) compared blockchain adoption in the supply chain with the implementation considerations of RFID using multiple case studies of blockchain pilots. His work is one of the few research that considered blockchain adoption at different stages of implementation from use case development, pilot, and roll out. Rogerson and Parry (2020) also conducted multiple case studies in the food sector to investigate the enablers and challenges for blockchain adoption. Blockchain can improve SC visibility and trust, but the main barriers for adoption include trust in the technology, governance, fraud and human errors, and consumer data access and willingness to pay. Their study identified that blockchain application at scale is most likely to take place where consumers are willing to pay a premium price to fund the technology. Wang *et al.* (2021) provided in-depth insights on how blockchain is implemented in a multi-tier complex supply networks based on a longitudinal empirical case study in the construction industry.

Other empirical studies included the adoption of information systems theories and using surveys to investigate how the different constructs influence blockchain adoption in the supply chain (Alazab *et al.*, 2021; Fosso Wamba *et al.*, 2020; Kamble *et al.*, 2019; Queiroz *et al.*, 2021; Wong *et al.*, 2020).

Organisational factors have been strongly recognised in the literature as important determinants for information technology (IT) adoption within enterprises (Tornatzky *et al.*, 1990). Factors such as top management support and organisational size have been widely investigated in the literature to determine the degree to which they facilitate or hinders technology adoption (Grandon and Pearson, 2004; Janssen *et al.*, 2020; van de Weerd *et al.*, 2016). Blockchain's core characteristics are anticipated to change relationships, operating business models, and potentially regulatory requirements (Clohessy *et al.*, 2019), stressing the important role of top management in facilitating or hindering blockchain adoption.

Traditionally, large organisations with more IT resources are more positively inclined to adopt new technologies (Damanpour, 1992; Lee and Xia, 2006). However, with the fast pace of technological development that require organisational flexibility and adaptability, SMEs are found to be more capable of adopting new technologies (Clohessy *et al.*, 2019; van de Weerd *et al.*, 2016). The impact of organisation size on blockchain adoption is still not clear, and there is a need for empirical research to investigate the relation between blockchain adoption and organisation size (Clohessy *et al.*, 2019). Organisational readiness for the adoption of new technology is another important factor that has been widely considered in the literature (Wang *et al.*, 2016, 2010). However, there is limited empirical literature specifically investigating the impact of organisational factors on blockchain adoption and deployment (Clohessy *et al.*, 2019).

Several other factors influencing blockchain adoption and deployment in the supply chain have been noted but dispersedly in the literature. Maull et al. (2017) identified the development of open standards as a key enabler for digital revolution. Alles and Gray (2020) stated the important role of auditing in blockchain traceability solutions to tackle the first mile problem, i.e., ensuring that the blockchain data is isomorphic with the real world it represents. Caldarelli *et al.* (2021) highlighted the need for management involvement in blockchain projects for their success and for developing an understanding for blockchain to fully appreciate its features and capabilities. Sternberg *et al.* (2021) addressed the necessity of involving all the SC partners to achieve the transparency and traceability benefits of adopting blockchain in the supply chain.

Many researchers discussed blockchain and trust indicating the potential of blockchain to tackle trust issues in the supply chain (Agrawal *et al.*, 2021; Fu *et al.*, 2020; Kamble *et al.*, 2019; Kummer *et al.*, 2020; Stranieri *et al.*, 2021; Tönnissen and Teuteberg, 2020). Blockchain shifts the trust issue from people or organisations to the technology itself (Lo *et al.*, 2017; Maull *et al.*, 2017), improving the trust between the SC partners once they trust the integrity of blockchain transacting and validation processes (Babich and Hilary, 2020; Queiroz *et al.*, 2021). Thus, trust is an important factor influencing the adoption behaviour of blockchain (Babich and Hilary, 2020; Queiroz *et al.*, 2021). Besides having trust on the blockchain system, there is a need to trust the validity of the blockchain data inserted and shared among the different SC partners (Queiroz *et al.*, 2021). Having an agreement on the consensus mechanism used for validating the blockchain transactions can help improve trust in the blockchain solution and its data (Queiroz *et al.*, 2021; Schmidt and Wagner, 2019).

Information sharing and disclosure is another key consideration for blockchain adoption in the supply chain. Information disclosure has been previously discussed in the literature (Chen *et al.*, 2015; Zimmer *et al.*, 2010). However, the topic has gained increased attention with the emergence of blockchain (Babich and Hilary, 2020). Choi et al. (2020) considered blockchain features to investigate product information disclosure structure within the service supply chain. Their research indicated that when the information auditing costs are low or products have high profit margins, there is more tendency to disclose more information about the products to increase the number of customers and maximise the sellers' benefits. Guo *et al.* (2020) also investigated blockchain impact on environmental-related information disclosure in the fashion industry.

Last but not least, the required level of traceability is an important factor affecting blockchain SC applications across the different industries (Dasaklis *et al.*, 2019; Eryilmaz *et al.*, 2020; Hastig and Sodhi, 2020; Kuhn *et al.*, 2021). Blockchain has emerged as potential technology enabling SC traceability (Dasaklis *et al.*, 2019; Hastig and Sodhi, 2020), and an increasing number of blockchain applications aimed at enabling SC traceability in the different industries (Agrawal, Sharma, *et al.*, 2018; Baralla *et al.*, 2021; Bechtsis *et al.*, 2019; Casino *et al.*, 2021; Eryilmaz *et al.*, 2020; Haroon *et al.*, 2019; Xu *et al.*, 2019). However, limited research investigates the factors affecting the application of blockchain in enabling SC traceability (Hastig and Sodhi, 2020).

Dasaklis *et al.* (2019) defined three different levels of granularity for SC traceability across three categories: stakeholders, processes and units. They proposed a blockchain-based SC traceability solution that uses forensic audits and blockchain tokens to ensure the integrity, provenance and traceability of products across the food supply chain. Hastig and Sodhi (2020) investigated the use of blockchain for SC traceability in the cobalt mining and pharmaceutical industries considering the different stakeholders needs and traceability requirements. Eryilmaz et al. (2020) indicated that traceability requirements vary across the industries depending on different aspects, including the scope of traceability, product identification, level of detail, and the required number of steps of history information.

Table 3 summarises the main factors identified throughout the literature review that influence blockchain adoption in the supply chain. We classify these factors as blockchain related, organisational, and external factors.

Table 3. The main factors influencing blockchain adoption in the supply chain identified in the literature

Classifications	**Factors**	**Relevant Reference**
Blockchain related factors	Blockchain technical factors, including blockchain maturity, design, scalability, block size, and time to process transactions	(Casino *et al.*, 2019; Clohessy *et al.*, 2019; Crosby *et al.*, 2016; Feng *et al.*, 2020; Janssen *et al.*, 2020; Jović *et al.*, 2019; Lopes *et al.*, 2021; Mendling *et al.*, 2018; Swan, 2015; Wang *et al.*, 2016; Wang, 2020; Wong *et al.*, 2020)
	Blockchain compatibility and integration with other systems	(Clohessy *et al.*, 2019; Kayikci *et al.*, 2020; Lindman *et al.*, 2017; Lopes *et al.*, 2021; Queiroz *et al.*, 2019)
	Awareness and knowledge of blockchain	(Caldarelli *et al.*, 2021; Glaser, 2017; Janssen *et al.*, 2020; Lopes *et al.*, 2021; Wang, 2020; Wong *et al.*, 2020)
	Blockchain interoperability	(Casino *et al.*, 2019; Feng *et al.*, 2020; Kamble *et al.*, 2020; Kayikci *et al.*, 2020; Lacity, 2018a; Loklindt *et al.*, 2018; Sanka and Cheung, 2018; Thakkar *et al.*, 2018; Tseng and Shang, 2021; Wang, 2020; Wang, Singgih, *et al.*, 2019)
	Blockchain governance	(Atzori, 2015; Beck *et al.*, 2018; Buchmann *et al.*, 2017; Crepaldi, 2019; De Filippi and Loveluck, 2016; Janssen *et al.*, 2020; Lacity, 2018a; Lee, 2017; Pedersen *et al.*, 2019; Wang, 2020; Wang *et al.*, 2021; Wang, Singgih, *et al.*, 2019)
	Ease of adoption	(Queiroz *et al.*, 2021)
	Blockchain data security	(Clohessy *et al.*, 2019; Janssen *et al.*, 2020)
	Perceived benefits from blockchain adoption	(Clohessy *et al.*, 2019; Crosby *et al.*, 2016; Kamble *et al.*, 2019; Lopes *et al.*, 2021; Seebacher and Schüritz, 2017; Wang *et al.*, 2016)
Organisational factors	Organisation readiness	(Clohessy *et al.*, 2019; Lindman *et al.*, 2017; Swan, 2015; Wang *et al.*, 2016, 2010; Wong *et al.*, 2020)
	Organisation size	(Clohessy *et al.*, 2019; Janssen *et al.*, 2020; Mendling *et al.*, 2018)

	Top management support	(Caldarelli *et al.*, 2021; Chen *et al.*, 2018; Clohessy *et al.*, 2019; van Hoek, 2019a; Janssen *et al.*, 2020; Lopes *et al.*, 2021; Mendling *et al.*, 2018)
	Willingness to share knowledge and information	(Fosso Wamba *et al.*, 2020; Lopes *et al.*, 2021; Sternberg *et al.*, 2021; Wang, Singgih, *et al.*, 2019)
	Shared information and information disclosure considerations	(Babich and Hilary, 2020; Choi *et al.*, 2020; Guo *et al.*, 2020; Lopes *et al.*, 2021; Wang, Singgih, *et al.*, 2019)
	Ability to involve all necessary SC partners	(Jović *et al.*, 2019; Sternberg *et al.*, 2021; Wang *et al.*, 2021)
	Norms and cultures	(Janssen *et al.*, 2020; Queiroz *et al.*, 2021; Wang, Singgih, *et al.*, 2019)
	Business process characteristics to support use of blockchain	(Eryilmaz *et al.*, 2020; Janssen *et al.*, 2020)
	Resources availability	(Queiroz *et al.*, 2021; Sternberg *et al.*, 2021; Wong *et al.*, 2020)
	Availability of funds or willingness to invest	(Lopes *et al.*, 2021; Sternberg *et al.*, 2021; Wang, Singgih, *et al.*, 2019; Wong *et al.*, 2020)
	Data availability	(Fosso Wamba *et al.*, 2020; Lopes *et al.*, 2021; Sternberg *et al.*, 2021)
	Trust concerns between the different parties	(Alazab *et al.*, 2021; Babich and Hilary, 2020; Kamble *et al.*, 2019; Lo *et al.*, 2017; Maull *et al.*, 2017; Pedersen *et al.*, 2019; Queiroz *et al.*, 2021; Sternberg *et al.*, 2021; Wüst and Gervais, 2018)
	Need for traceability	(Dasaklis, Casino, Patsakis, *et al.*, 2019; Eryilmaz *et al.*, 2020; Hastig and Sodhi, 2020; Sternberg *et al.*, 2021)
	Auditing requirements	(Alles and Gray, 2020; Casino *et al.*, 2019)
External factors	Regulations and legislations	(Chen *et al.*, 2018; Clohessy *et al.*, 2019; Feng *et al.*, 2020; Janssen *et al.*, 2020; Jović *et al.*, 2019; Lindman *et al.*, 2017; Maull *et al.*, 2017; Seebacher and Schüritz, 2017; Wang *et al.*, 2021; Wang, Singgih, *et al.*, 2019; Wong *et al.*, 2020)
	Standards for blockchain	(Chen *et al.*, 2018; Feng *et al.*, 2020; Jović *et al.*, 2019; Lindman *et al.*, 2017; Maull *et al.*, 2017; Seebacher and Schüritz, 2017; Wang, 2020; Wang *et al.*, 2021; Wong *et al.*, 2020)
	Market structure and dynamics	(Chen *et al.*, 2018; Clohessy *et al.*, 2019; Janssen *et al.*, 2020; Lindman *et al.*, 2017)
	Pressure for information disclosure	(Sternberg *et al.*, 2021)

Regarding blockchain adoption barriers, Aich *et al*. (2019) and Wong *et al.* (2020) addressed the lack of knowledge about blockchain and its potential advantages in the supply chain as a main reason behind its low deployment rate across the different industries. Babich and Hilary (2020) identified lack of privacy, lack of standardisation, the garbage in garbage out (GIGO) problem, the blackbox effect where consumers are required to "trust" the technology

implementation and the potential inefficiencies as the main weaknesses for blockchain. Agrawal *et al.* (2018) identified several barriers to blockchain-enabled traceability in the textile and clothing supply chain, including costs of the traceability system, immaturity of blockchain, data security, blockchain scalability issues, potential human errors, information sharing challenges and blockchain integration with other systems. In the manufacturing industry, Kurpjuweit *et al.* (2021) identified the lack of expertise on blockchain, lack if clear governance mechanisms, and lack of organisational resources as the main barriers for blockchain adoption in additive manufacturing.

Blockchain scalability is a critical issue hindering the development of the technology (Zhou, Huang, *et al.*, 2020). It does not only impact its application in public networks or cryptocurrencies since the technology has proven to add economic value in other business applications, including supply chain and logistics (Eklund and Beck, 2019; Glaser, 2017; Xu *et al.*, 2019). Several factors influence the scalability of blockchain, including (1) type of the blockchain network, (2) complexity of selected consensus mechanism, (3) nature of network transactions traffic flow, (4) complexity and performance of deployed smart contracts, and (5) expected growth of the network in terms of size and complexity (Eklund and Beck, 2019). Most blockchain networks adopted in the supply chain are permissioned networks, where organisations restrict information sharing to certain SC partners. Malik *et al.* (2018) proposed the use of sharding technique to tackle the increasing transaction load in a permissioned blockchain networks.

A further technical challenge is ensuring data validity, especially with smart contracts due to the oracle problem (Caldarelli *et al.*, 2020). The oracle problem arises from the involvement of an oracle (e.g., human, artificial intelligence) to insert data to the blockchain and smart contract from an external environment, raising risks related to data authenticity and validity (Caldarelli *et al.*, 2020). These issues are not relevant in cryptocurrencies as all data is immutable and created within the blockchain network. However, in non-financial applications, the trustworthiness of the data depends on the trustworthiness of the oracle inserting the data (Caldarelli *et al.*, 2020).

Researchers have also identified several potential inter-organisational and intra-organisational barriers for blockchain adoption in the supply chain (Caldarelli *et al.*, 2021; Kamble *et al.*, 2019, 2020; Kayikci *et al.*, 2020; Kouhizadeh *et al.*, 2021a; Queiroz *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020). We summarise the main barriers in Table 4.

Table 4. The main barriers for blockchain adoption in the supply chain identified in the literature

Classification	Main Barriers for blockchain adoption	Reference
Blockchain related barriers	Lack of knowledge about blockchain	(Caldarelli *et al.*, 2021; Kamble *et al.*, 2020; Kurpjuweit *et al.*, 2021; Saberi *et al.*, 2019; Wong *et al.*, 2020)
	Blockchains security and privacy concerns	(Agrawal, Sharma, *et al.*, 2018; Babich and Hilary, 2020; Feng *et al.*, 2020; Kamble *et al.*, 2020; Saberi *et al.*, 2019; Wang, Singgih, *et al.*, 2019)
	Blockchain interoperability	(Casino *et al.*, 2019; Feng *et al.*, 2020; Jović *et al.*, 2019; Kamble *et al.*, 2020; Kayikci *et al.*, 2020)
	Immaturity of blockchain	(Agrawal, Sharma, *et al.*, 2018; Jović *et al.*, 2019; Lopes *et al.*, 2021; Miehle *et al.*, 2019; Saberi *et al.*, 2019; Wamba and Queiroz, 2020; Wang and Li, 2019)
	Blockchain integration with other systems	(Agrawal, Sharma, *et al.*, 2018; Clohessy *et al.*, 2019; Kayikci *et al.*, 2020; Lopes *et al.*, 2021; Queiroz *et al.*, 2019; Wang *et al.*, 2020)
	Blockchain scalability issues	(Agrawal, Sharma, *et al.*, 2018; Jović *et al.*, 2019)
	Trust in the blockchain	(Babich and Hilary, 2020; Rogerson and Parry, 2020; Wang, Singgih, *et al.*, 2019)
Organisational and SC barriers	Data immutability when dealing with data and human errors	(Agrawal, Sharma, *et al.*, 2018; Kamble *et al.*, 2020; Rogerson and Parry, 2020; Saberi *et al.*, 2019)
	Information sharing and disclosure challenges	(Agrawal, Sharma, *et al.*, 2018; Choi *et al.*, 2020; Rogerson and Parry, 2020; Saberi *et al.*, 2019)
	Data validity	(Agrawal, Sharma, *et al.*, 2018; Babich and Hilary, 2020; Caldarelli *et al.*, 2020; Kamble *et al.*, 2019, 2020)
	Cultural challenges	(Queiroz *et al.*, 2021; Saberi *et al.*, 2019; Wang, Singgih, *et al.*, 2019)
	Partners resistance to blockchain adoption	(Kamble *et al.*, 2020; Lopes *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020)
	Lack of incentive to adopt the technology	(Lopes *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020)
	Costs of required investments	(Agrawal, Sharma, *et al.*, 2018; Kamble *et al.*, 2020; Lopes *et al.*, 2021; Saberi *et al.*, 2019; Wang, Singgih, *et al.*, 2019)
	Lack of resources	(Feng *et al.*, 2020; Kamble *et al.*, 2020; Kayikci *et al.*, 2020; Kurpjuweit *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020; Wong *et al.*, 2020)
	Lack of new organisational policies for using blockchain	(Saberi *et al.*, 2019)
	Lack of management support	(Lopes *et al.*, 2021; Saberi *et al.*, 2019)
	Problems in SC collaboration, communication and coordination	(Saberi *et al.*, 2019; Wang *et al.*, 2021; Wang, Singgih, *et al.*, 2019)

External Barriers	Having regulatory and legal restrictions	(Feng *et al.*, 2020; Jović *et al.*, 2019; Kamble *et al.*, 2020; Kshetri, 2018; Saberi *et al.*, 2019; Wang *et al.*, 2020)
	Lack of standards	(Babich and Hilary, 2020; Feng *et al.*, 2020; Jović *et al.*, 2019; Wang *et al.*, 2020)
	Market competition and uncertainty	(Saberi *et al.*, 2019)

2.2.3.1 Major literature gaps in identifying the factors and inhibitors influencing blockchain adoption

The literature review highlights a wide range of factors potentially influencing or hindering blockchain adoption. These factors can vary across the industries, supply chains, and application areas. However, previous research is mostly conceptual with limited empirical evidence identifying the factors and challenges in real supply chain settings (van Hoek, 2019a, 2019b; Sternberg *et al.*, 2021; Wamba and Queiroz, 2020).

Meanwhile, practitioners are preceding academics in experimenting with blockchain in various supply chain and enterprise applications (Lacity, 2018a; Treiblmaier, 2020). Janssen *et al. (2020)* addressed the need for a holistic approach for investigating blockchain adoption within the complex institutional, social and organisational ecosystem (Janssen *et al.*, 2020). Kamble *et al.*, (2020) stressed the need for more research on blockchain adoption in specific sectors to identify the barriers and enablers of blockchain adoption. Sternberg *et al.* (2021) also stressed the need for in-depth studies for blockchain adoption and implementation to better understand both the intra-organisational and inter-organisational factors that influence its adoption in the supply chain. They argued that the inherited complexity of the supply chain calls for in-depth understanding of the benefits and challenges of blockchain adoption and deployment in the supply chain in a detailed level. We identify this gap below.

Literature Gap No 3: There is a lack of empirical research investigating the organisational factors, pre-requisites, and barriers for blockchain adoption within different supply network configurations.

Verhoeven *et al.* (2018) addressed the importance of considering the technology features when deciding its application in a particular business use case. Blockchain scalability is a major issue hindering its wide scale adoption. Most blockchain applications are at the pilot stage with limited applications at scale. Several researchers have been investigating technical solutions to address blockchain scalability issues (Chauhan *et al.*, 2018; Eklund and Beck, 2019; Malik *et*

al., 2018; Zhou, Huang, *et al.*, 2020). However, there is lack of research investigating the factors that influence the scalability of blockchain-enabled SC solutions from a SC perspective.

Literature Gap No 4: There is a lack of research investigating the factors influencing the scalability of blockchain-enabled SC solutions from a SC perspective.

2.2.4 Blockchain decision frameworks in the literature

Several decision frameworks for the use of blockchain have been developed over the past years (Table 5). Maull *et al*. (2017) proposed a decision flowchart to identify when and which type of DLT is suitable for different scenarios, considering the need for very rapid transactions, contractual relationships, the need to use trusted third party and share write access, and the alignment of participants' interests. These factors were key to identifying whether DLT is suitable or not. The flowchart provided early insights into the key considerations when implementing DLT. However, it does not include some of the core characteristic of blockchain such as data immutability and traceability. Lo *et al*. (2017) proposed an evaluation framework to assess the suitability of blockchain versus conventional databases considering having multiple parties involved, need for a trusted authority, centralised operation, and the transparency, traceability, immutability, and performance requirements. Their framework is one of the earliest models that considered the use of off-chain data storage to overcome the limitations of blockchain and critically identified the potential use of existing technologies alongside conventional databases rather than blockchain. Peck (2017) proposed a flowchart to determine whether blockchain is needed or not and the type of the blockchain network, considering the need for traditional database, multiple parties updating the database, trust issues among participants, security against attacks and data redundancy, use of third-party, data privacy and data control requirements. However, their decision framework did not consider the need for data immutability which is one of the core capabilities of blockchain. This limitation is also evident in Wüst and Gervais (2018) decision flow chart.

The World Economic Forum (WEF) (WEF, 2018) provided a practical framework for business leaders that has many similarities with Maull *et al.* (2017) flowchart to guide when to use blockchain technology. In their framework, three main factors were essential to eliminate the need for blockchain, including removing intermediaries, working with digital assets, and creating a permanent record for the digital assets. They also considered the performance and storage requirements as questionable factors, highlighting a limitation to blockchain that might

be overcome in the future. The WEF framework included several important considerations that were not highlighted in the previously developed frameworks such as the use of digital assets and the need for permanent records of transactions. However, it assumed that interested parties are already working with digital assets which is not necessary the case especially in blockchain applications in the supply chain. Organisations are increasingly starting to implement different methods that enable products' physical and digital identification to effectively use blockchain. Furthermore, blockchain performance and storage capacity requirements are important considerations for blockchain adoption, but they differ depending on the application area. For example, in the case of Walmart, blockchain application in the FSC has significantly improved the performance of the product recall processes where information retrieval time was reduced from weeks to seconds (Hyperledger, 2019).

Pedersen *et al*. (2019) developed a ten-steps decision framework to determine when to use blockchain and the type of blockchain network, considering the need for shared database, having multiple parties involved, having trust issues and conflict of interests, need for immutable log and data accessibility requirements. They added two dimensions related to governance rules among the different participants and the nature of stored data whether it is changeable or not. Despite having different governance rules is an important capability of blockchain supported by the use of consensus mechanisms, it is not necessary a decisive factor in the use of blockchain but rather in defining the type of blockchain network.

2.2.4.1 Major literature gaps in blockchain decision models

Table 5 summarises the different factors considered in each of the previously developed decision frameworks for blockchain. None of the proposed models considered all the core technical capabilities of blockchain or considered its applications in the supply chain. There is a lack of research that provides guidance to the identification of potential application areas for blockchain in the supply chain or guides the decision-making regarding blockchain applications in the supply chain. We identify these gaps below.

Literature Gap No 5: Lack of empirical research that guides the decision making for blockchain application in the supply chain and the identification of blockchain use cases.

Table 5. Overview of the main decision frameworks for blockchain adoption developed in the literature

Considered Element	Maull *et al.* (2017)	Lo *et al.* (2017)	Peck (2017)	Wüst and Gervais (2018)	WEF (2018)	Pedersen *et al.* (2019)
Need for a shared database			Can a traditional database technology meet you need?			Need for a shared common database?
Need for state storage				Do you need to store state?		
Need to remove intermediaries					Are you trying to remove intermediaries or brokers?	
Work with digital assets					Are you working with digital assets (Versus physical assets)?	
Creation of permanent record		Is immutability required?			Can you create a permanent authoritative record of the digital asset in question?	Need for an objective immutable log?
Traceable record of transaction		Is transaction history required?				
Performance requirements	Very Rapid Transactions?	Is high performance required?			Do you require high performance rapid (milliseconds)?	
Data storage Capacity Requirements					Do you intend to store large amount of non-transactional data as part of your solution?	
Multiple parties	Need shared write access?	Is multi-party required?	Does more than one participant need to be able to update the data?	Are there multiple writers?	Do you require shared write access?	Multiple parties involved?
Trust	Need to use a trusted party?	Is trusted authority required?	Do you and all those updaters trust one another?	Can you use an always online trusted third party (TTP)?	Do you want or need to rely on a trusted party? e.g. for compliance for liability reasons	Involved parties have conflicting interests/trust issues?
	Writers known and trusted?		Would all the participants trust a third party?	Are all writers trusted?	Do contributors know or trust each other?	Parties can/want to avoid a trusted third party?
Various governance rules						Rules governing system access differ between participants?

Transacting rules						Transacting rules remain largely unchanged?
Relationships	Contractual Relationships?				Are you managing contractual relationships or value exchange?	
	Writers' interests unified?				Are contributors' interests unified or well-aligned?	
Decentralisation (Security)		Is trusted authority decentralizable?	Is this database likely to be attacked or censored? Do you need redundant copied in multiple distributed computers?			
Type of blockchain Network	Need to control functionality?		Does the data need to be kept private?	Are all writers known?	Do you need to be able to control functionality?	Need for public access?
	Should transactions be public?		Do you need to control who can make changes to the blockchain software?	Is public verifiability required?	Should transactions be public?	Are transactions public?
	Where consensus determined?					Where is consensus determined?
Limitation	No consideration of data immutability.	No consideration of the different types of blockchain networks.	No consideration of data immutability. No consideration of digital representation of assets	No consideration of data immutability. No consideration of digital representation of assets	Working with digital assets might not be in place but can be initiated through blockchain adoption. Blockchain performance and storage capacity requirements differ per application area and still under development	No consideration of digital representation of assets. Governance rules falls more under the type of blockchain network rather than a key decision-making element for the use of blockchain

2.3 Theoretical Perspective on Blockchain Adoption and Application in the Supply Chain

The multidisciplinary nature of blockchain research (Casino *et al.*, 2019; Queiroz *et al.*, 2021; Saberi *et al.*, 2019; da Silva and Moro, 2021) calls for the considerations of multidisciplinary theoretical perspectives to develop better understanding of blockchain capabilities and implications. Various organisationsal management and information systems theories have been adopted in previous blockchain research to illustrate how existing and well-established theories can be applied and modified to describe, explore and predict the changes that may accompany the introduction of blockchain.

The resource-based view (RBV) (Barney, 1991; Wernerfelt, 1984), relates the competitive advantage of a firm to its ability to possess resources and capabilities that are valuable, unique and difficult to imitate. Treiblmaier (2018) suggested that RBV can help investigate the organisational resource requirements for blockchain adoption. Agency theory or principal-agent theory (PAT) (Eisenhardt, 1989a) considers the various interests between principals and agents and the use and implication of information asymmetry. PAT can help investigate how the different parties interact in the blockchain system considering the transparency provided by blockchain (Kummer *et al.*, 2020).

The transaction cost analysis (TCA) theory (Coase, 1937; Williamson, 1981), namely the ex-ante costs of initiation and agreement combined with the ex-post costs of control and adjustment, broadens the perspective by considering multiple SC players. Roeck *et al.* (2020) adopted TCA to study the impact of DLT on SC transactions based on empirical data. Their study showed the positive impact of DLT on reducing SC transaction costs, reducing dependency on third parties, and changing power distribution between suppliers and buyers. Cole *et al*. (2019) argues that both the TCA and PAT theories will exhibit a renaissance within the context of blockchain application in the supply chain due to the implication of blockchain on trust between the different parties.

Information processing theory (Galbraith, 1974), considers the organisations as systems that need to process information to reduce uncertainty. With blockchain, organisations might need to adopt information process theory to evaluate the competitiveness of different blockchain networks (Saberi *et al.*, 2019), to identify information processing requirements from blockchain adoption (Martinez *et al.*, 2019), and to analyse how blockchain transparency can improve existing information-processing capabilities (Kummer *et al.*, 2020).

Institutional theory (Hirsch, 1975) considers the external pressures, institutional norms and practices in which organisations are embedded-in and influenced-by. Kummer *et al.* (2020) suggested using institutional theory to investigate whether internal or external pressures drive blockchain adoption.

Network theory (Latour, 2005) investigates the inter-organisational relationships and their management, and network effects (Katz and Shapiro, 1985) correlate the value or utility of a good or service with the number of its users, may both be important to investigate supply SC relationships in the context of blockchain. Queiroz and Wamba (2019) incorporated network theory in their conceptual model to investigate the main drivers for blockchain adoption in the supply chain. Sternberg *et al.* (2021) and Li and Zhou (2020) argued that blockchain applications in the supply chain is subject to network effects as the benefits of blockchain comes from and increase by having multiple parties adopting the technology.

Demand theory (Mark *et al.*, 1981; Morgenstern, 1948), calls for a thorough investigation of consumer behaviour and needs and the implications they have on decision-making in organisations. da Silva and Moro (2021) investigated the impact of blockchain adoption and consumer trust including their behaviour towards provided products and services. They addressed the limited blockchain research investigating blockchain implications on consumers' trust. Wang *et al*. (2021) adopted the theory of business models (Teece, 2010) to investigate in-depth the requirements for blockchain deployment within complex multi-tier supply networks. Saberi *et al*. (2019) suggested the need to borrow theories from other fields such as sociology and economics to better understand and conceptualise blockchain as a multidisciplinary academic discipline. They proposed the potential implication of blockchain on trust-related theories such as social capital theory, and resource dependency theory to examine buyer-suppliers' relationships.

Other studies in blockchain-SCM adopted information technology theories, including the technology acceptance model (TAM) (Davis, 1989), the unified theory of acceptance and use of technology (UTAUT) (Venkatesh *et al.*, 2003), technological, organisational, and environmental framework (TOE) (Tornatzky *et al.*, 1990), organisational systems (IOS) adoption theory (Premkumar *et al*., 1997), task-technology fit (TTF) (Goodhue and Thompson, 1995), technology readiness index (TRI) (Parasuraman, 2000), theory of planned behaviour (TPB) (Ajzen, 1991), sense making theory (Weick *et al.*, 2005), and inter-information system success (DeLone and McLean, 2003) models to investigate blockchain adoption behaviour in the supply chain (Alazab *et al.*, 2021; Caldarelli *et al.*, 2021; Clohessy *et al.*, 2019; Fosso

Wamba *et al.*, 2020; Kamble *et al.*, 2019; Kouhizadeh *et al.*, 2021a; Queiroz *et al.*, 2021; Queiroz and Wamba, 2019; Sternberg *et al.*, 2021, 2021; Tan and Sundarakani, 2020; Wang, Singgih, *et al.*, 2019; Wong *et al.*, 2020; Yang, 2019).

Several researchers have integrated multiple organisational and information systems theories to provide combined perspective on their research. Treiblmaier (2018) has related the four economic theories of transaction cost analysis, principal agent theory, resource-based view, and network theory to investigate the structural and the managerial aspects of blockchain applications in the SCM. Chang *et al*. (2019) discussed TCA and PAT within the context of blockchain application in international trade processes. Martinez *et al*. (2019) studied blockchain effects on customers order management processes considering both the RBV and information processing theory. Queiroz and Wamba (2019) adopted UTAUT and network theory to understand the motivations behind blockchain adoption in the US and India. Fosso Wamba *et al.* (2020) adopted both the TAM and UTAUT theories to investigate the relation between blockchain adoption and SC performance. Alazab *et al*. (2021) also adopted UTAUT model, Information Systems Success (ISS) model, TTF model, and two trust- based IT innovation constructs namely Technology Trust and Inter-organisational Trust to analyse the factors influencing blockchain adoption in the supply chain using a cross-sectoral survey. Table 6 provides an overview of the range of theories considered in blockchain-SCM research.

Table 6. Summary of the main theories adopted in blockchain-SCM research

Theory	**Relevance in blockchain and SCM research**
Information Processing Theory	To help organisations assess and improve their information analytics capabilities when adopting blockchain (Kummer *et al.*, 2020; Martinez *et al.*, 2019; Saberi *et al.*, 2019).
Network Theory and Network Effect Theory	To investigate the drivers for blockchain adoption (Queiroz and Wamba, 2019). To investigate the SC relationships when adopting blockchain (Kummer *et al.*, 2020; Treiblmaier, 2018).
Resource-based view theory	To help identify required resources and capabilities for blockchain adoption and deployment (Treiblmaier, 2018). To evaluate the emergence of competitive capabilities due to blockchain application in business models and processes (Martinez *et al.*, 2019).
Agent Theory	The transparency provided by blockchain can leads to new perspectives on principle-agent theory (Chang *et al.*, 2019; Cole *et al.*, 2019; Kummer *et al.*, 2020; Treiblmaier, 2018).
Transaction Cost Analysis Theory	To identify new perspective on SC transactions management (Cole *et al.*, 2019). To investigate the reduced costs from blockchain adoption by eliminating paper-work and need for documents verification processes (Chang *et al.*, 2019). To investigate reduced transaction costs by eliminating intermediaries (Schmidt and Wagner, 2019; Treiblmaier, 2018).

Institutional Theory	To investigate whether blockchain adoption is driven by internal or external pressures (Kummer *et al*., 2020).
Demand Theory	To investigate how consumer behaviour and needs influence the organisations decisions regarding blockchain adoption.
Inter-organisational Systems Adoption Theory	To identify the drivers and barrier for blockchain adoption in the supply chain (Sternberg *et al.*, 2021).
Sensemaking theory	To help in understanding the perception of SCM professionals towards blockchain benefits, potential implications, and developmental path (Wang, Singgih, *et al.*, 2019)
Information Technology, Innovation Theory, and TOE Framework	To identify and investigate the technological, organisational and environmental factors influencing blockchain adoption and deployment in the supply chain (Caldarelli *et al.*, 2021; Clohessy *et al.*, 2019; Kouhizadeh *et al.*, 2021b).
UTAUT, TAM, TRI, TPB, TTF, and ISS	To investigate blockchain adoption behaviour in the supply chain (Alazab *et al.*, 2021; Kamble *et al.*, 2019; Queiroz *et al.*, 2021; Queiroz and Wamba, 2019; Wong *et al.*, 2020).

2.4 Summary of Literature Gaps and Research Questions

Despite the emergence of blockchain in 2008, research on the topic in the operations and SCM academic literature exhibited a significant time lag. It started to emerged in 2016 (Treiblmaier, 2020) and the past five years have witnessed a very significant increase in blockchain-SCM literature (Rejeb, Rejeb, *et al.*, 2021). However, there are still tremendous research challenges and opportunities to develop this emerging multidisciplinary field. Specifically, there is limited research investigating the key factors, pre-requisites and challenges of blockchain adoption that take into account the complex SC characteristics and their management. Although many gaps were highlighted throughput this literature review, we recall the major knowledge gaps that will be addressed in this research (Sections 2.2.2.8, 0, and 2.2.4.1):

Literature Gap No 1: *Lack of empirical research that investigates organisations' motivations of blockchain adoption and application in the supply chain in the different industries*

Literature Gap No 2: *Lack of empirical research that investigates the influence of the industry characteristics on blockchain adoption and application in the supply chain*

Literature Gap No 3: *Lack of empirical research investigating the organisational factors, pre-requisites, and barriers for blockchain adoption within different supply network configurations.*

Literature Gap No 4: *Lack of research investigating the factors influencing the scalability of blockchain-enabled SC solutions from a SC perspective.*

Literature Gap No 5: *Lack of empirical research that guides the decision making for blockchain application in the supply chain and the identification of blockchain use cases.*

Researchers have used both conceptual and empirical research approaches. We classify and summarise the research approaches in the reviewed literature in Table 7. Most of the blockchain-SCM research is conceptual and based on the use of secondary data sources. It also focuses on investigating the technicalities of blockchain resulting in a lack of research that investigate the organisational complexities accompanied with blockchain adoption (Janssen *et al.*, 2020; da Silva and Moro, 2021).

Furthermore, many researchers have anticipated the potential benefits and barriers for blockchain adoption in the supply chain (Cole *et al.*, 2019; Grover *et al.*, 2018; Hughes *et al.*, 2019; Jardim *et al.*, 2021; Rejeb, Keogh, *et al.*, 2021; Wang, Han, *et al.*, 2019). The increasing number of reviews of the limited literature has resulted in a recurrence of the same themes of claimed benefits, applications, and anticipated challenges for blockchain in the supply chain but with a lack of supportive empirical evidence.

The limited empirical blockchain-SCM research have been based on the use of case studies, surveys, and interviews. The use of case studies have been adopted to test developed frameworks and blockchain systems in a specific SC context (Dede *et al.*, 2021). Treiblmaier (2020) recommended the use of case studies to investigate blockchain applications in practice and systematically transfer industry knowledge and experience into research agendas that support theory testing and development and design of science research.

van Hoek (2019a, 2019b) conducted three case studies at the pilot stage across three different industries namely logistics, consumer products and retail to investigate the main considerations when adopting blockchain in the supply chain. Tseng and Shang (2021) conducted multiple case studies across different industries to analyse the impact of blockchain on the role of intermediaries in Taiwan. They used structured interviews to collect data across four industries: medical care, farming, accounting, and supply chain. However, none of the research that considered blockchain applications in different sectors have investigated the influence of the industry characteristics, including product, business processes, supply network configuration, industry standards and regulations, and market and customer demand characteristics on blockchain adoption and application. These characteristics were noted in some sectoral research (Alazab *et al.*, 2021; Eryilmaz *et al.*, 2020; Patelli and Mandrioli, 2020), but no research has taken a cross-sectoral perspective when investigating blockchain applications. The

majority of case study research is also limited in the number of cases used (i.e. single case study) (Baralla *et al.*, 2021; Bodkhe *et al.*, 2020; Garrard and Fielke, 2020; Maity *et al.*, 2021; Wang *et al.*, 2021; Yusuf *et al.*, 2019), level of detail investigated (Fu *et al.*, 2020; Patelli and Mandrioli, 2020), and/or investigate a case study at an initial stage of development or pilot stage (Baralla *et al.*, 2021; Bodkhe *et al.*, 2020; Casino *et al.*, 2021; Danese *et al.*, 2021; van Hoek, 2019a; Maity *et al.*, 2021).

In this research, we conduct rigorous empirical research to address the literature gaps and provide comprehensive answers to the following research questions (RQ):

RQ1: How do industry characteristics influence blockchain applications in the supply chain?

RQ2: What are the main motivations for blockchain adoption and application in the supply chain?

RQ3: What are the key pre-requisites and inhibitors for blockchain adoption and deployment in the supply chain?

RQ4: What factors influence the decision-making and scalability of blockchain-enabled solutions in supply chain applications?

Table 7. Overview of main research approaches in the blockchain-SCM literature

Main Research Methodology	Main Approach	Relevant References
Conceptual	General overview	(Agrawal, Sharma, *et al.*, 2018; Cole *et al.*, 2019; Saberi *et al.*, 2019; Tijan *et al.*, 2019)
	Literature Review	(Grover *et al.*, 2018; Gurtu and Johny, 2019; Hughes *et al.*, 2019; Jović *et al.*, 2019; Kummer *et al.*, 2020; Lim *et al.*, 2021; Pournader *et al.*, 2020; Queiroz *et al.*, 2019; Rejeb, Rejeb, *et al.*, 2021; Rejeb, Treiblmaier, *et al.*, 2021; Wamba and Queiroz, 2020; Wang, Han, *et al.*, 2019)
	Theory	(Choi and Luo, 2019; Kummer *et al.*, 2020; Rejeb *et al.*, 2019; Schmidt and Wagner, 2019; Treiblmaier, 2018)
Empirical	Case Study	(Baralla *et al.*, 2021; Bodkhe *et al.*, 2020; Caldarelli *et al.*, 2021; Danese *et al.*, 2021; Fu *et al.*, 2020; Garrard and Fielke, 2020; Gausdal *et al.*, 2018; van Hoek, 2019a; Patelli and Mandrioli, 2020; Philipp, 2020; Sternberg *et al.*, 2021; Tan and Sundarakani, 2020; Tönnissen and Teuteberg, 2020; Tseng and Shang, 2021; Wang *et al.*, 2021; Yusuf *et al.*, 2019)
	Interviews and workshop	(van Hoek, 2019c; Kayikci *et al.*, 2020; Loklindt *et al.*, 2018; Lopes *et al.*, 2021; Philipp *et al.*, 2019; Wang, 2020; Wang, Singgih, *et al.*, 2019)
	Survey-based	(Alazab *et al.*, 2021; Fosso Wamba *et al.*, 2020; Kamble *et al.*, 2019; Queiroz *et al.*, 2021; Wong *et al.*, 2020; Yang, 2019)
Technical	Framework Development	(Dasaklis, Casino, Patsakis, *et al.*, 2019; Fu *et al.*, 2018; Irannezhad and Faroqi, 2021; Janssen *et al.*, 2020; Malik *et al.*, 2018; O'Leary, 2017; Pal and Yasar, 2020; Singh *et al.*, 2020; Song *et al.*, 2021; Wang *et al.*, 2020)
	System development	(Bechtsis *et al.*, 2019; Bocek *et al.*, 2017; Chen *et al.*, 2020; Dolgui *et al.*, 2020; Eryilmaz *et al.*, 2020; Figorilli *et al.*, 2018; Peronja *et al.*, 2020; Schyga *et al.*, 2019; Sylim *et al.*, 2018; Toyoda *et al.*, 2017; Yusuf *et al.*, 2019)

Chapter 3: Research Methodology

In this research, we use multiple research methodologies to conduct rigorous empirical research that addresses the research questions and contributes to the emerging body of knowledge. We justify our approach in this chapter.

The overall research methodology is described in Figure 2. We started by investigating the limited academic literature to identify the current state of blockchain-SCM research to inform the research questions and methodology design. The primary research methodology is a multiple case study complemented with an analysis of reported blockchain use cases and consortia and an executive workshop to enrich the research findings and enable their validation, triangulation, and generalisation. The multiple case study part consisted of an empirical investigation of four cases with leading organisations at various stages of blockchain adoption and in different sectors and geographical regions. It enabled in-depth understanding and analysis of the main motivations behind blockchain adoption, the key pre-requisites and inhibitors for blockchain adoption in the supply chain, and the main factors influencing blockchain decision-making, adoption and scalability.

A within-case analysis was conducted in each case study to produce individual reports on the respective organisation. The findings were summarised and validated by the organisations. In addition, a cross-case analysis was conducted to compare and contrast the findings from each case study.

The second study used secondary data sources to analyse blockchain use cases and consortia reported between 2017-2021. It investigated the main motivations behind blockchain adoption, the main application areas, and the influence of industry characteristics on blockchain application. The third study included the design and analysis of an executive workshop discussing the main drivers, inhibitors, and factors influencing blockchain-enabled SC traceability, one of the prominent areas for blockchain applications in practice and literature. The findings from these studies provided rich insights into blockchain adoption in the supply chain. They were analysed, compared and discussed to answer the research questions rigorously and develop novel conceptual and decision frameworks with significant theoretical and practical implications.

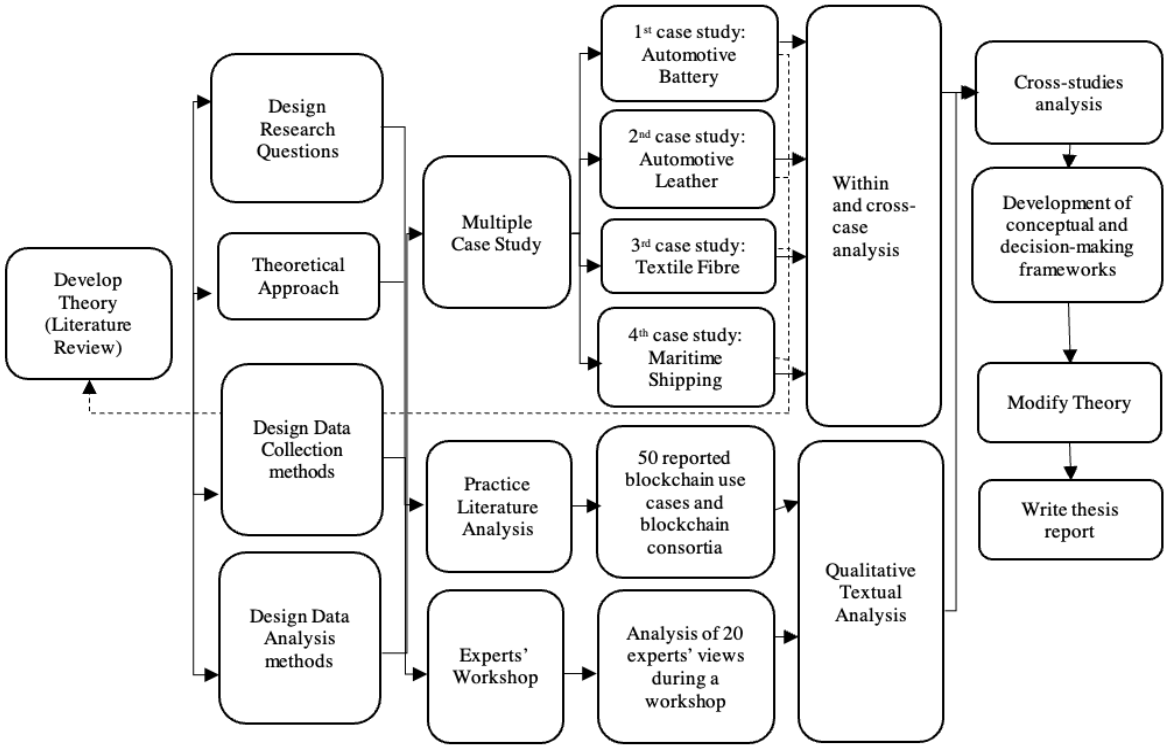


Figure 2. Overview of the research methodology

This chapter is organised as follows: Section 3.1 describes the theoretical underpinnings and research approach. Section 3.2 describes the case study design. Section 3.3 describes the methodology for analysing the reported blockchain use cases. Section 3.4 describes the workshop design and questions. The chapter concludes with the methods used for the cross-study analysis in Section 3.5.

3.1 Theoretical Underpinnings and Research Approach

SCM researchers have adopted different theoretical perspectives to investigate blockchain adoption and application in the supply chain (Table 6). However, blockchain is an emerging technology, and there is limited empirical research and theory development considering its application in the SCM (Sternberg *et al.*, 2021). The existing body of knowledge on blockchain-SCM research is limited, and its application in practice is still in its infancy. Thus, the adoption of existing theory in research can potentially limit the investigation of this emerging phenomena to pre-defined perceptions and might oversee other potential new considerations not previously identified in theory literature. Therefore, we consider the use of grounded theory to be important when studying blockchain technical features, its adoption and application in a supply chain context to provide opportunities to develop new theoretical

perspectives that advance the emerging multidisciplinary body of knowledge. Glaser and Strauss (2017) describe grounded theory as *"the discovery of theory from data systematically obtained from social research".* In grounded theory, theory is developed throughout the research process as a result of data collection and analysis (Mkhomazi and Iyamu, 2013). The use of grounded theory was also recommended and deemed necessary by Saberi et al. (2019) and Sternberg et al. (2021) to advance blockchain development in both theory and practice. In this research, the use of grounded theory supported the collection of comprehensive data related to the research questions that were further analysed to provide valuable insights into blockchain adoption and application in the supply chain. These insights can lay the foundation for future theory-driven research in this prominent field.

We also discuss the research philosophy which is our set of beliefs and assumptions that helped in designing and conducting the research work. Considering the research aim to analyse blockchain adoption in the supply chain, several ontological (i.e., views on nature of reality) and epistemological (i.e., views on truth and legitimate knowledge) assumptions were investigated to determine the best theoretical approach (Scotland, 2012; Slevitch, 2011). Two aspects of the research aim present key ontological assumptions: First aspect is associated with blockchain adoption; Who decides this adoption? These types of decisions are usually made by people working in different organisations. Hence, there is a need to understand their perspectives about the technology and the context in which they are making these decisions. Second aspect is SCM, a wide field in social sciences that "*encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies*" (CSCMP, 2013). Thus, in SCM, organisations interact with each other to facilitate the movements of products across the different supply networks. Supply networks are socially constructed entities incorporating different people's perspectives, cultures, norms, and other social factors that are important to understand how these networks are created and operated.

Considering these important two aspects, a social constructionist approach has been taken in carrying out this research. Social constructionism "*states that meaningful learning occurs when individuals are engaged in social activities such as interaction and collaboration*" (Amineh and Asl, 2015). It helps considering the different people's behaviours, relationships and

perceptions of the world they are living in and that they can perceive the same reality in different ways (Galbin, 2014; Scotland, 2012). It also acknowledges that communication and interaction processes between people play an important role in understanding the world (Galbin, 2014). By taking this approach, the differences in people's perceptions in each case study and how they approach and make decisions about blockchain adoption were considered in the research.

The research also takes the epistemological orientation of interpretivism to help interpreting and providing insights into people's different perspectives. In the context of this research, it helps interpreting people's perspectives of their supply network, their SC relationships, and their understanding of blockchain and its capabilities. The interpretivist approach allows the researcher's knowledge and empirical experience to be part of the process and supports that people perceive reality based on their own experiences with the world and are not necessarily the same for everyone (Saunders *et al.*, 2009; Walsham, 1995). This is an important aspect of this research.

Pursuing the constructivist and interpretivist approaches is ideal for this research. Taking the constructivist approach helps in case study design and how they are conducted, while the interpretivist considers the involvement of the researcher in the process and the interpretations of the case study information. These approaches are also recommended by Yin (2018) when using a case study for research. Finally, the research also adopts Friedman methodological thesis that points out that the research assumptions are not necessarily have to be precisely accurate as long as they are good approximations of the research purpose on hand, and they can provide sufficiently accurate predictions (Tsang, 2016). This supports that there is always room for further development of concepts.

3.2 Case Study Design

Studying a contemporary and emerging technology like blockchain and its SC applications requires an in-depth investigation of its capabilities and the SC characteristics in which it is deployed. Hence, conducting multiple case studies to investigate this contemporary phenomenon is the most appropriate approach. Several researchers advocated using multiple case studies to provide in-depth observation, external validity and overcoming potential research bias (Eisenhardt, 1989b; Voss *et al.*, 2002; Yin, 2018).

Yin (2018) defined a case study based on scope and features. In terms of scope, it is defined as *"an empirical method that investigates a contemporary phenomenon in-depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident."* And in terms of features: *"A case study copes with the technically distinctive situation in which there will be many more variables of interest than data points, benefits from the prior development of theoretical propositions to guide design, data collection and analysis, and relies on multiple sources of evidence with data needing to converge in a triangulating fashion."*

Using multiple sources of evidence, a case study provides a holistic approach to the phenomenon under study (Noor, 2008). According to Crowe *et al.* (2011), "*The case study approach helps in generating in-depth multifaceted understanding of a complex issues in its real-life context*". Case studies are most suitable to study contemporary events. There are three types of case study: exploratory, descriptive, and explanatory (Yin, 2018). This research investigates the relative factors influencing blockchain adoption and assesses the potential benefits derived from its application in the SCM. We identify the unit of analysis in the research as the organisation's blockchain project/solution. The case studies are considered both exploratory and explanatory since we explored and described the SC context and existing challenges in each case study. Then, we identified the key pre-requisites and inhibitors for blockchain adoption and the key factors that influenced the decision-making regarding blockchain adoption and application area.

Considering the appropriate number of case studies, we conducted four case studies in the range specified by Eisenhardt (1989). We followed Yin (2018) steps to design the case study by identifying the: (1) case study questions, (2) case definition and boundary, (3) data collection methods, and (4) chosen criteria for interpreting the findings.

3.2.1 Case study questions

The case study questions are derived from the main research questions to include all important aspects to be considered in each case (

Table 8). To answer the first research question, we first need to understand the specific SC and industry characteristics of the case study organisation. This includes the characteristics of the supply network structure, products and business processes, SC relationships, the external environment in which it operates, and the specific SC challenges. Similarly, to understand the motivations behind blockchain adoption, we need to examine blockchain capabilities in

overcoming existing challenges and meeting business needs. Here, we assessed the participants' knowledge about blockchain. Most case study participants were knowledgeable about blockchain and its capabilities since they were directly involved in the blockchain projects within their organisation. However, in the first case study, some participants had only limited knowledge about blockchain. Hence, an illustrative presentation of blockchain and its capabilities was presented.

To identify the key requirements and inhibitors for blockchain adoption, we investigate several aspects, including the technical and managerial challenges and requirements prior to blockchain adoption, the solution configuration, and the type of data shared on blockchain. Finally, we investigate the factors that influenced decision-making, adoption, and scalability of blockchain, including the application area and the solution scalability plan.

Table 8. Research questions and case study questions

Research Questions	**Case study questions**
RQ1- How do industry characteristics influence blockchain applications in the supply chain?	➢ What are the SC, product, and business processes characteristics?
	➢ How does the external environment (i.e., government, market, customer demand) influence the supply network?
	➢ What major SCM challenges affect the specific industry and organisation's supply network?
	➢ What are the SC relationships characteristics?
	➢ What is the level of information sharing between SC partners?
RQ2- What are the main motivations for blockchain adoption and application in the supply chain?	➢ To what extent does the organisation know about blockchain?
	➢ How can blockchain help in overcoming existing SC challenges?
	➢ How does the industry and/or government influence blockchain adoption?
	➢ What value does blockchain bring to business compared to existing technologies?
	➢ Why did the organisation adopt blockchain in their supply chain?
RQ3- What are the key pre-requisites and inhibitors for blockchain adoption and deployment in the supply chain?	➢ What information systems are currently used in the supply network?
	➢ What are the characteristics of the adopted blockchain network?
	➢ What data is shared on the blockchain platform?
	➢ What technical and managerial challenges and requirements affected blockchain adoption in the organisation's supply chain?
	➢ What are the main concerns about blockchain?
RQ4- What factors influence the decision-making and scalability of blockchain-enabled solutions in supply chain applications?	➢ To what extent does the organisation know about its supply network?
	➢ How did the organisation adopt blockchain in their supply chain?
	➢ What is the application area for blockchain in the specific supply chain? and why?
	➢ What other factors facilitated/inhibited blockchain adoption?
	➢ What is the solution scalability plan?

3.2.2 The case study definition and boundary

In this research, we conducted four case studies of organisations at different industries and positions in the supply chain including automotive (Manufacturer), textile and apparel (Fibre producer), and maritime logistics (Integrated shipping and logistics organisation) industries. These industries are among the top industries experimenting with blockchain (Table 2) and have diverse products and business process characteristics in terms of complexity, maturity, and sensitivity. The role and impact of regulations also vary widely across these industries. The organisations' selection was based on meeting the following criteria:

- The company is interested in/already adopted blockchain in its supply chain.
- The company is in different stage of blockchain adoption and deployment: Not developed, Pilot, Implementation, or Commercialisation.
- The company is at different position in the supply network: Major supplier, Manufacturer, Retailer, Logistic provider.
- The company is willing to participate in the case study.

The scope of each case study varies considering the different business needs, stage of blockchain adoption, and application area of the blockchain solution in the organisation's supply chain. We describe each case study and its scope below:

Case No 1: Blockchain application in the automotive battery supply chain

a. Case study definition:

The case study organisation is an Automotive Original Equipment Manufacturer (OEM) with a long history that has now started the production of electric vehicles (EV). Since batteries' costs and performance are key aspects of EV manufacturing, the company plans to assemble the battery packs in-house. Therefore, it was interested in understanding the potential application of blockchain in its battery supply chain to tackle key SC sustainability issues. We refer to this organisation throughout the thesis as Organisation A.

b. Case study scope:

After understanding the key SC challenges faced by organisation A, the study focused on investigating the potential use of blockchain in the upstream cobalt supply chain from mining up to the OEM premises.

Case No 2: Blockchain application in the automotive leather supply chain

a. Case study definition:

The company is a premium automotive OEM interested in investigating the potential use of blockchain in its complex and global leather supply chain to enable its traceability. This case study is the most longitudinal and consisted of two stages over a period of 16 months. In the first stage, the organisation had not yet adopted blockchain and the study focused on investigating the potential challenges and opportunities for blockchain application in the upstream leather supply chain. This stage helped identify the requirements, challenges, and factors anticipated by the case study participants regarding blockchain adoption. It also helped shape a business case to pilot blockchain and secure governmental funds.

The second stage of the study included active participation in an intensive 6 months blockchain pilot project, that aimed at creating a blockchain-enabled digital twin for the upstream leather supply network and tackled the issue of the solution scalability in the global leather supply network. The second part of the case study is considered action research. Action research "*combines theory and practice (and researchers and practitioners) through change and reflection in an immediate problematic situation within a mutually acceptable ethical framework. Action research is an iterative process involving researchers and practitioners acting together on a particular cycle of activities, including problem diagnosis, action intervention, and reflective learning*."(Avison *et al.*, 1999). The researcher was actively engaged in the blockchain pilot project, and the project team also included the OEM suppliers and a blockchain provider. The findings from this part of the case study represent a summary of the learning and investigation processes conducted by the project team, including the researcher (Section 5.6). However, the analysis of the case study was conducted by the researcher (Section 5.7). We refer to this organisation throughout the thesis as Organisation A as it is the same organisation participated in the battery case study. However, the case study was conducted with different teams within the organisation.

b. Case study scope:

The first stage investigated the organisation's entire global leather supply network. The second stage included a selected local leather supply chain.

Case No 3: Blockchain application in the textile and apparel supply chain

a. Case study definition:

The case study organisation is a world-leading man-made cellulose fibre (MMCF) producer, that supplies different downstream applications including textile and apparel, non-woven applications, and industrial applications. The organisation has conducted several blockchain pilots in their downstream textile supply chain. We refer to this organisation throughout the thesis as Organisation B.

b. Case study scope:

The case study focused on blockchain application in the organisation's downstream textile supply chain. In the case study, an access to a demo of the developed blockchain solution was granted to evaluate its capabilities in meeting the organisation needs.

Case No 4: Blockchain application in the maritime logistics supply chain

a. Case study definition:

The organisation is a leading shipping company that developed an industry-wide blockchain-enabled shipping platform. The developed solution is commercialised and is open to the industry and shipping market. The case study considered the adoption of the blockchain platform within the organisation's vertically integrated supply chain and the entire shipping ecosystem. We refer to this organisation throughout the thesis as Organisation C.

b. Case study scope:

The case study focused on studying the characteristics of the developed blockchain-enabled shipping platform. It also investigated the organisation structure, vision and mission from developing the solution and its journey from a proof-of-concept until commercialisation.

3.2.3 Data collection methods

In each case study, we used a mix of primary and secondary data sources to attain comprehensive information answering the case study questions (Figure 3). Primary data were collected using semi-structured interviews and researcher observations to gain in-depth empirical data in each case study. We also reviewed the academic and practice literature prior to and during each case study to investigate the industry and SC characteristics and the existing blockchain applications in the sector. Additional secondary data (i.e., internal documentation) was supplemented by the case study participants to provide specific information about their supply chain and adopted blockchain solution. Table 9 summarises the interviewees' details and data sources used in each case study.

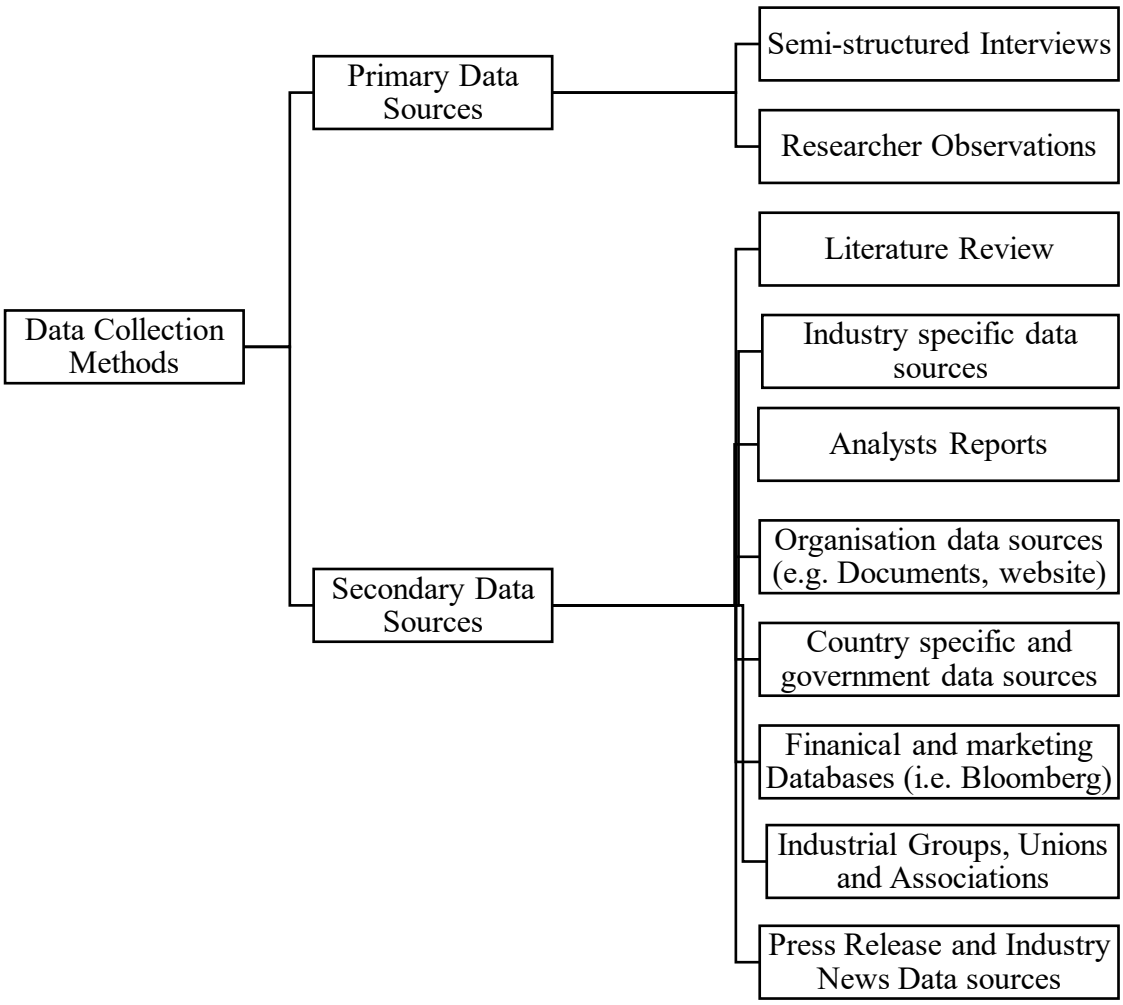


Figure 3. Overview of data collection methods and sources used in the research

In the third and fourth case studies that included one participant, the respective organisation provided detailed documentation covering the blockchain solution's objectives, characteristics, roles and responsibilities, and project management. The role of these participants satisfied the necessary expertise, end-to-end business view, and required understanding to comprehensively answer the case study questions without the need to include other participants. Furthermore, an access to the developed blockchain platform was provided to the researcher in organisation B's case study, and an overview of the platform was illustrated to the researcher in organisation C's case study. We describe each data source used next.

a. Primary Data Sources

1. Semi-Structured Interviews

Semi-structured interviews provide more flexibility for data collection compared to structured interviews (Noor, 2008). We conducted five interviews in the battery and leather case studies,

three interviews in the textile case study, and four interviews in the shipping case study. The interviews time range from 45 minutes to two hours. In every interview, a presentation was prepared to guide the discussion, including a summary of the case study findings to date for validation and new elements that were not discussed previously. In situations where there was less familiarity about blockchain, illustrative material was prepared for the participants (this mainly took place in organisation A battery supply chain). Each interview was recorded to make sure all information was captured and to allow the researcher to focus on the discussion rather than making notes. Each record was transcribed using the University of Nottingham Transcription Service and was reviewed to ensure accuracy of transcription. Each interview transcription was coded with date and participants name and positions. The transcriptions were then analysed according to the case study questions.

In general, the interviews consisted of three stages covered in multiple meetings: First, an overview of the SC characteristics, relationships, existing challenges, and motivations behind blockchain adoption were discussed. Second, the blockchain solution capabilities to address the business needs and the challenges and pre-requisites for blockchain adoption were discussed. In cases where there is a blockchain solution in place, we further discuss the solution features, the type of shared blockchain data, and the solution scalability strategy, requirements, and challenges in the third stage of interviews. Table 9 shows the number of interviews conducted in each case study and the time of each interview.

2. Researcher Observations

The researcher also incorporated observations regarding the organisation environment to provide information not directly collected using other methods. It helped particularly in identifying the key pre-requisites and barriers for blockchain adoption, which were validated by the participants at later stages. The first case study included face-to-face meetings, which helped in enriching the observatory data. However, the remaining interviews were conducted remotely limiting the insights derived from observations[2].

b. Secondary Data Sources

Secondary data sources cover any other data sources that already exist and are collected for other purposes rather than the research in hand (Calantone and Vickery, 2010). They have many advantages in this research including:

[2] Due to covid

- Less time and effort are required to obtain data since it is already collected.
- Eliminates researcher bias towards the collected data, which helps in triangulating the research findings.
- Provide different insights and perspectives to the research problem.

We briefly describe the main secondary data sources used in this research:

1. Existing academic literature

Reviewing the available literature is important for understanding blockchain development in the supply chain and its ability to tackle existing SCM challenges. This was crucial to understand the different aspects of each case study and to validate the research findings.

2. Industry specific data sources

These are specialised data sources for a particular industry that provide rich data, including industry reports, statistics, trade flows, sales and production volumes, suppliers' directory, and/or industry regulations and key trends. These data sources were useful to understand the key industry trends and supply network characteristics to investigate whether they influence blockchain adoption and SC application area.

3. Analysts reports

These reports are usually generated by market and research institutes and consulting firms, including Gartner, Deloitte, etc. They provide rich information about key trends in the market. Several blockchain-related reports were generated containing useful information about potential blockchain SC use cases and implications. Relevant analyst reports were reviewed in the research.

Table 9. Case study participants and information sources used

	Organisation A Case Study 1	**Organisation A Case Study 2**		**Organisation B Case Study 3**	**Organisation C Case Study 4**
Organisation Position	OEM Manufacturer	OEM Manufacturer	OEM Manufacturer/ Suppliers/ Blockchain Provider	Fibre Producer	Shipping and logistics provider
Industry	Automotive Battery	Automotive Leather	Automotive Leather	Textile and Apparel	Maritime Logistics
Blockchain Adoption Stage	Not adopted – considering	Developing use case pre-pilot	Pilot project (Action research)	Multiple pilots in place	Operational
Scope of study	Upstream the battery SC	Entire leather supply network	Selected upstream and downstream SC actors	Downstream the textile SC	Maritime shipping processes
Number of informants	6	5	10 from four organisations including automotive OEM, leather supplier, blockchain technology provider and University of Nottingham	1 (multiple meetings)	1 (multiple meetings)
Number of semi-structured interviews/ meetings	5 interviews and 2 post case study meetings	5	Weekly project meetings over a six-month period and individual meetings with suppliers	3	4
Time of each interview/meeting	First (1:08hrs), second (1:40hrs), third (2:00 hrs), fourth (00:55hrs), and fifth (00:40hrs). Two post study meetings (1:00 hr each)	First (1:10hrs), second (1:21hrs), third (1:00 hrs), fourth (00:55hrs), and fifth (00:40hrs).	Project meetings (1:00hrs) every week Individual meetings (00:45-1:00hrs)	First (1:30hrs), second (1:00hrs), and third (1:07 hrs).	First (1:00hrs), second (1:00hrs), third (1:10 hrs), and fourth (1:05hrs)
Level of informants	IT Director (ITD), Purchasing Senior Manager (PSM), Purchasing Manager (PM), Battery Raw Material Buyer	Purchasing Manager (PM), IT Director (ITD), Senior Project Manager (SPM), Environmental Compliance Manager (ECM), Senior	Sustainability Director, Production Manager, Digital Transformation Senior Manager, Purchasing Manager, Change Manager, Project Manager, Sustainability and Environmental Compliance Manager, Blockchain Solution Consultant	Value Stream Manager	Blockchain Solution Expert and Regional Manager

	(BRMB), Supply Chain Design Manager (SCDM), Senior Project Manager (SPM)	Sustainability Engineer (SSE)			
Function of informants	Purchasing, IT, Supply Chain Design, Sustainability, Digital Transformation	Purchasing, IT, Sustainability, Digital Transformation	Digital Transformation, Purchasing, Sustainability, Production, Project Management, Change Management	Digital Supply Chain Transformation	Product Management
Additional sources	Accessible secondary data Internal documentation	Accessible secondary data Internal documentation	Accessible secondary data Internal project documentation (Monthly presentations, project documentation, final reports)	Accessible secondary data Internal documentation Solution Demo	Accessible secondary data Internal documentation

4. Organisation data sources

Organisation data sources include public data like the organisation's website, or private data that requires authorisation from the organisation. Both public and private data (upon authorisation) were used in this research to provide additional information in each case study.

5. Country specific and government data sources

Government data sources include information about the policies and regulations governing the different industries, which is important to understand the external environment of the different supply chains. It also helps in appreciating the impact of regulations on the business operations and supply chains. This is crucial in studying blockchain development as different governments are taking different approaches towards the technology.

6. Financial and marketing databases

Even though the SCM field considers the material, information and financial flows within and between the different SC entities, the majority of SCM studies have focused on the material and information flows in the supply network with less research investigating the financial flows (Pfohl and Gomm, 2009). Growing attention has been drawn to this area to study SCM from the perspective of financial flows (Pfohl and Gomm, 2009). This has been facilitated by the availability of numerous financial databases containing rich financial information, e.g., Bloomberg and COMPUSTAT.

Bloomberg provides SC data by the SC analysis function (SPLC) that provides data for over 200,000 supply chains (Peterson, 2022). It identifies the organisations' suppliers, customers, and competitors based on their financial flows. This type of information helped mapping the SC configuration in the automotive battery case study, which was highly appreciated by the case study participants and helped in identifying the potential SC for blockchain adoption.

7. Industrial groups, Unions and Associations

These data sources are provided by groups of organisations in a particular industry or of countries sharing the same regulations and resources or aiming to achieve certain goals. There are existing bodies that are investigating blockchain and its application in a variety of use cases across the industries including Hyperledger, R3, and Ethereum. More industry-specific

blockchain consortiums include MOBI[3] in the automotive industry. These data sources are rich with information that were useful to contextualise the different case studies.

8. Press Releases and Industry News data sources

Press release and news information are considered key information sources, particularly for blockchain study. The hype around blockchain has made the different organisations interested in experimenting with the technology in different areas. These organisations tend to advertise their projects to gain a marketing boost and competitive advantage. These announcements are often rich with information about the purpose of the project, the parties involved and the SCM issue they are trying to overcome using blockchain. These reports were considered in each case study to understand the state of blockchain adoption in the specific industry. Furthermore, news information was useful in mapping the automotive battery supply network as some organisations tend to announce their partnerships with major mining companies to secure supply and ensure sustainability.

3.2.4 Data analysis and interpretation techniques

Two levels of analysis were conducted for the case studies: within case study and cross-case analysis. Various techniques were used across the different case studies depending on the stage of the blockchain solution (i.e., operational, system already in place, under development, not developed), blockchain application area (i.e., products, business processes), and data sources used, including:

1. Content Analysis (Within- and cross-case analysis)

Content analysis is *"the research technique for the objective, systematic, and quantitative description of the manifest content of communication*" (Berelson, 1952). It was used throughout the research to analyse and interpret collected data to answer the research and case study questions.

2. Supply Chain Mapping (Within-case analysis)

A supply chain map is *"a representation of the linkages and members of a supply chain along with some information about the overall nature of the entire map"* (Gardner and Cooper, 2003).

[3] https://dlt.mobi/

Different maps were developed in each case study to better understand the SC application area of, and requirements for blockchain adoption.

3. SWOT Analysis (Within-case analysis)

The strength, weakness, opportunity and threat (SWOT) analysis was mainly used in the shipping case study to provide additional insights into the development and operation of an industry wide solution. SWOT analysis was part of the within-case analysis in the fourth case study to provide additional insights into the motivations and the factors influencing the solution adoption and scalability (related to SWOT strengths and opportunities) as well as the challenges and inhibitors for its use (related to SWOT weaknesses and threats) taking into account two perspectives- organisation C internal perspective and the industry ecosystem external perspective. SWOT is a common strategic tool helps identify the internal strengths and weaknesses and the external opportunities and threats, setting the ground for strategic planning and decision-making (Helms and Nixon, 2010). Since the fourth case study included an operational and industry-wide platform, the use of SWOT analysis helped provide detailed insights into the key strengths and weaknesses of the developed shipping platform and its key capabilities as a digital solution, as well as the key opportunities and threats in having such an industry-wide solution in the industry.

4. Cross-Case Synthesis

This technique was used to analyse the findings across the four cases. To undertake cross-case synthesis, we adopt the case-based approach rather than the traditional variable-based approach (i.e., comparing cases at the level of variables) as it is important to consider the context of each case study (i.e., industry characteristics, SC environment and configuration) as well as the underlying patterns within it (i.e., specific factors affecting blockchain adoption). The case-based approach for cross-case synthesis maintains the integrity of each case and compares or synthesises the within-case patterns across the cases (Yin, 2018).

3.2.5 Case study validity

To ensure validity, we followed the recommendations of Barratt *et al.* (2011) and Beverland and Lindgreen (2010) on external and internal validity and reliability of data. We also considered the additional criteria by van Hoek (2019b) to ensure rigorous case studies. Table 10 summarises the criteria to ensure the case study validity.

Table 10. Case study validity screens

Validity Screens	Case study validity
Number of cases	Four cases representing different industries, supply chains and geographical expansions to provide broad and comprehensive insights into the different industry characteristics and operating environments.
Justification of case method	There is lack of empirical research investigating blockchain applications in the supply chain and limited applications of blockchain in practice, hindering the use of other research methodologies. Hence, this study aims to provide in-depth investigation of the factors influencing blockchain adoption by closely engage with leading organisations in this domain.
Data sources	Semi-structured interviews, a variety of secondary data sources, and access to the adopted blockchain solutions.
Reliability	Multiple informants in two case studies and one in the other two. The use of internal organisation documentations and multiple secondary data sources helped reduce the risk of bias.
Interview and coding process	Use of Nvivo and excel to analyse the interview transcripts to answer the case study questions. Answers were summarised and confirmed by the participants to ensure correct interpretation.
Number of coders	The researcher for the transcript and internal documentation and for writing the final report provided to the organisation. The supervisor reviewed and commented on the final analysis. Participants in the case study verified and validated the case study findings.
Internal Validity	Using pattern matching across the four case studies.
External Validity	Different organisations operating in different industries and regions. Different supply network configurations, product and business processes, and organisation position in the supply chain.
Unit of analysis	The blockchain pilot/solution of the participating organisation.
Theory Vs phenomenon focus	Use of grounded theory to investigate the blockchain phenomenon comprehensively.
Data analysis	Within case analysis (content analysis, supply chain mapping, and SWOT analysis), and cross-case analysis.

3.3 Practice Literature Study Design

Blockchain applications in SCM continue to develop with an increasing number of blockchain projects being announced (Vadgama and Tasca, 2021). To complement and triangulate the multiple case study findings, we independently analysed the most prominent blockchain projects reported across six major industries from 2017 to 2021 to answer the first two research questions (Section 2.4). These industries include automotive, aerospace, food and beverages, textile and apparel, pharmaceutical, as well as logistics and global shipping. The selection of these industries captures the diversity in blockchain SC applications across different industrial contexts. The study provides wider coverage, elicits the public statements that the different organisations make about blockchain and why they are pursuing it and identifies the variety of blockchain application areas in practice. Most organisations do not disclose in-depth details about their project that include the factors influencing the adoption and the challenges faced in the project. These aspects were mainly investigated in the case studies. We explain the data collection and analysis methods next.

3.3.1 Data collection methods

A wide variety of secondary data sources from the practice literature were surveyed, reviewed, and analysed to gain insights about the current state of blockchain applications across the targeted industry sectors. To begin the data collection process, we reviewed the business and enterprise blockchain news website Ledger Insights[4]. We focused our research on the supply chain news category and we reviewed the title of 587 articles from February 2018 (beginning of the website) to August 2021. We then excluded the following news articles:

- Repeated announcements about the same projects over time
- Announcements that were related primarily to financial aspects such as securing funds
- Announcements that were either government-led or blockchain technology provider announcements about new developed solutions
- Announcements that were in other sectors not included in the study such as energy and construction.

The initial screening resulted in 218 blockchain announcements in the six sectors targeted. These were then further investigated extensively using other data sources to identify more information about the blockchain application and the organisations engaged in the projects and to ensure data triangulation and validity. These data sources include popular blockchain news

[4] https://www.ledgerinsights.com/about-us/

providers such as Coin Insider[5] and Coindesk[6] were used, complemented by industry specific data sources such as the Maritime Executive, and Fashion for Good, as well as accredited news providers like Reuters and Forbes. Similarly, industry reports and publications of industry associations (e.g., Aerospace Industry Association and Innovative Medicine Initiatives), blockchain consortia (e.g., MOBI) and publications from leading IT and consulting companies (e.g., IBM and Deloitte) were reviewed to provide insights into the main applications across the different sectors. The broad range of sources used helped us to avoid selection bias by triangulating the data from multiple sources and ensuring that sufficient information was available about the project. We, further applied the following screening steps to identify our study sample:

- We considered blockchain projects that they were industry-led initiatives, which comprise projects led by a focal firm or group of supply chain partners.
- We considered only cases that included sufficient information to identify- the motivations for initiating the blockchain project, the application areas, and the industry characteristics relevant to the blockchain project selection and application area.

Based on this exhaustive search, we selected 50 blockchain use cases from the practice literature for further analysis (Table 11).

3.3.2 Data analysis methods

We used the software NVivo 12[7] from QSR International to conduct a qualitative analysis of the reported cases. Nvivo enables rigorous content analysis to discover underlying themes and their reoccurrence patterns (Stock and Boyer, 2009). It is also flexible as it enables data analysis in various formats, e.g., textual datasets, videos, and pictures. It deploys the following concepts: *nodes* refer to the codes used by the researcher to assign meaning to specific text in the dataset; a *node tree* is a group of nodes falling under a certain category; *free nodes* are nodes that are not part of any tree (Mani *et al.*, 2018).

We used NVivo for textual analysis to identify themes related to: (1) the principal motivations for blockchain adoption, (2) the targeted application area(s), and (3) relevant industry characteristics that have influenced the selection of the application area. We present the NVivo analysis results in Section 9.1.

[5] https://www.coininsider.com
[6] https://www.coindesk.com/
[7] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/about/nvivo

Table 11. Cases identified for SC blockchain applications (2017 to 2021)

	Use case No[8]	Organisation	Blockchain Application Description	Reference	Reference Type
Automotive Industry	1	Hyundai	Automating manual processes to reduce lead time and cost and to facilitate SC finance	Torres (2019)	News Website
	2	Lamborghini	Tracking vehicle history and streamlining vehicle authentication processes	Wood (2019)	News Website
	3	BMW	Tracing products across the SC (front lights)	Essbauer (2020)	Press Release
	4	Ford Motors	Tracing products across the SC (cobalt)	Wolfson (2019)	Forbes News
	5	Volkswagen	Tracing products across the SC (cobalt)	Wolfsburg (2019)	Press Release
	6	Volvo	Tracing products across the SC (cobalt)	Volvo Cars, (2019)	Press Release
	7	Ford Motors	Tracing products across their entire life-cycle (lithium-ion batteries)	Everledger (2020)	Press Release
	8	Mercedes-Benz	Tracking CO_2 Emissions across the SC (cobalt)	Ledger Insights (2020a)	News Website
	9	Mercedes-Benz	Digitalizing and managing suppliers' contracts across the supply chain	Rombach (2019)	Company Website
	10	Hyundai	Secure customers' data when using the vehicle smart application	Hyundai Motor and Kia (2019)	Company Website
	11	Volkswagen	Collecting and protecting vehicle odometer data against fraud	Akilo (2018)	News Website
	12	Hyundai	Collecting and protecting vehicle history record data against history counterfeit	Hyundai Auto Ever (2019)	Company Website
	13	Jaguar Land Rover (JLR)	Collecting road conditions and weather data from vehicle and reward customers with cryptocurrencies for data sharing	JLR (2019)	Company Website
	14	Daimler AG	Collecting data from vehicle and reward customers with cryptocurrencies to foster eco-friendly driving habits	Smith (2018)	News Website

[8] The use case number is used in [ ] to refer to each organisation use cases in subsequent chapters

	15	Porsche	Enabling the traceability of plastics and tracking of CO_2 emissions	Adsale Plastics Network (2020)	Press Release
Aerospace Industry	16	Airbus and Rolls-Royce	Tracking aircraft parts across the SC and managing their data	Bryan (2018)	Reuters News
	17	Rolls Royce	Managing aircraft assets to reduce engine overhaul time	Ledger Insights (2019)	News Website
	18	Block Aero	Digitalisation of assets and asset data management	Block Aero (2019)	Company Website
	19	Boeing	Developing technical solutions for urban aerial mobility	SkyGrid (2020)	Company Website
	20	SITA MRO Blockchain Alliance Consortium	Maintaining, repairing and overhauling (MRO) engine data management and tracing aircraft parts across the SC	SITA (2020)	Company Website
	21	Aerospace Industries Association (AIA)	Digitalizing the Department of Defense form 250 (DD250) process	Authenticiti Inc (2021)	Company Press Release
Logistics and Global Shipping	22	Maersk Group	Digitalisation of shipping processes, trade documents and shipping data	TradeLens (2020)	Company Website
	23	Alibaba and China Merchants Ports	Digitalising import and export transactions and integrating them into logistics value chain	The Maritime Executive (2020)	News Website
	24	Cargo Smart	Improving shipment documentation management	CargoSmart (2018)	Company Website
	25	Port of Rotterdam	Managing and tracking shipments and improving port efficiency	Douwstra (2019)	News website
	26	Alibaba Logistics	Standardising the bill of lading document	Ledger Insights (2020b)	News Website
	27	Mediterranean Shipping Company (MSC)	Digitalizing the issuance and exchange of an electronic bill of lading	MSC (2021)	Company Press Release
Food and	28	Chateau Marguax	Tracing products across the SC (Wine)	Zimmerman (2017)	News Website

	29	Walmart	Tracing products across the SC (Pork and Mango)	Hyperledger (2019)	Company Website
	30	Alibaba Food	Tracing products across the SC (Food)	The Maritime Executive (2018)	News Website
	31	Carrefour	Tracing products across the SC	Carrefour (2018)	Press Release
	32	JBS	Enabling traceability in the beef cattle production value chain	Kamel (2021)	Press Release
	33	E-Live Stock Global	Proving the origin and tracking the medical records of cattle	Light (2021)	Press Release
	34	Birra Peroni	Providing non-fungible tokens for each batch of beer for better SC visibility and efficiency	EY Global (2021)	Press Release
	35	HEMA	Enabling product traceability across the SC (Coffee).	World Coffee Portal (2021)	News Website
Pharmaceutical Industry	36	Modum	Monitoring and track products'' ambient condition during transportation	Rohr (2019)	Company Website
	37	Merck (MSD)	Tracing prescribed drugs downstream their SC and protect patients	Merck (2020)	Company Website
	38	Pharmaledger consortium	Ensure drugs' authenticity, enabling secure development of an eLeaflet, and tracking drugs tracking	IMI (2020)	Company Website
	39	Mediledger consortium	Tracing drugs across the SC	Mediledger, (2019)	Company Website
	40	Moderna	Enabling the traceability of vaccine batches across the SC and maintaining digital health passes for individuals	IBM Newsroom (2021)	Press Release
	41	Tech Mahindra	Monitoring and tracking vaccine distribution and usage in the SC	Tech Mahindra (2021)	Press Release
Textile and Clothing	42	LVMH	Tracing products across the SC	ConsenSys (2019)	Press Release
	43	Hugo Boss	Tracing products across the SC	Hackling (2019)	News Website
	44	Arianee Consortium	Creating digital certification of valuable assets	Arianee (2020)	Company Website
	45	Chargeurs Luxury Materials	Ensuring product quality, sustainability and traceability across the supply chain (wool)	Chargeurs (2018)	Company Website

	46	Martine Jarlgaard	Tracing products across the SC	FIA (2020)	Company Website
	47	C&A Foundation	Tracing products across the SC (organic cotton)	C&A Foundation (2019)	Company Website
	48	Lenzing Group	Tracing products across the SC (manmade cellulose fibers)	Lenzing (2020)	Company Website
	49	U.S Cotton Trust	Tracking and verifying the movement of cotton fiber across the SC	US Cotton Trust Protocol (2021)	Press Release
	50	UK Fashion and Textile Association (UKFT)	Enabling product traceability and improving transparency in the SC	UKFT (2021)	Press Release

3.4 Executive Workshop Design

The executive workshop is the third study conducted for this research. It was organised at the end of the leather pilot project. However, additional organisations and participants not included in the project were invited to the workshop to discuss the overall challenges and opportunities for blockchain-enabled SC traceability. The workshop had the following objectives:

- Investigate the drivers and challenges for blockchain-enabled leather SC traceability.
- Identify leather traceability costs and benefits and potential operational implications.
- Recommend an appropriate level of traceability for the automotive leather.

The workshop focus was only on blockchain deployment for SC traceability as it was the focus of the pilot project. Furthermore, the complexity of the leather supply network configuration and the challenges associated with hide identification and tracking raised several questions about the motivations behind traceability, the required and feasible level of traceability that can be achieved using blockchain, and the type and amount of traceability data shared on the blockchain traceability solutions. All these made it an important issue to investigate in greater detail in a focused workshop. However, since it included more organisations and more participants than the one involved in the project, we considered it as a separate complementary study in the research.

The workshop included 22 participants from five organisations with various levels and areas of expertise, including:

- Automotive OEM (6 participants): Change Management (Manager), Digital Transformation (Senior Project Manager), Digital Transformation (Project Manager), Project management (Project Manager), Sustainability and Environmental Compliance (Manager), Purchasing (Global Commodity Lead).
- Leather Supplier (5 participants): Head of Sales (Manager), Innovation and Sustainability (Director), Hide Procurement (Director), Projects (Project Accounts), Operations (Operations Lead).
- Blockchain Provider (9 participants): Founder (CEO), Business Development (Manager), Sales (Vice President of Sales), Project Management (Project Manager), Project Consultant, Client Partners (3), Business Operations (Manager).

- Two external organisations (NGO)(2 participants): First NGO (Senior Manager), Second NGO (Managing Director).
- University of Nottingham (1 participant): Workshop Moderator (Professor)

The workshop participants were divided into four groups based on their expertise and each group was given a set of four questions (Table 12), to discuss and answer in a panel format where one participant from each group presented the group answers at the end of the workshop. The overall workshop length was three hours with a half an hour at the beginning to introduce the workshop and the themes that would be addressed. The workshop was video recorded, and participants' answers were recorded and transcribed. The principal researcher got access to the video recording and transcription for the analysis using content analysis method. The four group were organised as follows:

- Group 1 (5 participants): Innovation and Sustainability Director (Leather Supplier), Environmental Compliance Manager (OEM), Digital Transformation Project Manager (OEM), CEO (Blockchain Provider), Vice President of Sales (Blockchain Provider).
- Group 2 (5 participants): Senior Manager (NGO), Global Commodity Lead (OEM), Project Manager and two client partners (Blockchain Provider).
- Group 3 (6 participants): Managing Director (NGO), Digital Transformation Senior Project Manager (OEM), Head of Sales and Project Accounts (Leather Supplier), and Business Development Manager and Business Operations Manager (Blockchain Provider).
- Group 4 (6 participants): Project Manager (OEM), Change Manager (OEM), Hide Procurement Director (Leather Supplier), Operations Lead (Leather Supplier), and Project Consultant and Client Lead (Blockchain Provider).

Table 12. Executive workshop groups questions

Group 1 **(Drivers/Imperatives/Opportunities)**	**Group 2** **(Challenges/Inhibitors/Barriers)**
1. What are the most significant drivers for higher levels of traceability across the LSC (upstream and downstream)? **2.** Which stakeholders (companies, countries, regulators, customers, etc.) are interested in achieving higher levels of traceability and why? **3.** What existing certification, assurance, compliance, or regulatory schemes may enable, support or provide opportunities to achieve higher levels of traceability across the LSC (upstream and downstream)? **4.** What level of traceability should we aim for across the LSC (upstream and downstream), and can this level be enabled with a blockchain solution?	1. What are the most significant inhibitors, challenges and barriers to achieving higher levels of traceability in the LSC (upstream and downstream)? 2. Which parties/stakeholders may be unwilling, resist, of fail to support higher levels of traceability and why? 3. What existing operational approaches, methods, or policies may inhibit, constrain or limit the achievement of higher levels of traceability in the LSC (upstream and downstream)? 4. What level of traceability should we aim for across the LSC (upstream and downstream), and can this level be enabled with a blockchain solution?
Group 3 **(Costs/Benefits /Trade-offs)**	**Group 4** **(Business Processes/ IT/ Blockchain)**
1. What additional costs might be incurred by higher levels of traceability across the LSC (upstream and downstream)? **2.** What benefits can be realised by higher levels of traceability across the LSC (upstream and downstream), and can they be quantified? **3.** Which parties incur which costs and which parties gain which benefits from higher levels of traceability across the LSC (upstream and downstream)? **4.** What level of traceability should we aim for across the LSC (upstream and downstream), and can this level be enabled with a blockchain solution?	1. What business process challenges will arise in realising higher levels of traceability across the LSC (upstream and downstream)? 2. What technical and integration challenges (IT, systems, and blockchain) will arise in realising higher levels of traceability across the LSC (upstream and downstream)? 3. Who will own and/or govern an LSC traceability system (blockchain-enabled or other), and what implications does this have for participation, power, control and influence? 4. What level of traceability should we aim for across the LSC (upstream and downstream), and can this level be enabled with a blockchain solution?

3.5 Cross Study Analysis

The findings from all three studies were analysed to provide comprehensive answers to the research questions and to enable the development of important frameworks. Two main methods were used to conduct the cross-studies analysis:

1. Pattern Matching Logic

Pattern matching logic is a technique in which a comparison between the empirical findings from the case study are compared to predicted ones (Trochim, 1989; Yin, 2018). We use pattern matching to compare the three studies' findings to validate and complement the findings from each study and to identify common patterns and themes. This helped in providing comprehensive answers to the research questions.

2. Framework Analysis

Framework analysis is the main method used in this research for cross-studies analysis and for the development of multiple frameworks that address the research questions and contribute to the emerging body of knowledge. Framework analysis is an established and rigorous data analysis method for qualitative research that works best with research that has specific questions and a limited timeframe. It provides a systematic approach to data analysis that is comprehensive and iterative. It is a transparent process in which the data, thematic framework, and indexing processes are accessible to others who can easily judge the data analysis process (Srivastava and Thomson, 2009). Ritchie and Spencer (2002) identified five stages in framework analysis:

- Familiarisation: The process during which the researcher becomes familiarised with the collected data.
- Identifying a thematic framework: The process of identifying emerging themes in the dataset. They can arise from prior themes or issues, but the collected data dictates them.
- Indexing: The process of identifying the portion of the data that correspond to a particular theme. Qualitative data analysis tools like Nvivo can be used for indexing.
- Charting: The indexed data is summarised into charts according to the thematic framework.
- Mapping and Interpretation: This step involves the interpretation of developed charts, thematic framework, and dataset summaries. Depending on the objective of the

qualitative analysis, the researcher can either be *"defining concepts, mapping range and nature of phenomena, creating typologies, finding associations, providing explanations, and developing strategies"* (Ritchie and Spencer, 2002).

Figure 4 shows the data analysis methods used in the different stages of the research. Content analysis was used throughout the research to analyse available literature, collected data, and other secondary data sources to inform the research at the different stages. SC mapping (all case studies) and SWOT analysis (shipping case study) were used as part of the within case analysis to help understand the organisations' SC configuration characteristics and help further analyse the operational industry-wide shipping solution, respectively. The cross-case synthesis was used to compare the findings of the individual case studies to provide comprehensive insights into the research questions. Finally, for cross-study analysis, we used pattern match logic to compare the findings across the different studies and framework analysis to identify and develop frameworks from the collected data in the three different studies.

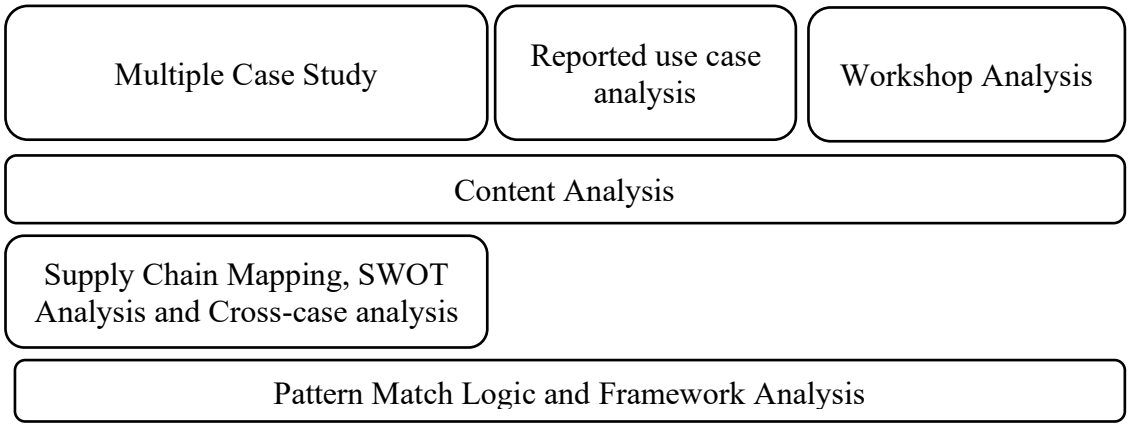


Figure 4. Overview of data analysis methods used in the research

Chapter 4: Blockchain Adoption and Application in the Automotive Battery Supply Chain

4.1 Case Study Industry Characteristics

The Lithium-ion battery (LIB) is the main battery used in Automotive electric vehicles due to its high-power output. It consists of four main components -anodes, cathodes, electrolytes, and separators - formed in different shapes to produce cylindrical and prismatic battery cells (Chung *et al.*, 2015). Six main materials go into LIBs: Lithium, Cobalt, Nickel, Copper, Aluminium, Graphite, and Manganese. Most battery materials, especially Cobalt and Lithium, are scarce and are only mined in a few countries (Mayyas *et al.*, 2019).

LIB manufacturing comprises several steps (Figure 5), that take place in a global complex supply network. The Asian region dominates battery cell production, with more than 90% of global battery cell manufacturing in China, Korea and Japan (Batteries Europe, 2020). LIB packs are assembled in locations proximate to OEMs for end-product manufacturing (Chung *et al.*, 2015).

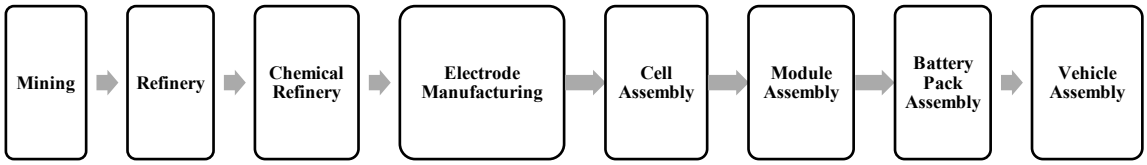


Figure 5. Automotive battery value chain

EVs must be competitive on several aspects, including cost, range, charge time and an operating lifetime to replace internal combustion vehicles (Sharma and Manthiram, 2020). Each LIB component is important and has differentiated technical and quality specifications that can impact the overall battery performance (Chung *et al.*, 2015). The scarcity of battery materials to meet the increasing demand has significantly impacted material prices and increased the pressure to secure long-term materials supply (Mayyas *et al.*, 2019).

LIB materials mining and battery manufacturing raise several sustainability concerns. Both processes can have lasting social impacts on the surrounding communities, including the use of child labour for Cobalt mining in Democratic Republic of Congo (DRC) and dangerous working conditions (Sharma and Manthiram, 2020). Battery recyclability is another concern

due to the lack of environmental regulations for LIB recycling, which could help lower its environmental impact (Mayyas *et al.*, 2019).

Cobalt is a main material used in the cathode active materials that provides structural stability in LIB (Mayyas *et al.*, 2019). Cobalt is a by-product of Copper and Nickel. Current research aims at reducing the amount of cobalt used in LIBs due to its associated risks, including (1) the single source of supply, i.e., DRC and its political instability, and (2) cobalt mining companies being controlled by China, giving them high power in the industry (Mayyas *et al.*, 2019).

Several automotive OEMs started experimenting with blockchain to ensure the ethical sourcing of minerals and enable traceability in complex networks. Cobalt has been the focus of most applications e.g., Ford Motors (Wolfson, 2019) and Volvo Cars (2019). Organisation A also wanted to investigate the potential application of blockchain in its cobalt supply chain.

4.2 Case Study Main Characteristics

Organisation A manufactures two types of EVs, full and plug-in hybrid EVs. Batteries are the most expensive part of the vehicle. The company uses two types of battery cells - pouch and prismatic cells - which makes the purchasing process more efficient and facilitates bulk supply and economy of scale.

The organisation's battery manufacturing processes are tightly controlled and have rigorous quality and testing requirements. The process for introducing a new cell program is costly and lengthy, taking at best 24 months for production sample, design, and production tooling to develop a good new cell and additional six months to ensure its durability and line validation.

Organisation A has two suppliers for its assembled battery packs, who are responsible for managing the complex upstream battery supply network. The battery performance is very sensitive to changes in raw materials, justifying the limited number of suppliers used. However, it exposes the company to potentially high risks, including shortages of supply and delays, which might affect production continuity. Organisation A plans to assemble its battery in-house and source battery cells instead. However, it lacks detailed knowledge about its upstream supply chain.

Organisation A's SC relationships are dyadic with limited and powerful tier 1 suppliers, has a cost and delivery focus, and a limited range of products with a high level of complexity and innovativeness. These relationships can be described as follows:

- Business-as-usual supply: There is no long-term contracts or partnerships with the tier 1 suppliers.
- Lack of transparency: Tier 1 suppliers are unwilling to share information about their upstream supply chain. Limited information is shared in the supply chain, including annual volume and battery specifications.
- Different SC cultures: The OEM and upstream battery suppliers operate in different cultures, affecting their communication.
- High dependency on a limited number of suppliers: Organisation A relies on only two major Tier 1 suppliers to supply its battery pack, exposing the organisation to supply shortages and disruption risks.
- Lack of trust: The OEM cannot guarantee that batteries are made from consistent material sources despite them being responsible for warranting the battery to the customer.

Different standards and regulations affect organisation A's battery supply chain, including the rule of origin and battery recyclability. Since the batteries are the most expensive part of the vehicle, it determines the origin of the vehicle, i.e., if the batteries are outsourced from China, then EVs assembled in Europe are considered of Chinese origin and are subject to tax and duty fees. The organisation's strategy of assembling the battery pack will help reduce these costs. Furthermore, battery recycling legislations vary across countries, e.g., in Europe and China, OEMs are required to recycle batteries. Therefore, it becomes important to understand the battery's origin, bill of materials, and sourcing processes.

EV demand is growing, and electrification is becoming a mainstream in the organisation vehicle's portfolio. However, the sustainability of battery materials is a growing concern. The case study participants indicated that investors have frequently asked them about the sustainability of their cobalt supply chain and whether it is free from child labour.

At the time of the case study, the company had started piloting E2open[9], a centralised SC planning and management solution with its Tier 1 suppliers for another commodity but was considering its use in the battery supply chain. The company has several internal systems used mainly to collect information from suppliers.

[9] https://www.e2open.com/

4.3 Summary of the Key Challenges in Organisation A's Battery Supply Chain

1. Lack of transparency and limited information sharing with suppliers

One of the key challenges facing organisation A is the limited information shared between the organisation and its tier 1 suppliers. This is due to many factors, including (1) the powerful position of the battery manufacturers in the battery value chain as they control the upstream supply network; (2) the nature of the contractual relationship between the organisation and its suppliers; (3) the relatively small vehicle volumes of organisation A compared to other major automotive OEMs working with the same suppliers; and (4) the increasing involvement of automotive OEMs in the battery manufacturing processes, which is forcing the tier 1 suppliers to protect their intellectual property (IP) and market share. All these factors increased the reluctance between organisation A and its Tier 1 suppliers to share information.

2. Lack of SC visibility and traceability

The dyadic relationship between organisation A and its Tier 1 battery suppliers has resulted in a lack of visibility and of knowledge of organisation A about its supply network, which can affect the business' performance and sustainability at several levels.

The scarcity of battery raw materials and the social and environmental concerns associated with their extracting and processing forced OEMs to secure long-term supplies of lithium, cobalt and nickel and to work with organisations beyond their tier 1 to ensure sustainable operational practices, e.g., Volkswagen (Wolfsburg, 2019b) and Tesla (Daly, 2020). Organisation A's current strategy for supply is contractual and business-as-usual and its current approach to sustainability is fairly traditional, achieved mainly through signing terms and conditions with suppliers. Organisation A has no further involvement in the upstream supply chain since their Tier 1 suppliers essentially control it. This has led to high risks in securing battery materials supply, and with the growing sustainability concerns, it has made its battery supply chain more vulnerable to unethical sourcing practices and negative social and environmental impacts.

3. Ensuring quality of raw materials and manufacturing processes

Quality is a major challenge in the battery supply chain. The battery is highly sensitive to changes in the properties of its raw materials, their sourcing origin and manufacturing processes. This makes it very costly to change the supply chain as, with every new supplier, battery cells must be tested and validated to ensure the consistent battery performance.

Therefore, OEMs need to ensure consistent quality of the materials and manufacturing processes. Currently, organisation A sets the specification required for its Tier 1 battery suppliers and has a specialised team responsible for checking the manufacturing operations in Tier 1 plants and reporting any capacity related concerns. However, the organisation has limited knowledge or guarantees about the battery materials sourcing beyond Tier 1.

4.4 Mapping Organisation A Battery Supply Chain

Figure 6 shows the configuration of organisation A's battery supply chain and their tier 1 suppliers. Since the organisation lacks knowledge about its upstream supply chain beyond these suppliers, we used different data sources, including Bloomberg database, press releases, and company website information to map the upstream SC network for the main six components of the battery electrode: Lithium (Li), Cobalt (Co), Nickel (Ni), Manganese (Mn), Aluminium (Al), and Graphite (C). We categorise the different upstream stages of battery manufacturing as mining, refinery, battery chemicals (including precursors and cathode or anode materials), and battery cells. We present the cobalt map in Figure 7, and the others maps in Appendix A.

The links between the different SC entities in the maps represent existing financial flows between the relative companies based on Bloomberg database. It must be noted that this information is limited as there can be other suppliers not identified in Bloomberg and it does not guarantee that identified suppliers are part of organisation A's supply chain. Nonetheless, the maps provided useful insights into each SC size, complexity, geographical distribution, and potential key players.

The future configuration of Organisation A will include in-house battery pack assembly, which will help the company improve its internal capabilities, reduce costs, localise part of its supply chain, and increase battery pack design flexibility.

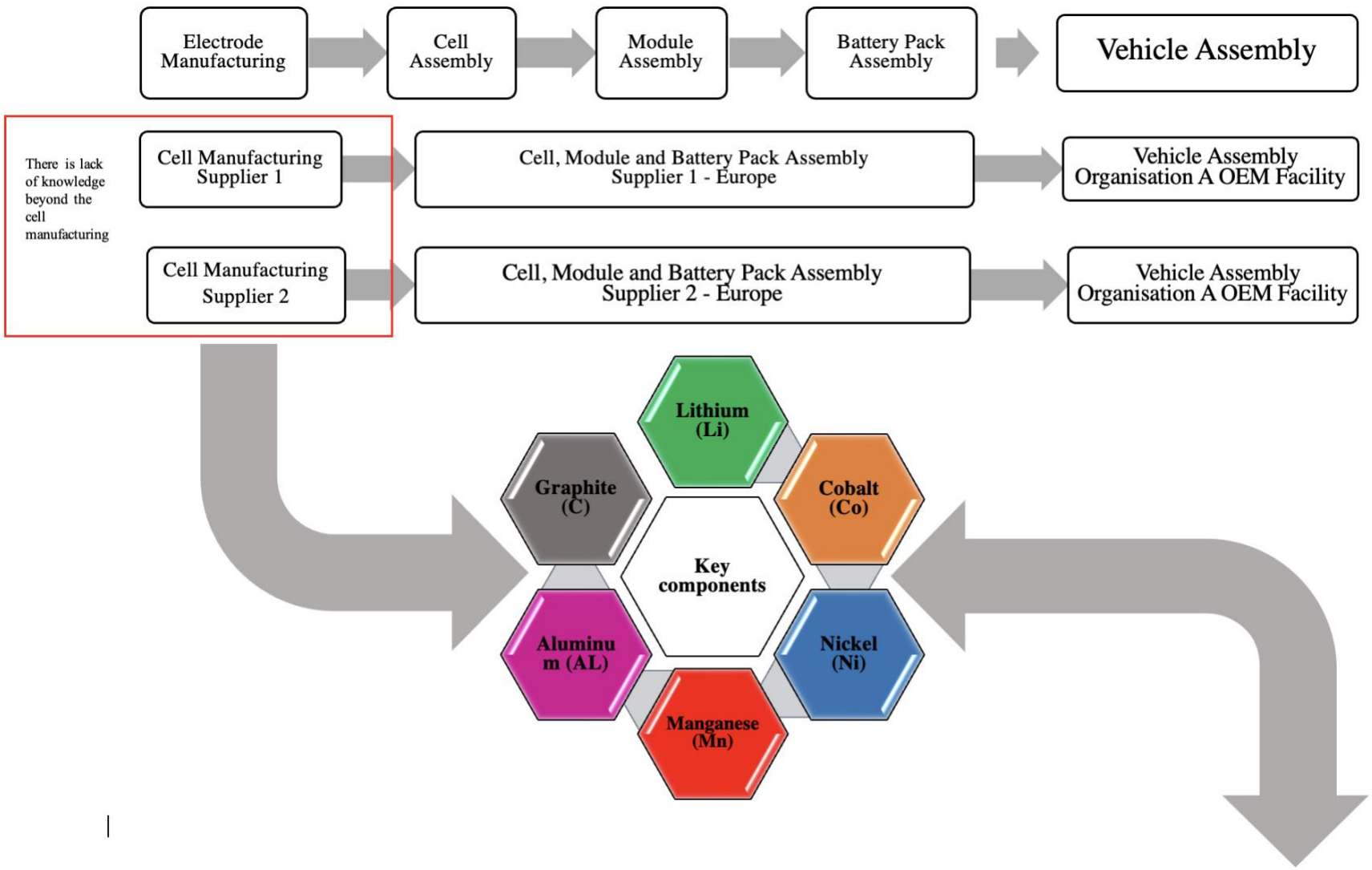


Figure 6. Overview of organisation A battery supply chain

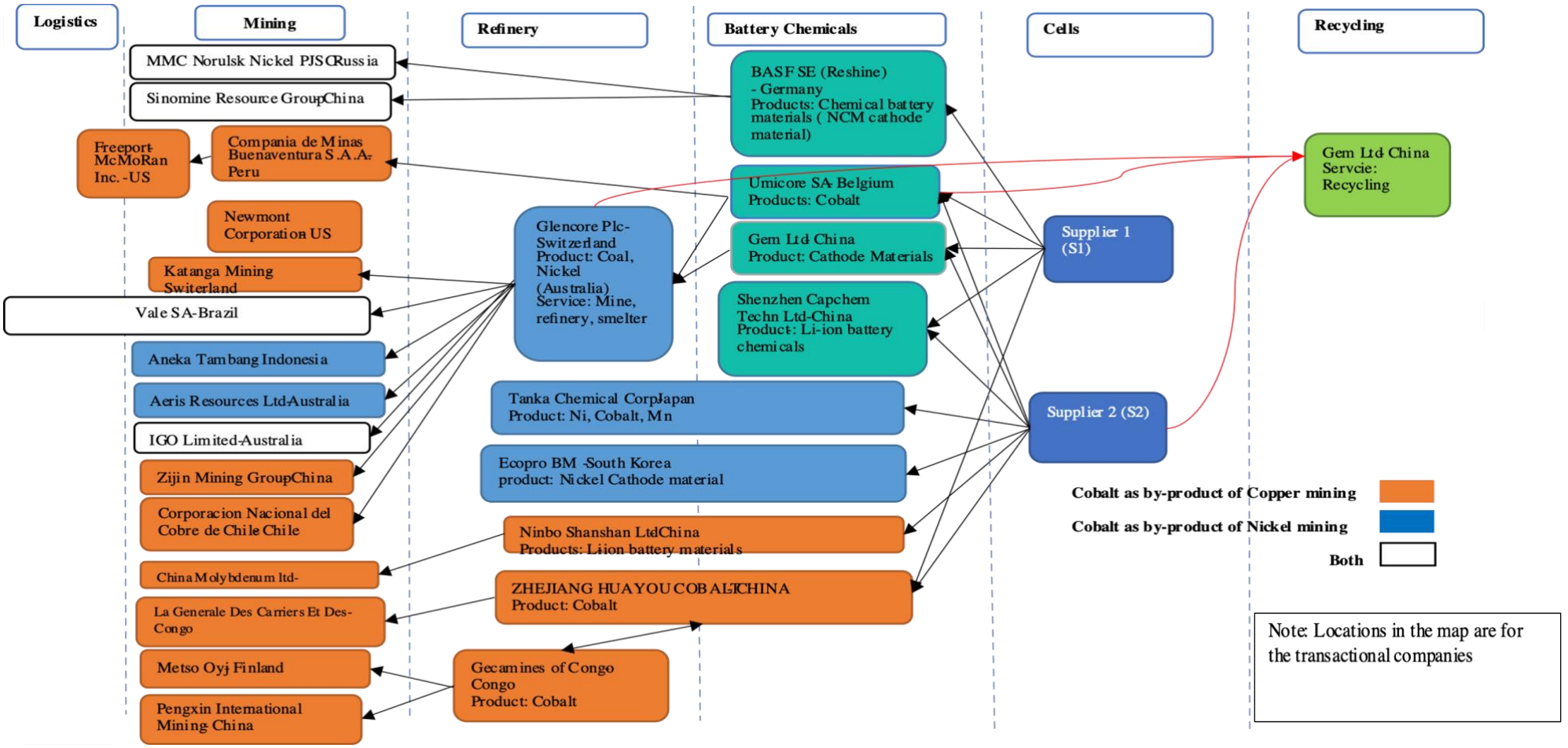


Figure 7. Organisation A Cobalt and Nickel supply chain map

4.5 Blockchain as a Potential Solution in Organisation A Battery Supply Chain

In this case study, Organisation A aimed at investigating potential application of blockchain in its cobalt supply chain. We include interviewees quotes in *italics* where relevant and their position.

Several factors have influenced the selection of the cobalt supply chain, including (1) the complexity of cobalt mining as it is a by-product of copper and nickel "*it's the most difficult (SPM)*[10]*"*, (2) the complexity of cobalt traceability "*Cobalt is the worst to track (BRMB)*", and (3) the organisation's key stakeholders concern about cobalt sustainability "*that's the one we get questioned about from our stakeholders (PSM)"*. Questions like *"is there child labour, is it from Congo, all these kinds of questions! (BRMB)"*.

The developed SC maps identified several potential SC partners based on the case study participants' knowledge about their involvement in the OEM battery or because of their strong position in the battery value chain. Participants' rationale for using blockchain includes it being a proof and providing complete visibility "*it gives us complete visibility. So its proof (PSM)*".

The case study participants identified other opportunities for blockchain application in the battery supply chain, considering its capability in providing a secure platform for information sharing and an immutable, traceable and secured record of transactions. These opportunities include:

- **Optimising SC planning:** One participant suggested using blockchain to share volume requirements data across the SC to secure supply and commit to agreed schedules to prevent material shortages and delays. However, issues related to data security and difficulty of identifying the end customers in the allocated upstream SC stages have been acknowledged.
- **Tracking battery recycling at end-of-life:** The participants indicated that the OEM could potentially be paying twice for the same battery materials when the battery recycling party is the cathode supplier. They addressed the importance of having a traceability system for batteries at end-of-life to help identify the closed-loop and realise potential cost reduction.
- **Ensuring SC sustainability:** By applying blockchain to enable product traceability and ensure the ethical sourcing of raw materials like cobalt.

[10] Please refer to Table 9 for the exact titles of the interviewees

- **Ensuring battery quality:** Having all the suppliers in the blockchain network could ensure consistency of materials sources, preventing use of suppliers that have not undergone the necessary testing and validation process without the knowledge of OEM.

The case study participants indicated that they are pressured from corporate responsibility and sustainability perspectives to understand what happens in their supply chain, ensure the ethical sourcing of materials, and reduce CO_2 emissions and SC risks. They anticipated that existing certifications would not be sufficient to certify their cobalt. For the organisation to enforce SC localisation, they need to know where the raw materials are coming from and be able to track them. Therefore, the organisation has expressed their interest in investigating the potential of blockchain in their battery supply chain.

"*We want to be able to have a tool to be able to really verify there is definitely nothing bad happening in our supply chain. But also, then to try to optimise that supply chain (PSM)"*, and *"the main reason we are interested in, the main driver is sustainability (PSM)*".

Despite the organisation's interest in blockchain to tackle some of their existing SC challenges, there were different levels of understanding of blockchain during the semi-structured interviews. Several questions regarding blockchain were raised, including:

"*Does the blockchain refer to the method of obtaining existing data which is already encapsulated in that way? (PSM)"* "*Is it like a full purchase to pay mechanism but not just between tier 1 and tier 2 but on a network that shares it with retailers, raw material suppliers? (PSM)"* "*What's the mining and consensus mechanism mean?(PSM)". "Do you think for the blockchain network, it will be one network like that for the whole batteries or it will be like few small networks (BRMB)"*

These questions reflected the limited understanding of blockchain. A pre-prepared set of slides, including an introduction to blockchain and examples, was presented to answer the participants' questions.

After establishing a basic understanding of blockchain, several views were raised regarding the potential type of blockchain shared data. One participant indicated sharing volume requirements data across the SC to eliminate waste and improve scheduling.

"*Scheduling is the one that is obvious, isn't it? In terms of retailers, OEM plants, to battery plants, to cells suppliers, to raw materials suppliers. You can just cut down all the waste in that supply chain if you are just sharing volume requirements (PM)*".

However, another participant raised the relatively smaller size of the business compared to other OEMs to enforce such information sharing and the privacy issue of sharing capacity information.

"You can't get capacity on the blockchain! (PSM)"

Furthermore, the participants indicated that the type of blockchain network they can potentially go for would depend on the data they would like to share.

"*It depends on the type of information. It's a benefit to the whole industry to have that type of a consortium on topics like sustainability because that's a win-win. On, I guess, our own internal supply chain, and for the information being shared in terms of costs, products, things that are more confidential by the nature, it becomes private* (PM)."

They also suggested that the Global Battery Alliance (GBA) can potentially go for a consortium model where different carmakers, battery manufacturers and material providers are all in agreement and are part of the network, providing that there would still be rules related to data sharing and accessibility by the different participants.

The participants acknowledged the necessary efforts to enable traceability in the complex battery SC and the need for engaging all the SC parties.

"It needs all of the linkages and work it through. It needs all these been setup, bought in by every party, and it needs to have all these links established (PSM)."

They also indicated the importance and challenge of knowing the bill of materials at each SC tier to enable traceability and establish the linkage between the different stages. They appreciated blockchain potential in enabling traceability but highlighted the difficulty in its implementation due to the complexity of the battery supply chain.

"*We can't do it because we need a bill of material from our suppliers. You need a commitment that they will upload that bill of material and every one of their suppliers on that same system and that all the way down the chain (PSM)."*

Several organisational factors influencing the organisation readiness for adopting the technology were highlighted, including the smaller position of the organisation in the automotive industry compared to other giant OEMs.

"*They are bigger than us, and they have more volume (BRMB)*".

Furthermore, organisation A's internal structure presents another challenge hindering its digital transformation. The organisation is functionally structured, has a fragmented landscape of siloed systems, and lacks SCM capability.

"*The biggest challenge that organisation A has, is it's very functionally organised and… when it comes to supply chain, we don't really have a single entity capable for defining or designing capabilities across the end-to-end and what that results in, is a number of point solutions within functions and don't necessarily apply outside the boundaries of those functions (SPM)".*

There is also a lack of SCM perspective within the organisation management due to absence of training and education and of management support.

"*There are only a small number of people in the business that really get the hedge around supply chain management (ITD)*", "*The reason for that is an absence of a long-term absence of training and education (ITD)*",

"It would be helpful if we had more leaders at the top, we understood the power and the importance of supply chain and digital and would be driving it (SPM)."

The participants also considered the investment requirements for blockchain-enabled SC traceability and the willingness of other SC partners to invest in it.

"*Depends on the investment. I am thinking about this because we want our suppliers all the way down to invest in it (PSM)" "They probably wouldn't do it if it's about costs (PSM)".*

Organisation A's SC relationship characteristics also present an outstanding challenge for blockchain adoption in their supply chain, including the existing cultural differences and the short-term contractual relationship. The participants acknowledged the importance of having joint ventures to facilitate collaboration.

"W*e would probably be able to have these discussions of more open collaboration... It becomes an easier topic because you are not worried about the next piece of business and the IP and all these types of stuffs. We are aware to get to a lot of these things, we absolutely have to do something more strategic (PM)*".

There is also a major conflict of interest hindering the upstream suppliers from being transparent and open as explained below.

"*Conflict of interest between network partners. I would say a bit about wanting to hide changes in the supply chain. It's very relevant in batteries. Because it's such a difficult*

industry because of the huge capacity expansion, the fact that the demand is outstripping capacity on a very consistent basis and the investments are so huge but also the demand is very substile at the moment, it's not stable demand growth. All that means that the suppliers and the supply chains continue to running short of capacity and having to chop and change and they can't do that by our terms, same as anybody else. So that doesn't motivate them to be open and transparent (PSM)."

Furthermore, participants highlighted that their suppliers are reluctant to share information because they are protecting their IP *"What we get back from the suppliers is very limited because it's absolutely their IP, they do not want us to go directly to them (PSM)"*. However, organisation A is dependent on these suppliers for battery supply *"We are in this unfortunate situation where we are sourced with two suppliers who are not necessarily transparent and that dictated by our technology choice (PM)"*. This indicates the more powerful and controlling position of the tier 1 suppliers in the organisation's battery supply chain.

The participants stressed the need for legislation to derive blockchain adoption in the battery supply chain, such as having the GBA mandating it and supported by OEMs that commit to only working with suppliers that are GBA complaint.

"The only realistic way to doing it is through legislation. Which I presume is through the GBA. You need to obey a certified or controlling authority in the field to force that (PSM)."

They also highlighted the immaturity of blockchain adoption in the automotive industry beyond the initial pilot stages and the immature understanding of its potential value.

"I just don't think we are mature enough if you look at all the pilots that have been done it's often around a minimum viable ecosystem to actually use the blockchain technology it is not the actual coding at all it is actually the adoption (SPM)."

4.6 Case Study Analysis

4.6.1 Analysis of blockchain capabilities in addressing organisation A's supply chain challenges

The case study participants acknowledged blockchain's capability in addressing many of their existing SC challenges through improved transparency and traceability. They considered blockchain application to enable cobalt traceability and ensure its sustainability to be the main motivations behind their investigation.

Figure 8 summarises how blockchain can be a potential solution for organisation A. Blockchain can promote information sharing among the reluctant SC partners, helping organisation A ensure the sustainability, traceability, and quality of their batteries. Blockchain can help visualise, track, and manage the complex cobalt supply network to enforce sustainable practices. With blockchain, only registered and certified suppliers can be part of organisation A supply chain, which will help ensure ethical sourcing and compliance to sustainability practices and consistent supply of raw materials to guarantee the quality of battery materials and reduce risks.

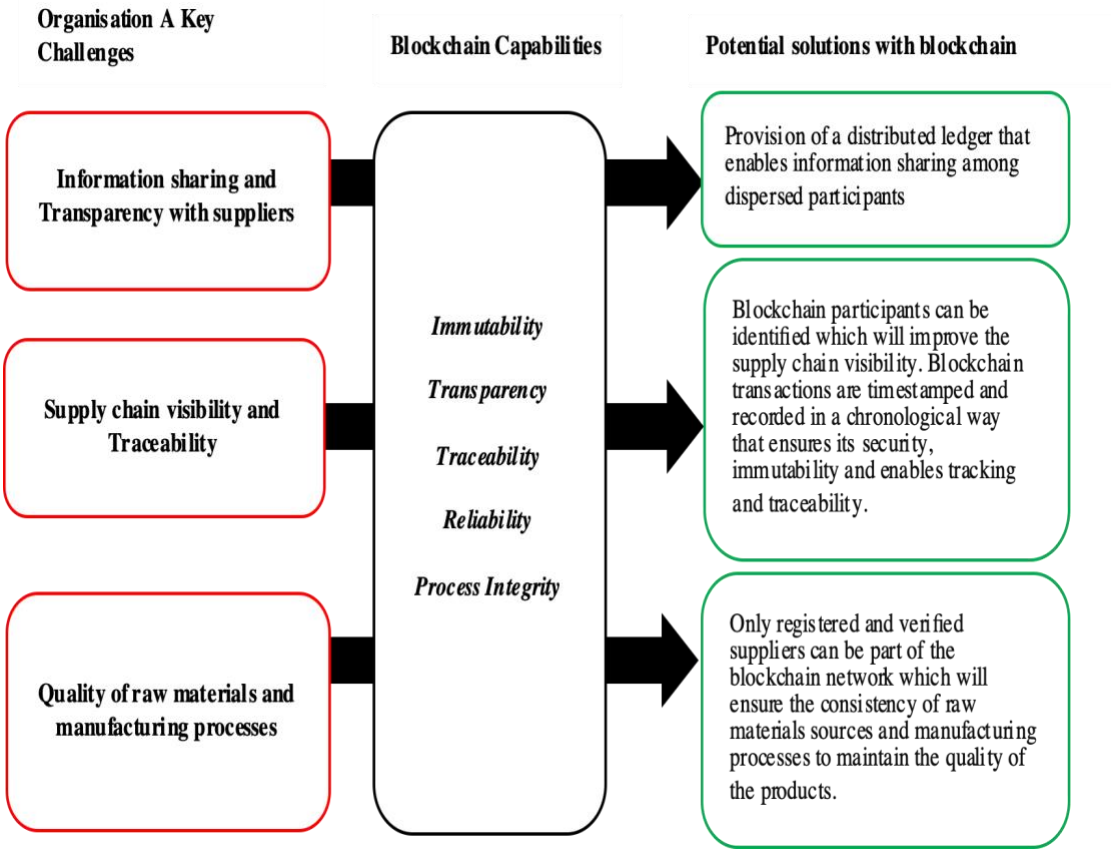


Figure 8. Blockchain capabilities in addressing organisation A challenges

4.6.2 Analysis of blockchain potential application area

Table 13 presents a high-level analysis for the six main components of the battery electrode based on the perception and interest of the case study participants. Lithium, Cobalt and Nickel are the scarcest and most expensive minerals used in the battery cells. Cobalt shares some parts of the Nickel and Copper supply chains. Organisation A was mainly concerned about its cathode materials, particularly its Lithium and Cobalt supply chains.

Table 13. Automotive battery materials comparison based on the case study participants

Factor	Li	Co	Ni	Mn	Al	C
Scarcity of the material	High	High	High	Low	Low	Low
Material costs	High	High	High	Low	Low	Low
Organisation A major interest	High	High	Low	Low	Low	Low

The lithium supply chain can be considered a less challenging supply chain for blockchain application since there are fewer SC steps and parties involved. It may be easier, relatively, to reach an agreement among the SC partners on developing a blockchain-enabled traceability solution. However, the many sustainability and social responsibility concerns and the increased SC complexity of cobalt make it a very challenging supply chain to track and visualise. This has also raised several concerns from organisation A's main stakeholders regarding their cobalt supply chain, making it the top potential application area for blockchain to enforce ethical and sustainable behaviour.

4.6.3 Analysis of potential blockchain data

To analyse the potential type of data that can be stored and shared in the blockchain network, we initially identified the potential participants in the network and the different types of data that can be shared. Figure 9 shows an example of the potential participants in organisation A's cobalt blockchain network, including all value-adding participants involved in the battery manufacturing. Other participants such as logistic providers, international organisation for standardisation (ISO), government authorities, auditing companies like RCS Global, and end customers can also be part of the network to access certain data, ensure data validity and/or enforce compliance. This exemplary network was developed based on discussions with the case study participants and with referral to the Hyperledger fabric modular configuration[11]. It shows a potential use of different data channels in the blockchain network between the SC partners and the other stakeholders interested in specific SC information. We discussed with the case study participants three different types of information that can be shared in the potential blockchain network:

- **Sensitive data** such as pricing, contract information, and order quantities. There are high privacy concerns related to sharing this type of information.

[11] https://www.hyperledger.org/

- **Supply chain data** such as order information, scheduling and transportation can be shared among the members of the cobalt value chain and logistics providers.
- **Sustainability and social responsibility data,** including raw material origin and suppliers' certification. Such information can be shared with standards organisations, auditing companies or even with organisation A end customers and investors.

Important considerations regarding the type of information to be shared were raised, including:

- Sensitive and private data that is shared between only two network participants does not justify the use of blockchain where the core principle is to provide a platform for decentralised information sharing among multiple nodes. For this purpose, respective organisations can share sensitive information through direct communication technologies.
- SC data such as plans, schedules, and transportation details are usually important for organisations with large volumes and capacity. However, blockchain might not necessarily be the best technology to support this type of information as this data is, by nature, changeable and there may not be a need to create a permanent record for it.
- Sharing sustainability data such as suppliers' certifications is considered a win-win scenario where every participant in the supply chain, regardless of their position and size, can perceive value from being part of a sustainable supply chain.

In the case of organisation A, the participants agreed that sustainability and social responsibility data is the best type of data to be shared in the potential blockchain network.

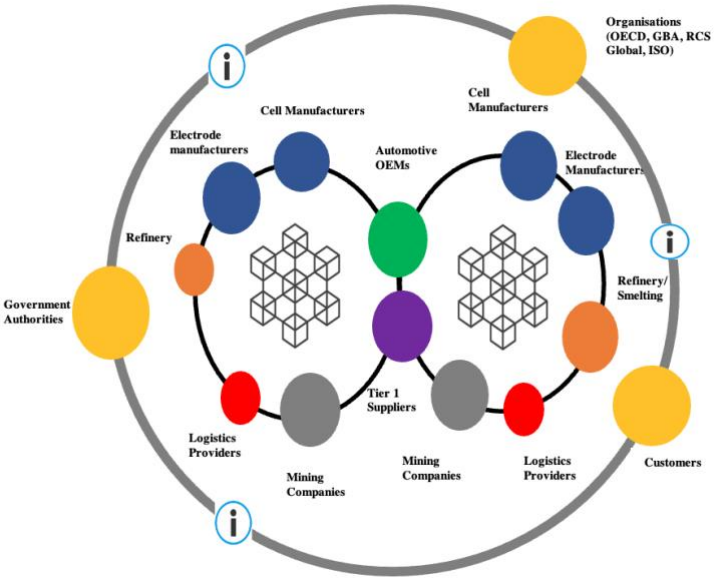


Figure 9. Organisation A potential cobalt blockchain network

4.7 Summary of Organisation A Decisions and Actions Post Case Study

After receiving the case study report, organisation A established a battery committee to discuss the next steps, including Directors, Senior Managers and Manager levels from digital transformation, purchasing, environmental compliance and sustainability, and operations departments. The principal researcher was invited to the first two committee meetings following the case study. A summary of the key actions include:

- Organisation A was keen on knowing its supply chain and identifying the SC partners contributing directly to its batteries. It has consulted several SC mapping companies who claimed the provision of SC maps using artificial intelligence and web crawling techniques. However, none of these companies guarantees the accuracy of the maps. The committee agreed that there is a need to include the Tier 1 suppliers in the mapping endeavour to ensure accuracy.

- Organisation A developed a questionnaire for its suppliers including transparency and sustainability-related questions such as: Where the raw materials are coming from? How and where do the manufacturing processes take place? Where do they source lithium? The answers received were mainly at the country level without sufficient information.

- Organisation A identified the top 8 possible priorities for blockchain used cases to be: (1) Ensure CSR compliance, (2) CO_2 footprint, (3) Secure supply, (4) Understand structural risks, (5) Understand dynamic risks (PESTLE), (6) Competitor intelligence, (7) Batch tracking to assure quality, and (8) Improve efficiency. The committee:

    - Agreed that the first two aspects of ensuring CSR compliance and tracking CO_2 footprints are the top priority. However, they indicated the third and four priorities to be important aspects to consider.

    - Agreed on setting certain information sharing requirements as a condition for selecting suppliers. This information includes SC mapping information up to the mines, annual certifications of all suppliers beyond Tier 1 and CO_2 footprint information.

    - Advised that the organisation is meeting current legislation in terms of CSR compliance and CO_2, and there are no current legal requirements for meeting specific CO_2 targets, but changes are expected in the future. They are closely engaged with different bodies to understand the evolving legislation.

- Did not see the current need to adopt any technological solutions to identify and understand their supply chain. They found blockchain use to track CO_2 interesting but for them to undertake but such an investment, there must be a clear value-adding to the organisation or a legal requirement for them to do so.

4.8 Case Study Discussion

This case study adds to the very limited empirical studies that have investigated the decision-making process for blockchain adoption in the supply chain. It revealed several opportunities and challenges for blockchain adoption and application in organisation A's battery supply chain. The meetings post case study indicated the organisation's priority areas and potential "affordable" solutions. The organisation decided to "stay close and watch" the developments of blockchain in the automotive industry and the evolving legislative requirements regarding the sustainable use and manufacturing of batteries. It also intends to include certain requirements in its future agreements with its suppliers to enforce sharing information. We summarise the key factors that directly influenced the decision made by the organisation as follows:

- The organisation's limited knowledge about their supply chain is a top inhibitor for carrying any SC investment. It also poses several risks to the organisation, including shortages of supply and being vulnerable to unethical SC practices.
- The organisation's inability to get the required information from its tier 1 suppliers indicate its less powerful position in the supply chain, which affects its ability to lead such a SC endeavour.
- Organisation A lacks clarity about the potential value from investing in technological solutions in their battery SC and the costs of required investments. The organisation is concerned about any additional investments and their impact on the battery costs.
- The organisation is meeting current legislation requirements regarding corporate social responsibility and the sustainability of its battery supply chain.

The lack of SC knowledge is a common challenge as many SC relationships are still dyadic. However, many organisations are increasingly aware of the importance of knowing their extended SCs to sustain their businesses. Several solution providers are responding to this need by claiming the development of SC maps using artificial intelligence and machine learning techniques, e.g., Transparency One[12]. Despite their ability to develop general SC maps, they

[12] https://www.transparency-one.com/

lack knowledge about the exact materials flows for the respective organisations. Hence, it is crucial for organisations to collaborate with their SC partners to develop accurate SC maps.

The organisation's position, power, and size influence its ability to lead a SC endeavour. Organisation A's perceived that upstream traceability should be enabled by the tier 1 suppliers considering their strong position in the battery network. Furthermore, internal organisational factors including the organisation's strategy, top management support and organisation readiness for digital transformation are all important factors affecting the decision-making regarding the adoption of new technologies and the implementation of SC solutions.

Investment requirements and the willingness of the different SC partners to invest in the SC solution can be key inhibitors for implementing SC solutions. Traditionally, most supply chains are profit-centric and aim at minimising costs across the supply chain. This has been the main reason for SC globalisation where organisations have targeted low-cost countries to carry out low value-adding activities. However, the increase in awareness regarding the social responsibility and sustainability issues of global supply chains, has stressed the importance of more connected supply chains. Therefore, there is a need to consider the cost requirements to achieve this connectivity.

Trust in the supply chain is an important aspect that has captured more attention with the emergence of blockchain technology. Organisations are increasingly becoming open to acknowledge the lack of trust in their supply chains. Traditionally, SC audits have played a crucial role in verifying the different organisations' claims, including their operational practices and meeting the agreed-upon terms and conditions. Audits are usually conducted periodically and are expensive and time-consuming activities. Blockchain has emerged as a technology that promotes trust in the supply chain by providing proof of immutable and traceable records of transactions across the supply chain that has the potential to optimise the traditional auditing processes.

Blockchain SC applications require collaboration among the different SC partners and their agreements on the data to be stored on the blockchain, the type of the blockchain network and its governance model. Having appropriate knowledge about blockchain and its capabilities can facilitate decision-making regarding blockchain network design. Furthermore, blockchain applications to enable products traceability in the supply chain requires the SC partners to tackle product identification issues at each SC stage, data capture mechanisms, and having established linkages between the different tiers of the supply chain.

Chapter 5: Blockchain Adoption and Application in the Automotive Leather Supply Chain

5.1 Case Study Industry Characteristics

Leather is a premium material used for many decades in the car interior. The automotive industry uses 15-18% of the total raw hides processed globally (Lectra, 2016), and 13% of tannery production in the European Union (EU) goes into the automotive industry (European Commision, 2021). The automotive leather is a top-grade leather that must meet high and stringent quality standards. It undergoes several tests to ensure its quality, durability and ageing properties (Leather International, 2001). Leather quality is highly affected by the tanning processes. Hence, the automotive OEMs select the leather suppliers to ensure its sourcing from high quality and reputable tanneries.

The automotive leather supply chain (LSC) is a directed supply chain. Automotive OEMs are in direct contact with the tanneries to determine the required leather quality and specifications for their tier 1 assemblers (Lectra, 2016). OEMs also need to ensure leather sustainability and the proper use of chemicals and waste management in the tanning processes. Therefore, they require these information from the tanneries (Lectra, 2016). There is no specific legislation related to the leather industry in the EU. However, the industry is strongly affected by other legislations for the use of chemicals, environmental impact, and use of animal by-products (European Commission, 2021).

The leather industry starts from the meat industry at the slaughtering stage. The leather hides then go into multiple production stages before it is supplied to the different downstream industries such as fashion, footwear, and automotive (Figure 10). There is a significant lack of traceability in the leather industry due to the large number of participants involved and the mobility and mixing of hides across the multi-tier supply chain. Leather is also associated with many environmental, social and economic risks, including deforestation, animal welfare, modern slavery and chemical and waste management (Moktadir *et al.*, 2021). Leather production is a labour-intensive process raising concerns regarding human rights and working environments (Moktadir *et al.*, 2021). Consumers increasingly demand sustainable products and information about leather provenance (Thakur *et al.*, 2020). In terms of economic risks, leather as a by-product of meat is, therefore, impacted by changes in meat production rates and meat prices (Moktadir *et al.*, 2021).

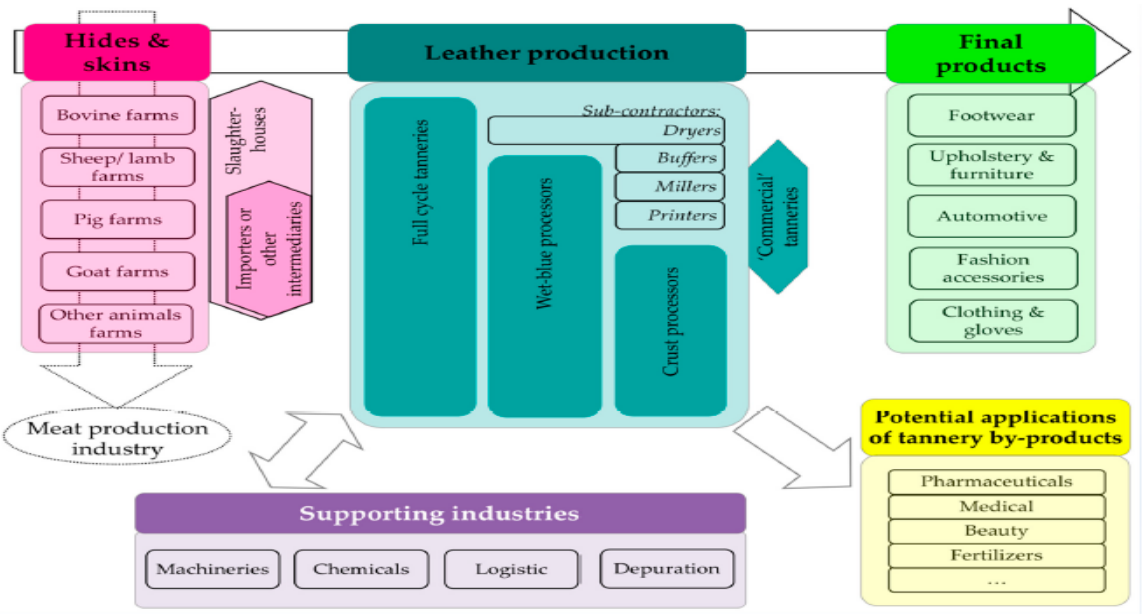


Figure 10. Leather industry global value chain. Source: (De Marchi and Di Maria, 2019)

5.2 Case Study Specific Supply Chain Characteristics

As a premium OEM, organisation A is one of the largest leather consumers in the automotive industry. It has a directed supply chain in which it nominates specific leather suppliers (i.e., tanneries) for its tier 1 interior and seat assemblers and communicates design and packaging requirements. Organisation A decides on the leather grade, price, and specifications with its leather suppliers for each vehicle programme and ensures that terms and conditions are aligned across its supply chain. Different teams are responsible for sourcing the different car's interior, including seating, headliners, doors and instrument panel and console (IP&C). In terms of purchasing processes, upon signing a contract, organisation A communicates its purchase orders and schedules with its tier 1 suppliers. Some leather finishing activities are outsourced to third parties nominated by the tier 1, and organisation A has limited visibility or control over these intermediaries. Figure 11 shows the information and materials flow in organisation A's LSC.

The majority of organisation A's leather seat and interior supply network is in Europe. The company has established long term relationships with four major European leather tanneries. The hides are sourced globally, but most tier 1 suppliers are located within hours of the organisation's assembly plants to meet the requirements of the just-in-time (JIT) production environment. The cutting, sewing and finishing takes place in various facilities dispersed mostly across Europe.

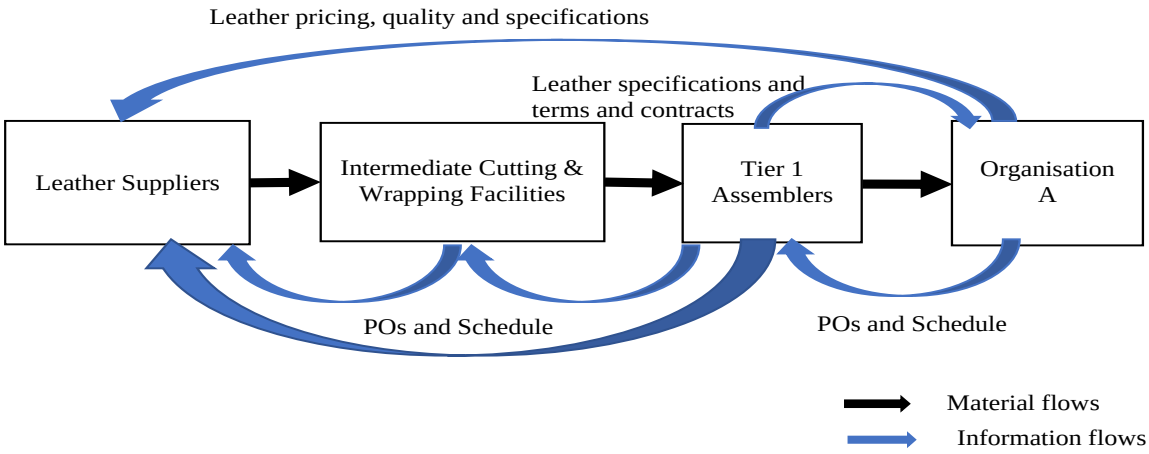


Figure 11. Information and material flows in organisation A leather supply chain

Leather tanning is a mature process with low level of technology involved. Leather cutting is increasingly becoming an automatic process, while in some facilities, it is still manual. Leather sewing is a labour-intensive process.

Three main types of leather used in organisation A's vehicles: Taurus, Semi-aniline, and Windsor leather. All four leather tanneries can supply different grades of leather. Usually, once specified, the leather grade and supplier for each vehicle programme remain fixed.

The SC relationships in organisation A's LSC can be characterised as follows:

- Directed supply chain: Organisation A controls leather sourcing decisions, negotiating prices and specifications with its leather suppliers and select the leather supplier for each vehicle programme for its tier 1 suppliers.
- Long term relationships: Organisation A has long-term relationships with its leather suppliers and Tier 1 assemblers (up to 20 years). The vehicle programme lasts for seven years, and once the LSC is set for the programme, it is very unlikely to change.
- Low dependency on leather suppliers: All leather suppliers are willing to supply organisation A with all types of leather. Organisation A can alternate between these four suppliers as it sees appropriate.
- High dependency on Tier 1 suppliers: Organisation A relies on a limited and highly specialised tier 1 suppliers for the different parts of the vehicle who can respond to the JIT production environment requirements and are mostly located close to the OEM plants.

The meat industry standards strongly influence leather. Organisation A tackles sustainability in a traditional manner using contractual terms and conditions for their leather suppliers and Tier 1 and compliance with ISO 14000 certification and auditing. The organisation gets

questioned frequently by non-governmental organisations regarding leather sustainability and use of leather. The organisation considers leather as a by-product of the meat industry. Organisation A's customers are also demanding information about leather provenance.

There are no shared information platforms used in managing the LSC. Most of the purchasing process is managed by spreadsheets and direct communication with suppliers.

The organisation was interested in blockchain traceability capability and its potential application in the LSC. This case study consists of two stages: (1) initial investigation of the potentials of blockchain in enabling leather traceability. This generated a comprehensive report that informed the organisation decision regarding blockchain adoption and helped develop a business case and secure funds to experiment with blockchain in the LSC. We refer to this stage as pre-pilot (Section 5.5). (2) Blockchain pilot project that aimed at using blockchain to create SC digital twin and enable traceability in a selected upstream LSC. It also investigated the requirements and challenges for the scalability of the blockchain traceability solution in the broader supply chain (Section 5.6).

5.3 Summary of the Key Challenges in Organisation A's Leather Supply Chain

1. Identifying leather provenance and enabling its traceability across the supply chain

One of organisation A's top challenges is enabling leather traceability in its complex global supply network. Leather traceability is a challenge upstream and downstream the leather tanning processes. In the upstream LSC, there is massive number of farmers and abattoirs worldwide from which leather can originate. There are also significant complexities in the downstream supply chain as the leather goes through different cutting, sewing, and wrapping facilities where the hides get mixed, wrapped and glued, increasing the challenges of maintaining traceability in the supply chain.

2. Ensuring the sustainability of leather.

Leather is associated with high environmental and social risks, including links to deforestation, animal welfare, and chemicals. Organisation A has frequently been asked about its leather sustainability and provenance by customers, investors, and different NGOs. Organisation A has committed to reduce its environmental impacts and has an ambitious overall strategy for sustainability. The difficulty of enabling leather traceability subjects the organisation to several social and environmental risks regarding its leather sustainability.

5.4 Mapping Organisation A's Leather Supply Chain

Organisation A has relatively good knowledge about their upstream LSC, especially between the tanneries and the OEM. We provide a high-level map of the overall SC configuration (Figure 12), along with brief analysis for the organisation supply chain.

The SC map captures the farm region, abattoirs, intermediaries, leather producers, leather trimming and sewing facilities up to the final Tier 1 seat assemblers and organisation A's assembly plants. The length of the LSC varies between 6-9 tiers depending on the origin of leather and the number of steps between the leather suppliers and the OEM.

Besides the seating, leather goes into different parts of the vehicles including headliners, doors, and IP&C, and each has a specialised car interior assembler. Organisation A's downstream supply network between the leather suppliers and the OEM consists of 46 different SC partners. Some SC partners have multiple facilities in different countries, including the OEM resulting in approximately 66 production facilities in the leather supply network between leather suppliers and the OEM. The majority of leather originates from North and South America. However, all value-added activities are completed in Europe except for a limited proportion assembled in North Africa.

The network analysis identified many critical players in organisation A's supply network between the Tier 1 and leather suppliers, over whom organisation A has no or little control. It also showed the importance of hide suppliers and farms as critical nodes in the network. Any disruption or non-compliance in any of these suppliers could impact organisation A's final operations. Therefore, it is crucial for organisation A to know about its supply network to mitigate risks and improve its SC planning and performance.

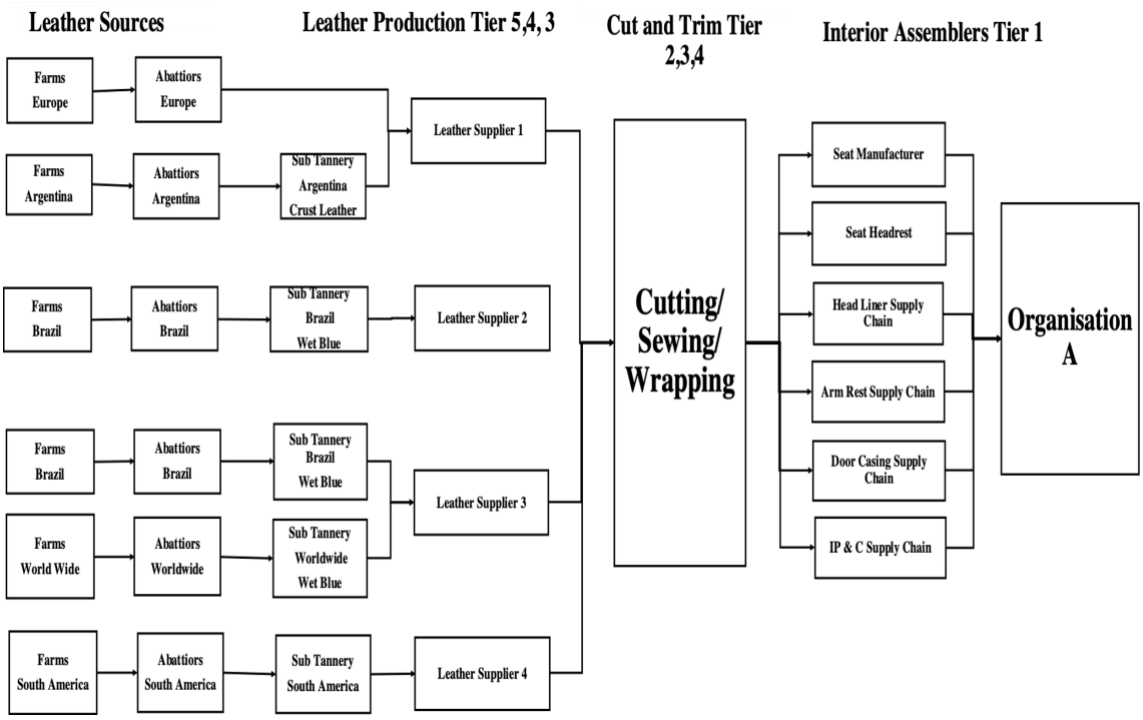


Figure 12. Organisation A's leather supply chain map

5.5 Pre-pilot: Blockchain as a Potential Solution in Organisation A's Leather Supply Chain

This section summarises the findings of the first stage in the case study, including interviewees quotes in *italics* where relevant and their position.

Leather is a high-risk commodity for organisation A as it has been frequently asked about its sustainability and provenance by several NGOs. Traceability is a top challenge in the organisation's LSC to ensure its sustainability. Hence, the organisation sought to be a pioneer in investigating the potential application of blockchain to enable traceability in the LSC.

The high-quality requirements for the automotive leather have made only a small proportion of produced leather suitable for automotive use compared to other sectors.

> *"In terms of leather, I think automotive are a small player (ECM)*[13]*"* and *"Automotive is generally very high-grade material... Its only bulls of a certain weight as in they are quite big. Therefore, of all the billion hides, ..., basically the top 10% I believe is all goes for automotive (PM)."*

Having leather in the vehicle is one of the main customers' criteria for vehicle selection.

[13] Please refer to Table 9 for the exact position

"People buy the car and expect the leather to be in there. It is one of their selection criteria (ECM)."

However, the OEM customers are demanding assurances on leather sustainability and provenance, forcing the organisation to consider ways to enable leather traceability and ensure its sustainability.

"They will be interested to be assured that their leather is coming from areas that are not causing deforestation, that is the level of information our customers require at this moment (SSE)."

The participants acknowledged the main challenges for leather traceability, particularly the SC complexity that hinders the implementation of traceability solutions.

> *"The first issue you are going to find is the complexity here is huge… you got four levels of supply. A lot of leather suppliers got a lot of humongous load of complexity in terms of farmers and abattoirs but even up stream is where it is really confusing. So we tend in purchasing we will source the interior of the car, we got a team that source the seats, a team to source the doors, a team to source the IP[Instrument Panel] and a team to source the headliners (PM)."*

Furthermore, to identify the provenance of leather used in a vehicle, there is a need to maintain traceability across the entire SC and prevent traceability loss at the later SC stages.

> *"There is no point in working on a really difficult bit in terms of the millions of the farms that are globally. If it gets to tier 3 or tier 4 supplier who just gets the leather and do it into something and then lose it over traceability we have got upstream (PM)."*

Leather tanneries are aware of the sustainability concerns regarding leather. They tend to collect massive information about the hides' sources and farms to provide assurances on leather sustainability and provenance.

"Getting to the tanneries. The amount of information they have is unbelievable and the amount of stuff they take A4 [papers] of every farm and batch they do (PM)."

"Our suppliers themselves have got systems in place to make these assurances (SSE)."

Leather suppliers can obtain all the necessary paperwork to identify a specific leather batch and potentially origin region, but these processes are manual and take a long time.

"In terms of leather, if we had a specific VIN number and someone could tell me this is the cut part, reference is on the back, I'm pretty sure the leather suppliers could. It will take time, nothing is that automated, but they will be able to go. Ok that was that batch of leather. We bought that batch of leather from here, from that agent. He bought it from this Abattoir. They can narrow it down to a region. That is possible but it is nothing very quick or automatic (PM)."

Despite the leather suppliers' efforts to enable leather traceability, the participants highlighted that they cannot guarantee whether they can trace leather back to a farm.

"Even though I trust them, I still don't know. Could they go back to the farm? (PM)"

The leather is stamped at the final stages of the tanning processes. At these stages, the leather hides are already mixed, making it difficult to trace them back to specific farm locations with certainty. For tanneries to be able to provide accurate sourcing information for each hide, they need to identify the hides before and after the tanning processes. Other SC partners will also need to maintain leather traceability, raising an important consideration regarding investment requirements.

"What I worry about is the investment that would be required to do it and also the amount of data that would come out of it (SSE)."

Another key consideration highlighted is the lack of common understanding of traceability considering the different traceability endeavours taken by the leather suppliers.

"It is quite a wide word… Traceability can mean so many different things to different people… it is controversial (PM)."

The participants were also concerned about the potential value of traceability data beyond informing the customers about the leather provenance.

"Even if we could trace back to the farm. What would we really do with that data? Other than maybe telling the customer that their interior leather has come from farms in whatever village in whatever country (SSE)."

Regarding blockchain, the knowledge about blockchain varied among the participants. Some participants considered the immaturity of blockchain and the potential challenges in its integration with many partners.

"But how does the system work because I think the main blocker will be the cost or the integration with many people (PM)."

Other participants acknowledged blockchain's capabilities in enabling traceability but highlighted the lack of clarity about the organisation's business needs.

"There are technologies out there. We have got a solution looking for a problem. We just need to understand why are we doing this? (SPM)"

Regarding SC relationships, organisation A's participants considered that the organisation has a strong position and the necessary power over its diverse leather network.

"We do have power over the supply chain because ultimately they don't know if I want to go get a Taurus leather from a new supplier. I can ultimately do it if I wanted to (PM)."

"We have got a very good leather supply chain. We tend to be very big part of their business as well, so we are a key customer for them (PM)."

However, organisation A is highly dependent on its tier 1 suppliers due to the just-in-time production environment.

"The main thing is that because they are JIT suppliers and that basically how the supply chain works for these suppliers and these commodities of interior (PM)."

"Another supplier will have to invest in a facility for that to happen and they will only do that if I would guarantee business. So, you tend to find the tier 1, we are a bit more locked in, or we have more partnerships because we have to (PM)."

Generally, there is a good level of information sharing and collaboration in the supply chain. Organisation A has ongoing discussions on how to improve leather traceability with all their suppliers. However, the participants highlighted the lack of abattoir interests and financial incentives for leather traceability.

"A lot of it is not driven by the leather supplier, but the abattoir, and they don't really care about traceability upstream (PM)."

"There is no financial incentive for the abattoir to do that (SSE)."

To better understand the implications and requirements of implementing blockchain-enabled traceability solution in the LSC, organisation A secured government funds to experiment with blockchain in a local supply chain. We provide more information in the next section.

5.6 Pilot: Blockchain Application in Organisation A Leather Supply Chain

Organisation A was looking for a local LSC to experiment with blockchain and to strengthen its position in securing government funds for the pilot. Organisation A partnered with a local leather tannery that supplies automotive leather, a local blockchain solution provider, and the University of Nottingham to investigate blockchain adoption in its LSC. Figure 13 presents the different partners motivations for the project that encouraged their participation. The project had the following objectives:

- Investigate hides traceability from the farm to the end of tanning processes.
- Hides identification and creation of SC digital twin using blockchain technology.
- Investigate the solution scalability requirements and challenges in the downstream SC from the tanneries to the OEM and other selected global leather supply networks.

Automotive OEM Main Motivations	**Leather Tannery Main Motivations**	**Blockchain Provider Main Motivations**	**University of Nottingham Main Motivations**
▪ Identifying the provenance of leather used in the OEM vehicles. ▪ Ensure leather compliance and sustainability. ▪ SC visibility and optimisation. ▪ Provide customers with improved options.	▪ Ensure leather sustainability. ▪ Understand the practicalities of leather traceability across the supply chain. ▪ Promote good practices.	▪ Expanding the solution to another sectors (meat and leather). ▪ Tackle global compliance issues. ▪ Enable waste tracking. ▪ Platform development.	▪ Empirically investigate the requirements and challenges for blockchain application for SC traceability and sustainability. ▪ Empirically investigate the feasibility of blockchain scalability in a complex supply networks.

Figure 13. The project partners motivations

The project work lasted for six months and included two main activities (Figure 14):

(1) Physical and digital tracking of hides from the abattoir to the end of tanning processes using blockchain-enabled traceability solution (Section 5.6.1).

(2) Investigate blockchain traceability and scalability requirements and challenges in selected downstream SC from the tannery to the OEM plant and other selected global LSCs. This

involved several conversations with some of the organisation's Tier 1 seat assemblers and another leather tannery in South America (Section 5.6.2).

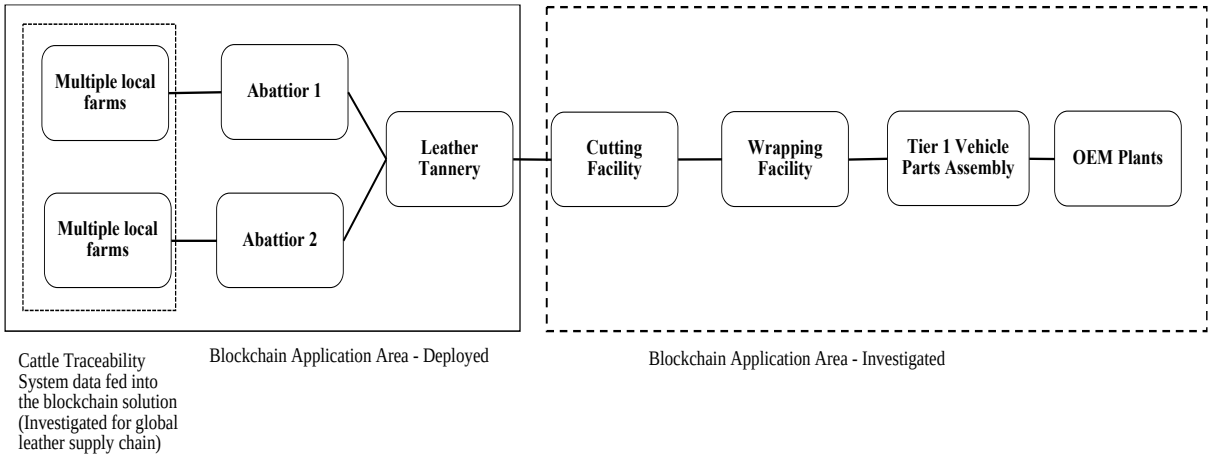


Figure 14. Organisation A blockchain project activities -Unit of analysis

5.6.1 Development of the blockchain traceability solution

To design and develop the blockchain traceability solution that accurately represents the real world, the project team had to initially understand and identify the scope of traceability, number of parties involved, leather processing steps, traceability data requirements and availability, and existing product identification methods and information systems.

Leather comes from animals on farms and is separated in the abattoir, which is the beginning of the LSC. At these points, leather can be identified using paper labelling or earring labelling. Leather traceability from the farm is easier to accomplish if there is a meat traceability system in place and if the tanneries have direct relationships to the abattoir. However, this is not always the case, and the hides may go through initial cleaning (e.g., hair removal) or sub-tanning processes before being sold to the main tanneries. The availability of a government-owned cattle tracing system (CTS) in the selected LSC, in which each cow has a cattle passport and is uniquely identified and tracked from birth to the abattoir, provides a rich and trusted source of traceability data. It also eliminated the need for replicating the data collection efforts to trace the cows' movements between different farms before being sent to the abattoir. In the project, two abattoirs were onboarded and two batches of 20 hides each were individually identified and tracked from the abattoirs and throughout the tanning process to create a SC digital twin on the blockchain platform.

We describe the design stages of the blockchain traceability solution next (

Figure 15).

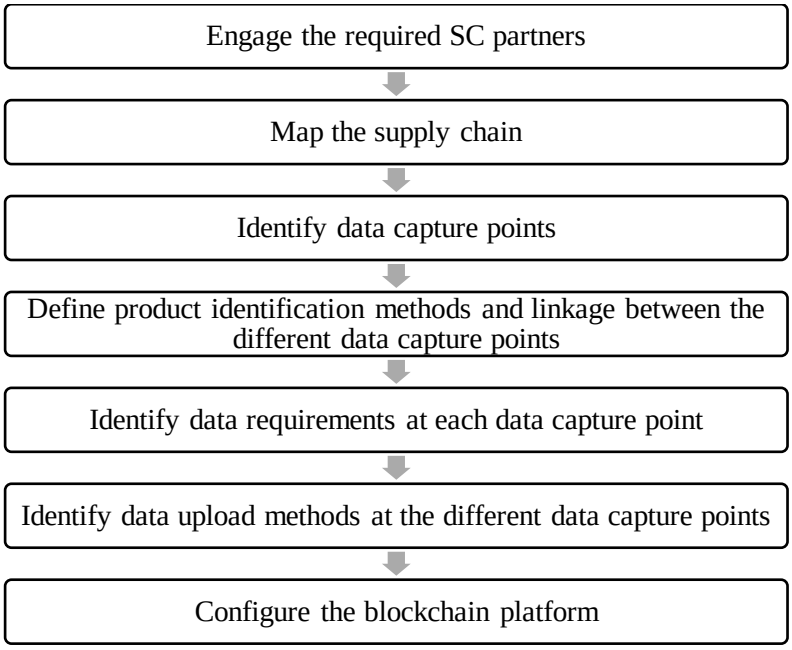


Figure 15. Design stages of the blockchain traceability solution

Stage one: Engage the required SC partners

This is the first stage in developing the blockchain traceability solution. The project team reached out to several abattoirs to engage in the project, explaining the project aim, its importance, why they are needed and what would be required from them. Some abattoirs were very interested in participating in the project, others were reluctant to disclose information. The team decided to include two abattoirs in the project. The abattoirs' use of CTS provided sufficient data about the cattle history, eliminating the need for engaging farmers in the pilot.

Stage two: Map the supply chain

Developing SC maps was crucial to understand how leather is transformed/processed as it moves in the LSC in order to identify appropriate data capture points for the design of the blockchain traceability solution.

Stage three: Identify data capture points

Two types of data capture points were identified (Figure 16):

1) Goods-in and goods-out data capture points between the SC partners' facilities

- Point A: This is the first data capture point for the leather as the cow arrives at the abattoir. Cow data, including its history and origin, is captured from the cattle passport and stored in the abattoir's internal database and later in the blockchain platform.
- Point B: After the slaughtering process, this data capture point captures the raw hide label when leaving the abattoir's facilities.
- Point C: This data capture point is at the entry point of hides at the leather tannery, ensuring that all hides are labelled and can be traced back to the abattoir.
- Point D: This is for the processed hides leaving the tannery to the downstream supply chain.

2) Within the tannery data capture points

- Point E: The raw hides are identified at the beginning of production at the liming process.
- Point F: After the liming process, the products go in sequence to fleshing and splitting to maintain their identification.
- Point G: After the splitting process, only one part of the hide proceeds to the tanning process. The other part goes to the food industry.
- Point H: Again, the hides are processed in sequence to maintain traceability.
- Point I: After measuring the processed hides.

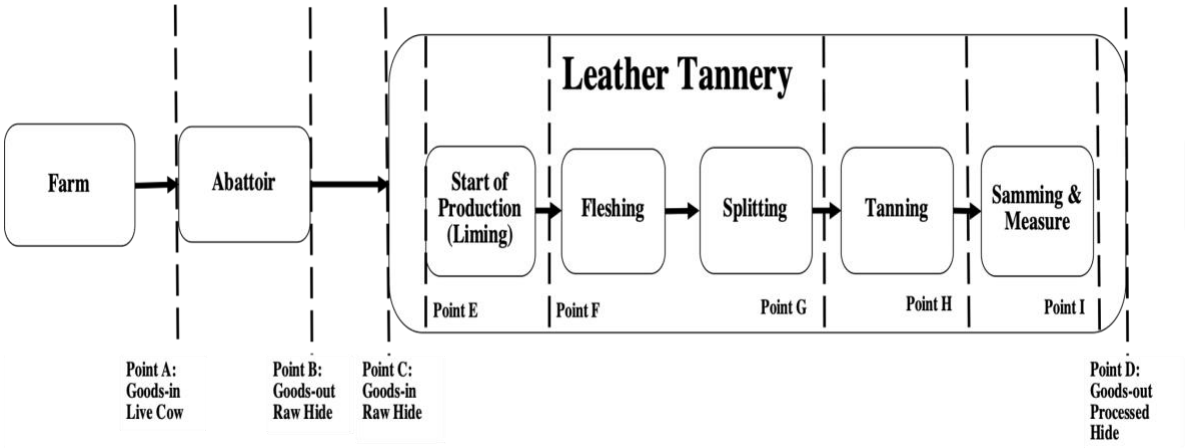


Figure 16. Overview of data capture points

Stage four: Define product identification methods and linkage between the different data capture points

Different hides identification number (ID) methods were used in the project, including:

- CTS passport number (Figure 17 A&B): This ID helped identify the hides coming in and out of the abattoirs. After slaughtering, additional tag number was added to each hide CTS passport number.

- Ear tags (Figure 17 C): At the start of production, each hide had a new ear tag indicating its unique identification inside the tannery and is linked to the CTS passport number and slaughter tag number. Ear tags were maintained between Points E& F, removed between Points F&G while the hides were processed one at a time to maintain their ID, and retagged after the splitting process to the hides' part that proceeded to the tanning processes.
- Laser engraving (Figure 17 D): A new hide ID is engraved on the finished hides.



Figure 17. Leather hide identification. Sources: A&B (Food Standards Agency, 2010), C (Internal), D (Auto Express, 2020)

Stage five: Identify data requirements at each data capture point

The project team initially adopted the traceability information identified by (UNECE, 2021) to define the potential traceability data. However, determining the data requirements at the different stages in the LSC and the optimal level of SC traceability to pursue remained as key challenges. Table 14 summarised the data collected in the two trials of hide batches.

Table 14. Summary of the information collected at each data capture point

Data Capture Point	Data Capture Identifier	Captured Information (Attributes)
1. Abattoir – Goods-in (Point A)	CTS Passport Number	Farms CTS Data including: - Producer code - Location (Area code) - Breed - Date of birth - Age - Origin - Number of movements - CO_2 emissions
2. Abattoir – Goods-out (Point B)	CTS Passport Number Slaughter Tag number	- Kill date - Kill number - Net weight - Grade - Transport ID (CO_2 emissions) -Energy use in process (CO_2 emissions)
3. Tannery – Goods-in (Point C)	CTS Passport Number Slaughter Tag number	- Date - Pack Number Market - Weight Range - Type - Origin - Preservation Method (Iced, salted, etc.) - Contracting tanning (Yes/No)
4. Tannery – Liming, Fleshing, splitting, and tanning processes (Point E, F, G & H)	Tannery Ear Tag number	- Date - Pack Number Market - Weight Range - Type - Origin - Preservation Method (Iced, salted, etc.) - Contracting tanning (Yes/No)
5. Tannery – Samming and measure (Point I)	Laser Engraving with the ear tag number	- Size (Square meter) - Grade - Weight
6. Tannery – Goods-out (Point D)	Laser engraved ID	- Transport ID (CO_2 emissions) - Customer ID - Energy use in processes (CO_2 emissions)

Stage six: Identify data upload methods at the different data capture points

Different data entry methods were explored during the project. The CTS data stored in the abattoirs' internal database was inserted to the blockchain platform manually using a desktop application. This option was also available for the tanneries along with the potential use of application programming interface (API) to directly connect with their ERP systems. However, for the proof of concept, since the data was captured for only two batches of hides, it was collected and stored in a spreadsheet, and entered manually to the platform.

Stage seven: Configure the blockchain platform

The blockchain solution provider was responsible for configuring the blockchain solution and creating the SC digital twin. The company provides a private, permissioned-based, and blockchain-enabled software-as-as-service (SaaS) platform based on Hyperledger Fabric. It supports various data input methods from a desktop application, mobile application, and/or with a secure system integration with the use of APIs and security protocols.

After investigating the LSC, data capture points, existing systems, and data availability and format, the company was able to configure a blockchain platform that supports leather traceability and identification across the supply chain. The platform captured the required traceability data at each data capture point as per Table 14. Figure 18 and Figure 19 present screenshots of the platform interface. The process starts by identifying the data capture point, date and responsible party and linking it to the previous data capture point in the supply chain. Next, additional information regarding the location, specific attributes, images and attachments can be added to the data point. Figure 20 and Figure 21show the visualisation interface for the supply chain's material flow, including a flow graph and a geographical map and the details of an exemplar data point.

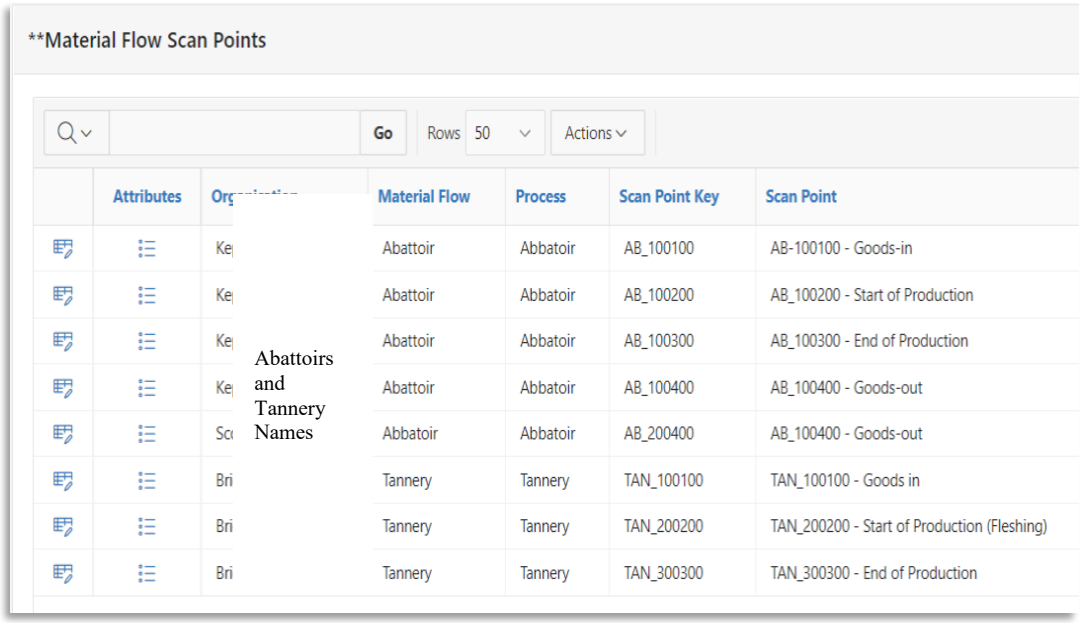


Figure 18. Blockchain solution data capture points screenshot

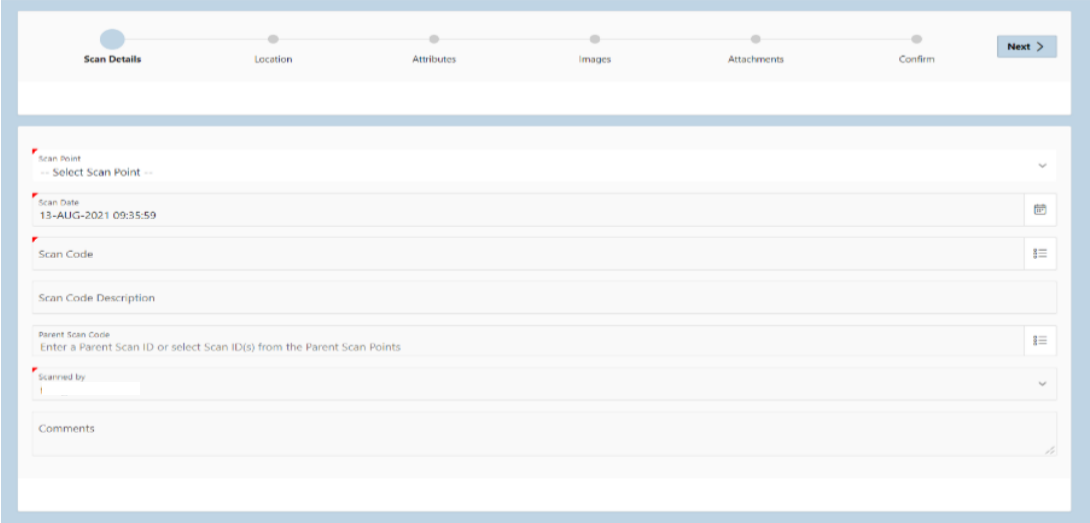


Figure 19. Data entry at data capture points screenshot

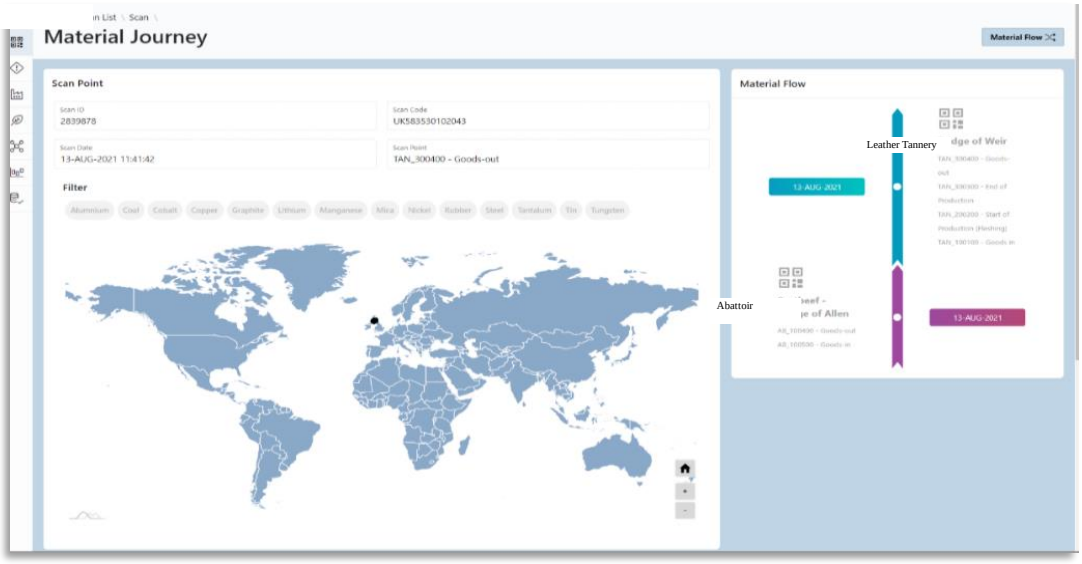


Figure 20. Example of material journey visualisation

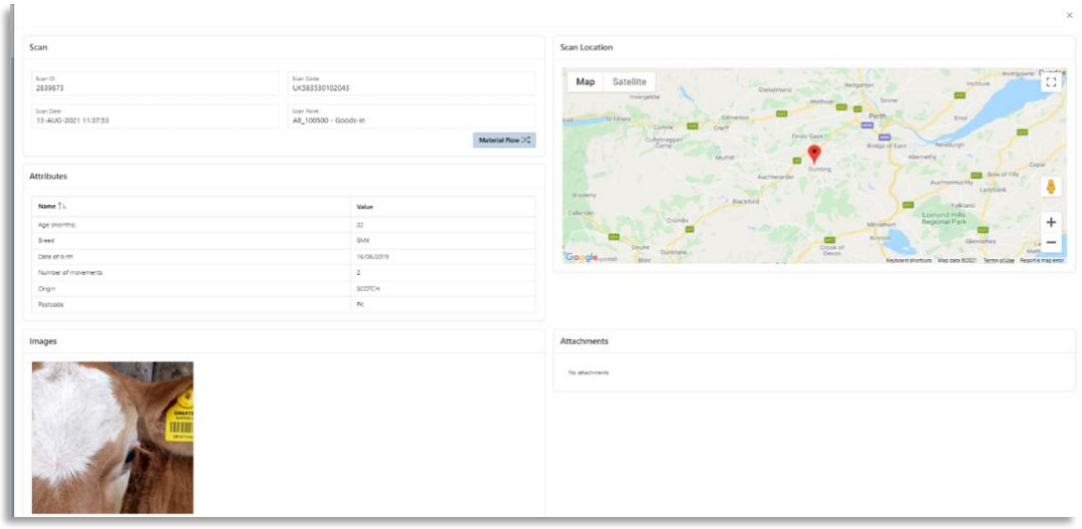


Figure 21: Example of a data capture point details

5.6.2 Leather traceability requirements in the downstream leather supply chain (from the tannery to the OEM facilities)

The project team investigated and analysed the traceability requirements and challenges in the downstream LSC to evaluate the scalability of the developed solution. They focused on one vehicle program and engaged one of the main tier 1 seat suppliers to understand their processes and current traceability level in the downstream LSC.

Figure 23 summarises the existing traceability methods and processes taking place in the downstream LSC. Leaving the tannery, leather is sent to the seat assembler's cutting facility, where the hides are stored in specified locations based on the leather supplier, grade and colour. The individual hides are checked before cutting to ensure the right material was selected. The cut pieces are then grouped in Kanban boxes and are sent to the sewing facilities, where the supplier has a dedicated sewing line for the OEM products. The Kanban boxes have a unique ID and are tracked through the facility production system. If the vehicle part is to be wrapped like for headrests, it is sent to another facility. After the sewing process, a trim cover label is attached to the sewn part. This trim cover label includes the part number and colour and is scanned at the seat assembly line. The trim cover label number is added to the final vehicle identification number (VIN).

The existing downstream traceability is achieved through the production processes. It does not track any information about the leather source and leather mixing can take place at the different stages. In this case, to identify the leather source, the leather lamination has to be removed to search for the laser engraved ID from the leather supplier on the hide (Scenario A – Figure 22). The seat assembler would be able to achieve a higher level of traceability by printing the leather batch number in the trim cover label as is required from other OEM manufacturers (Scenario B – Figure 22). For the selected vehicle program, processed hides are cut at the leather tannery, and each part includes a laser engraved ID for the commercial batch. Hence, leather traceability can proceed as described above (Scenario C – Figure 22). However, the cut parts are not linked to the processed hides.

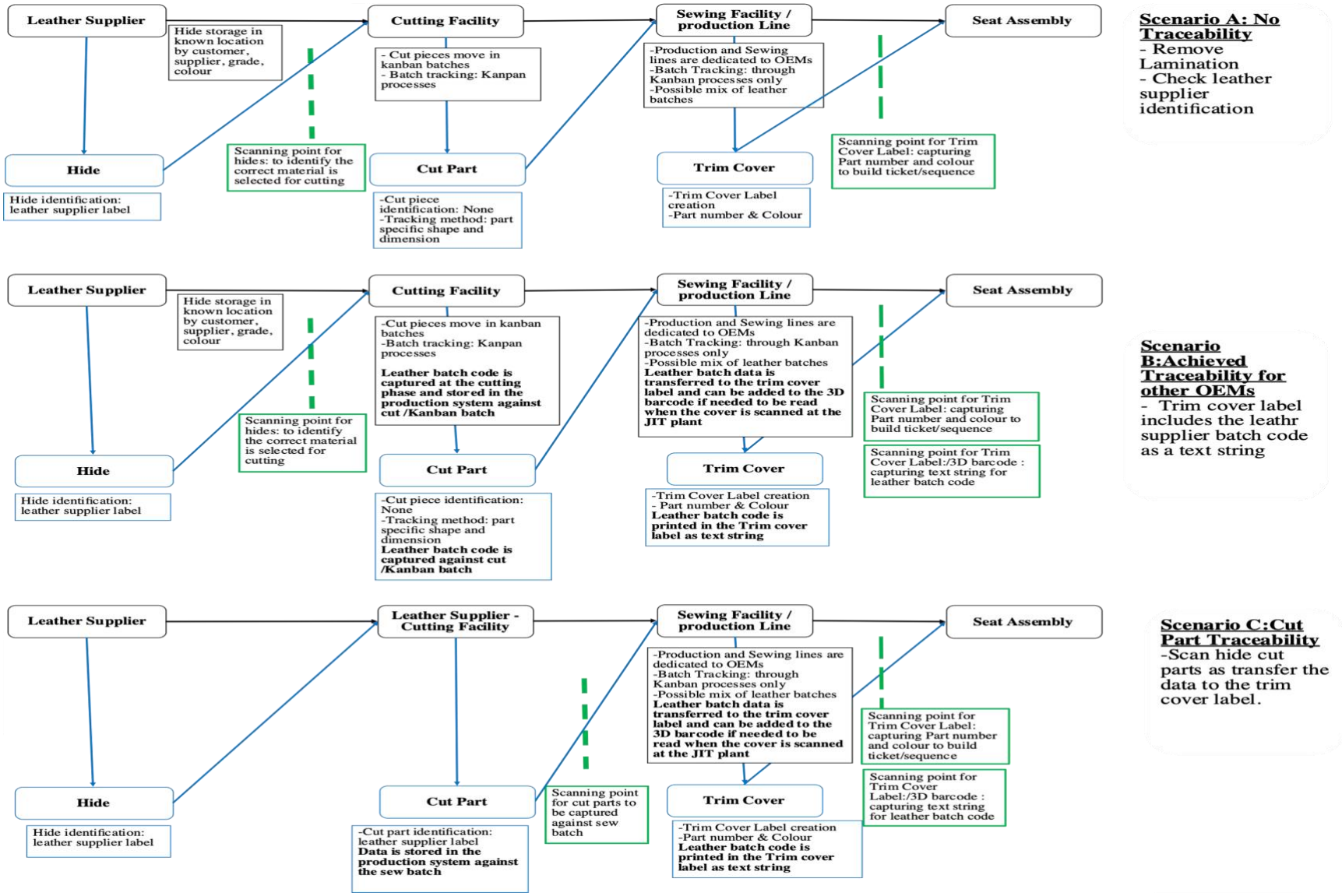


Figure 22. Downstream leather supply chain processes maps

The project team investigated: (1) potential product identification methods and (2) data capture points in the downstream LSC, for three levels of traceability:

- *Tannery level*: Enabling the traceability of a vehicle's leather to the leather supplier.
- *Batch level*: Enabling the traceability of a vehicle's leather to a specific batch from the leather supplier.
- *Hide level*: Enabling the traceability of each hide/cut part used in a vehicle to the leather supplier and hide origin.

1. Leather identification methods and requirements

The current identification method for the leather hides or cut parts leaving the tannery is laser engraving for the commercial batch number. One key limitation of this method is that it is not machine-readable, and the engraved part is usually hidden and glued on the final vehicle part. Manual checking for this ID would require more resources and time, resulting in higher costs and operational inefficiencies. However, having a batch number for the leather can enable tannery and batch-level traceability. Thakur et al. (2020) investigated the issue of maintaining leather identification during the tanning processes using several identification technologies, including RFIDs, dot peening and laser engraving for QR codes. They also considered whether these methods are machine-readable after the tanning processes. Although their research investigated leather identification within the tanning process, it provides opportunities for using these methods to maintain leather traceability in the downstream SC. Using machine-readable identification can potentially support the solution scalability and improve the traceability processes' efficiency. DNA Technology is another emerging technology that supports leather traceability. It uses molecular tags and/or non-pathogenic microorganisms sprayed onto the product to provide it with a unique footprint (Applied DNA Sciences, 2021). Figure 23 summarises the potential leather identification techniques and where they can be applied in the LSC.

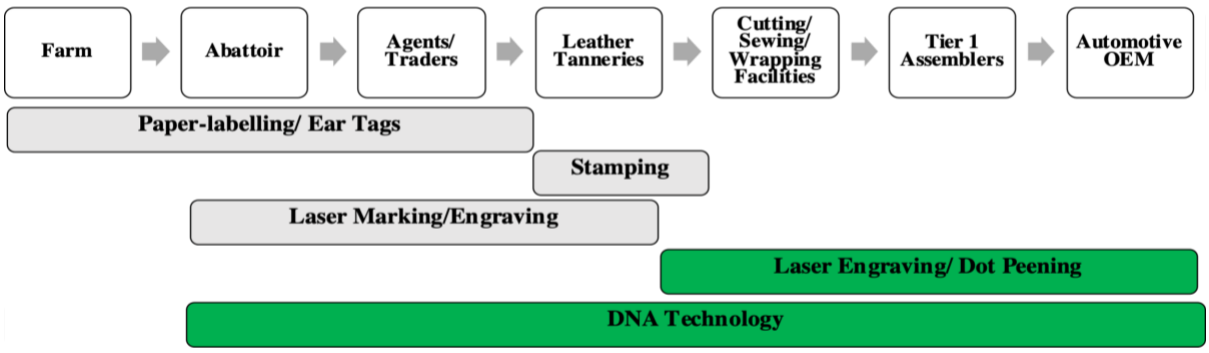


Figure 23. Potential leather identification techniques at the different stages of the leather supply chain

Two options could be pursued for leather identification. Using the existing commercial batch number used for leather batches leaving the tanneries, the laser engraving method would eliminate the need for additional investment and if maintained across the supply chain, could provide batch and tannery level traceability. However, upstream traceability information from the farm to the end of the production processes should be linked to the commercial batch number.

Developing a new identification numbering system can enable its standardisation across all leather suppliers and having it linked to the required traceability information. It also enables leather identification at different levels of granularity. **Error! Reference source not found.** summaries the potential identification technologies for each level of traceability and the upstream SC traceability requirements.

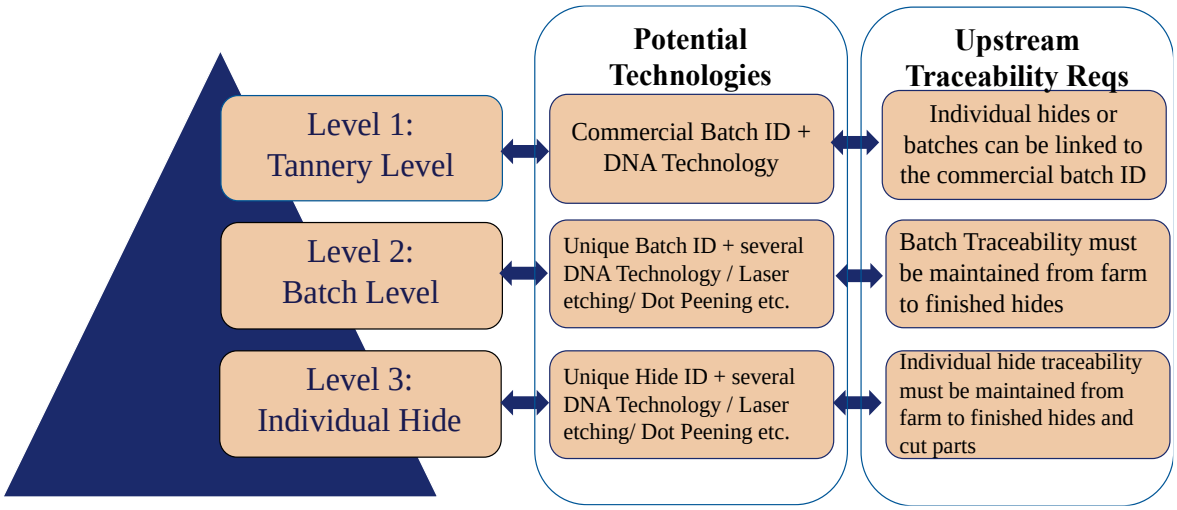


Figure 24. Leather identification technologies for different levels of traceability

2. Data capture points and requirements

The location of the data capture points differs depending on the desired level of traceability. We identify the data capture points for each level of traceability assuming that the leather is already cut at the leather tannery and is identified using a machine-readable technology:

- *Tannery level traceability*: Leather from each leather supplier should be identified and separated. For this level of traceability, batch mixing is not an issue considering the leather is from the same supplier. However, if batches are mixed from different leather suppliers, these suppliers must be identified, and their information has to be added to the trim cover label. Data capture points can be at the beginning and end of the sewing line where leather is identified and sorted depending on whether it is from a single or multiple sources.

- *Batch level traceability*: This level would require more controls on batch mixing and material flows since each batch must be identified and tracked. Sewing lines can be dedicated for each leather batch, and when batch mixing takes place, this information would need to be captured in the final trim cover label to show the number of the different batches in each trim cover. The batch numbers must also be linked with the leather supplier's ID. The data capture points are also at the beginning and end of the sewing line.

- *Hide level traceability*: Hide mixing is not an issue here since each cut part is uniquely identified and linked to the leather supplier. However, to enable this level of traceability, each cut part must be scanned as it is sewn in the sewing line. The sewing line consists of several stations and is a labour-intensive process. Each cut part ID must be linked to the final trim cover ID at the end of the sewing process. Figure 25 summarises the material control requirements and data capture points in the downstream LSC for different levels of traceability.

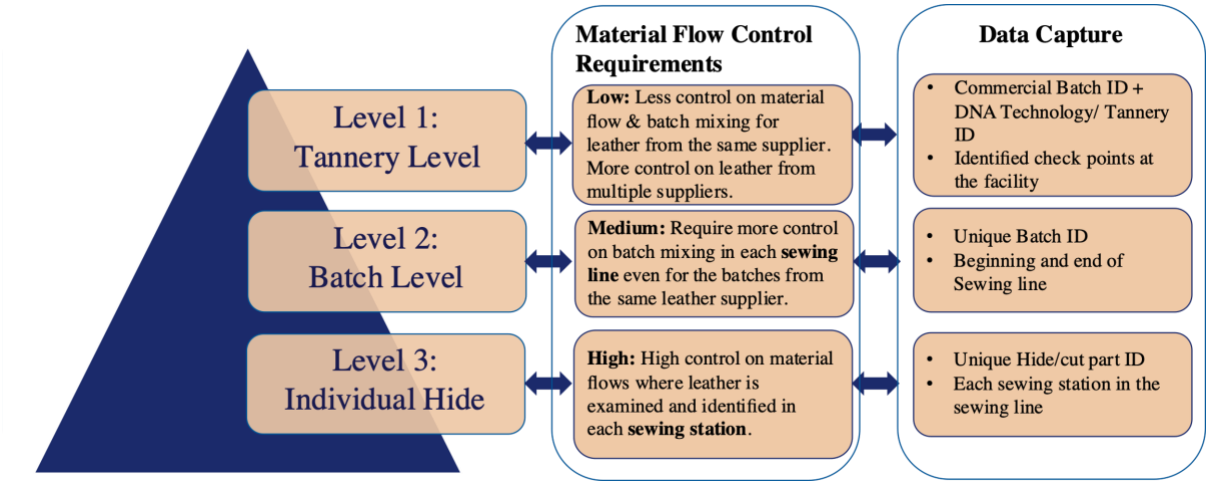


Figure 25. Material flow control requirements and data capture points for different levels of traceability

5.7 Case Study Analysis

5.7.1 Analysis of blockchain capabilities in addressing organisation A's leather supply chain challenges and blockchain application area

The leather tanneries are the most value-adding participants in the leather value chain. Prior to the blockchain pilot, organisation A had to determine which supply chain to consider for the pilot project. The SC characteristics vary among the different leather suppliers as presented in Figure 26.

There are 4 leather supplier which have similar SC characteristics in terms of length, complexity, and being subject to deforestation risks. Leather tannery 1, which sources most of

its leather from Europe and directly from the abattoirs, was selected for the pilot. By being entirely in Europe, the existence of government CTS provides a robust foundation for leather traceability at the beginning of the value chain, and these supply chains are not exposed to deforestation risks. All of these supported the selection of this leather supplier for the blockchain pilot. Experimenting with blockchain in a less complex LSC helped organisation A better understand how the blockchain system works and the likely investment requirements. The other leather suppliers (2, 3 & 4) represent larger parts of the OEM leather volume, stressing the importance and need for leather traceability in these supply chains.

The blockchain pilot provided evidence of blockchain capabilities in enabling leather traceability in organisation A's upstream supply chain. The developed blockchain platform enabled the provision of an immutable and traceable records of traceability information for leather from the cow until the end of the tanning processes. The blockchain project focused on implementing blockchain in the upstream SC because it is the most problematic part of the supply chain, suffering from severe lack of transparency and traceability and has major sustainability concerns (i.e., related to deforestation, animal welfare, modern slavery, use of chemicals, etc. (Moktadir *et al.*, 2021)). Furthermore, leather identification before and after the tanning process is a major issue hindering traceability at this critical stage of the supply chain. However, the requirements and challenges for extending leather traceability in the downstream supply network and other global LSCs were also investigated and highlighted.

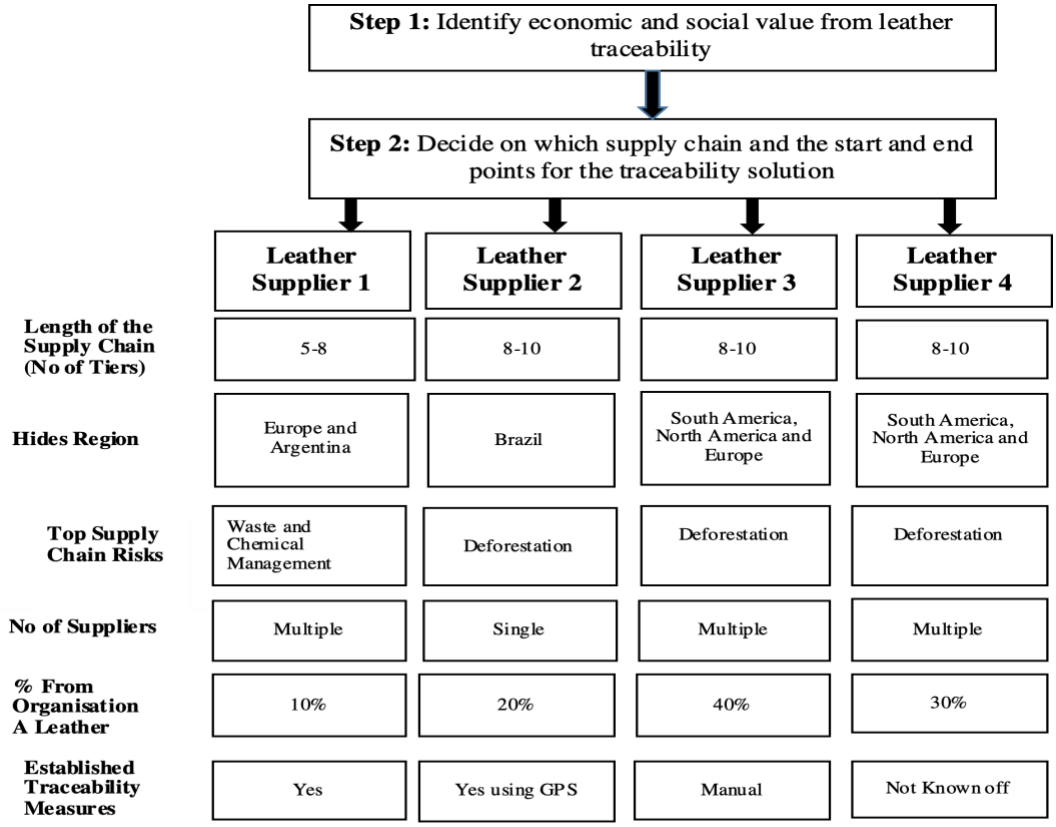


Figure 26. Organisation A leather supply chain analysis

5.7.2 Analysis of blockchain data

Organisation A used the MOSCOW[14] prioritisation method to better understand and prioritise their traceability requirements. These priorities were then analysed by the University of Nottingham team and translated to the different levels of traceability that can be desired by the project consortium (Table 15).

The blockchain solution was configured to enable traceability at a high level of granularity at the hide level i.e., product unit level, capturing information about the hide's origin, specifications, quality, and sustainability. At the process level, the platform captured the inputs and outputs of the slaughtering process at the abattoirs and of the tanning processes, which is also at high level of granularity. The platform also captured information about the facility location and activity, the stakeholder's name, and their role in the supply chain as well as transport details and location information. The project proved that traceability at a high level of granularity is possible but is not practical nor scalable as an industrial solution. Therefore, there is still a need to determine the optimal level of granularity and data sharing requirements across the LSC.

[14] https://www.agilebusiness.org/page/ProjectFramework_10_MoSCoWPrioritisation

Table 15. Traceability identifications levels and related information

Traceability Levels	**Levels of granularity/ identification**	**Traceability data**
Stakeholder Level	↓ Stakeholder	Abattoir
	↓ Organisation	Producer ID/Customer ID
Process Level	↓ Facility Activity	Breed
	↓ Process	Slaughtering processes ▪ CO_2 emissions ▪ Energy use in process (CO_2 emissions)
	↓ Subprocess	Tanning Processes ▪ CO_2 emissions ▪ Energy use in process (CO_2 emissions) ▪ Preservation Method (Iced, salted, etc.) ▪ Contracting tanning (Yes/No)
Traceable Asset Level	↓ Trade Units	Commercial batch ▪ Pack Number
	↓ Batch	Production Batch
	↓ Product Unit	Individual Hide ▪ Date of birth ▪ Age ▪ Number of movements ▪ Origin Information ▪ Kill date ▪ Kill number ▪ Net weight ▪ Grade
Transport Level	↓ Means of Transport	▪ Transport ID (To calculate CO_2 emissions) ▪ Pick-up and delivery dates and location
Location Level	↓ State/City	Location (Area code)

5.7.3 Analysis of the key pre-requisites and inhibitors for blockchain adoption and deployment in the supply chain

Four main pre-requisites were found crucial for blockchain adoption in the LSC. First, the project team realised the importance of engaging the abattoirs to support hide traceability to their farm origin. Second, they acknowledged the need for a tagging method for hides in the abattoir and during the tanning processes to maintain traceability. Third, there must be an agreement among the consortium participants on the level of traceability and the type of data to be collected and shared across the supply chain. Finally, the consortium identified the need for a method to validate and verify the data captured on the blockchain platform, such as the CO_2 emissions data that is calculated separately by the different SC participants.

The project team also faced many challenges, including:

- Hide identification during the tanning processes: Due to the chemical and mechanical processing of hides, none of the existing methods maintained hide traceability during the tanning processes.
- Identifying the farm location and considerations of GDPR: Despite having the upstream cattle traceability information available in the current national practices i.e., use of CTS, there are issues regarding data accessibility and privacy, hindering its storage in the permanent blockchain platform.
- Maintaining hide traceability downstream the LSC: The complexity of the downstream SC between the leather suppliers and the OEM poses a challenge and a risk of losing the upstream traceability at these later stages.
- Determining the optimal level of traceability: Throughout the project, the consortium struggled to define the optimal level of traceability to be targeted across the supply chain. This is due to the lack of standards for traceability in the leather sector and hence the lack of guidance into what level of traceability to achieve across the supply chain.
- Lack of OEM control and visibility in the downstream LSC: To enable end-to-end traceability, these SC partners need to be involved in implementing the traceability solution.
- Suppliers' unwillingness to share information: One of the abattoirs was reluctant to disclose information about their energy consumption.
- Current business processes in the tanneries are incompatible with traceability: The project revealed that hide mixing and chemical processing are inevitable during the tanning processes, increasing the complexity and difficulty of individual hides tracking.
- Hide tagging methods are cost prohibitive: The tagging method used by the involved tannery might not be used by other tanneries in the OEM leather supply network. This can affect the feasibility of the solution for the other tanneries where significant costs will be incurred to enable hide identification.
- Inability to access data from different sources: Beside the accessibility issue of CTS data, the different SC partners used different databases for product lifecycle assessment. These data sources were not open access, hindering their data accessibility and usage.

5.7.4 Analysis of the key factors influencing the scalability of blockchain solution in the leather supply chain

The pilot project investigated the issue of blockchain scalability in the LSC from a SC perspective. Several factors have been identified that are important to consider for the blockchain solution scalability in the global and complex LSC. We classify these factors into technical, organisational and supply chain factors:

a. Technical factors

- Maturity of blockchain: Despite the expertise of the blockchain provider in implementing blockchain in other supply chains, it is important to consider the evolution of the technology when aiming to scale it in the supply chain.
- Blockchain has several scalability issues affecting its throughput and performance. Most of these issues are related to large scale public blockchain networks, but permissioned private blockchain may be subject to the same risks with increasing number of participants and transactions.
- Blockchain platform configuration characteristics, e.g., its interface, integration methods, block size are all important aspects affecting its scalability. In the project, the blockchain provider has tested their platform in other complex and global supply chains ensuring it is configured in a scalable way.
- The type and amount of blockchain data set the requirements for data collection, storage and resources, which might not be attainable by the different network participants.
- Number of platform users: Depending on the purpose of the platform and the SC characteristics, the onboarding process might require investments, time and resources that could hinder the solution scalability among a large network of users. In the project, it was found that depending on the leather identification method, the number of platform users can differ e.g., when using DNA technologies at the tannery, the leather can be identified at the final stage without the need to enrol the intermediary SC partners.
- Having a solid governance model is important for solution scalability. Throughout the project, several important questions were raised regarding the rights of each partner and their roles and responsibilities.

- Blockchain solution interoperability with other information systems and blockchain platforms considering the increasing interest in implementing blockchain-enabled traceability solutions within the leather industry specifically and other industries.

b. Organisational factors

- Having or obtaining knowledge about the supply chain to enable the implementation of SC traceability system.
- Level of digitalisation in place, which is important to enable the creation of a SC digital twin. Leather Tanning is a mature process while there is an increasing automation in the leather cutting processes. The sewing and wrapping processes are labour-intensive and manual, while the final seat assembly involves various technologies and automation. All of these can potentially impact the solution scalability in the LSC.
- Product design: More than 100 leather cut parts go into a single vehicle. Hide mixing at the different SC stages is an inevitable process affecting the ability to maintain traceability and the solution scalability.
- Incentives of the different SC partners: The extent of value added by each SC member varies, and hence the value against costs for them. This might impact their engagement in the traceability solution and its scalability.
- Availability of resources and investments costs: Some parties might perceive the traceability cost to be high affecting their profit margins.

c. Supply chain related

- The SC configuration complexity affects the scalability of the traceability solution. The LSC is complex and globally dispersed ranging between 5 and 9 tiers.
- Level of SC integration: In some parts of the supply chain, suppliers are vertically integrated and in other parts, suppliers outsource some activities, increasing the complexity of the supply network and data collection requirements.
- Inconsistent business processes across the different supply chains: Some leather tanneries carry out the cutting process in-house and stamp the final cut part while others supply stamped hides to cutting facilities. These inconsistencies can affect the data capture methods, feeding into the blockchain system.

- Different product identification methods across the supply chain: In organisation A's supply network, each processing facility can have different hides' identification method, affecting the data collection methods considered for the traceability system. It might also affect the ability to create a digital SC twin for the different supply chains.
- The desired level of SC traceability affects the blockchain network configuration, the blockchain data, the investment and data requirements from the different SC partners, and the solution scalability.
- Lack of regulations to enforce required level of leather traceability, which would have facilitated the collaboration between the SC partners and encouraged the adoption of the traceability solution.
- Lack of industry standards for level of traceability and data sharing requirements in the supply chain. Development of industry standards would facilitate the design of the blockchain solution and the alignment between the SC partners.
- The nature of the SC relationships as it affects the willingness of the SC partners to participate in such endeavours.

5.7.5 Analysis of the key limitations of the developed blockchain solution

Some of the key limitations of the developed blockchain solution, include:

1. The exclusion of farms in the pilot project

The developed blockchain traceability solution relied on the local robust CTS controlled by the government to capture data about the farms instead of onboarding them. It helped in overcoming the complexity of establishing a new traceability system for cattle from birth to the abattoir. The use of existing CTS can also help in scaling the solution and implementing the solution in similar countries with similar established traceability systems. However, in most countries, these kinds of traceability systems are not established, especially in the developing countries responsible for most global leather production. Major meat suppliers usually have traceability systems and measures in place that can assure the sustainability of their products. Working with abattoirs that have established meat traceability systems can help in the development of the leather traceability solution from the farm origin.

2. The applied leather identification technique is not scalable

Initially the project aimed at using a specific leather stamper to identify the leather through the tanning processes. However due to unexpected delivery delays the team had to use manual tagging and retagging techniques using ear tags to demonstrate the ability to track leather between the different tanning processes. Despite that this process has helped in identifying the data capture point and the configuration of the blockchain platform, it is not scalable for an industrial operation and there is a need to implement another leather identification technique.

3. The blockchain solution was not scaled to the OEM plants

The developed blockchain solution was only implemented at the abattoir and the tannery. The downstream LSC was only investigated in detail to determine the requirements for traceability and for the solution scalability.

4. The blockchain solution was not integrated with the existing systems

Considering the time and size of the hide traceability trials, it was more cost-effective to manually enter the data to the blockchain system rather than using an API in the plant. However, the blockchain developer investigated and identified the possible options for manual/automatic data entry when the solution is implemented at scale.

5.8 Case Study Discussion

This case study provided in-depth empirical insights about how blockchain can be implemented in practice in a complex SC context. The case study started with an investigation to the potential opportunities for leather traceability in organisation A's LSC and the capabilities of blockchain in enabling such traceability. Four major opportunities were identified and discussed with the organisation, including ensuring leather sustainability, providing customers with improved leather options, optimising the LSC, and the opportunity to become a pioneer in the market in enabling leather traceability using the emerging blockchain technology.

Certain factors facilitated the initiation of the blockchain pilot project, including (1) the internal transformation within organisation A and the introduction of a new cross-functional SCM department that encouraged the development of SC solutions, (2) the availability of government funds to support technological development in industry, (3) organisation A has established good SC partnerships in the LSC because of its power and position, (4) there was an alignment in the motivations of the different partners undertaking the project.

By partnering with a blockchain solution provider, organisation A ensured that it has access to the necessary expertise to develop and configure the blockchain solution. The blockchain provider played an important role in designing and developing the traceability solution that captures hides data across the supply chain. Similarly, the leather tannery has strong expertise in the use of different tagging methods and was interested in studying the practicalities of leather traceability across the supply chain, which has contributed to the success of the project.

Additional factors that facilitated the project include organisation A's knowledge about the supply chain and the availability of a traceability system such as the CTS which has significantly helped in several ways including: (1) ease of engaging the different SC partners as they are already performing certain activities to enable hide traceability, and (2) the availability of the required information as it has already been collected to ensure the traceability of hides.

One of the key challenges highlighted throughout the project is related to defining the required level of traceability for leather across the supply chain. due to the lack of standards and guidance into what level to achieve. Furthermore, the project team struggled to identify and measure the value that can be derived from different levels of traceability and the related traceability costs and benefits considering the limited scope of the pilot project and that they are the first to implement blockchain in the leather supply chain.

The case study also stressed the importance of creating a digital SC twin that accurately represents the physical world. The development of the blockchain solution was not an issue. However, the main challenge was the physical identification of hides and establishing the link between the physical hide and its digital representation in the blockchain platform at the different SC stages. Important empirical insights into the key considerations for blockchain adoption and scalability in the LSC were identified and are useful for blockchain applications in the supply chain.

Chapter 6: Blockchain Adoption and Application in the Textile and Apparel Supply Chain

This chapter analyses blockchain adoption in organisation B's downstream textile supply chain (TSC). The industry characteristics were described in Section 2.2.2.3.

6.1 Case Study Specific Supply Chain Characteristics

Organisation B is a world-leading specialised fibre producer of sustainable and biodegradable fibres made from wood, including (1) the highly innovative and specialised fibres, lyocell, (2) the 2nd-generation specialised fibres, modal, and (3) the 1st-generation, viscose fibres. The company has several globally dispersed plants (Figure 27). The company sources wood from certified forests and carries out pulp production in its plants in Austria and the Czech Republic, while it sources pulp from qualified producers for the other plants. Organisation B's fibres go into three main downstream applications: (1) Textile and apparel applications; (2) Non-woven applications, including baby care and sanitary products; and (3) industrial applications e.g., packaging materials. Each application had a different downstream supply network configuration.

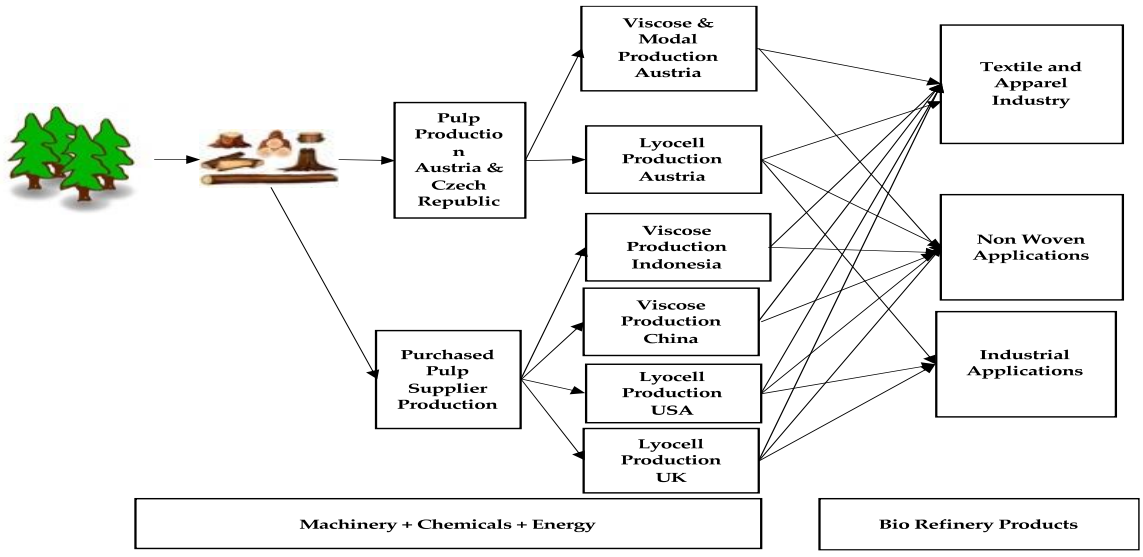


Figure 27. Organisation B supply network configuration. Data source (Organisation B Annual Report, 2020)

Lyocell and Modal are highly innovative and specialised fibres, while viscose fibres are considered a commodity. The organisation's strategy is to expand its production of innovative fibres. Most of the organisation's fibres go into textile applications and become part of the global complex multi-tier apparel industry.

The fibre production processes vary in terms of raw materials' recovery amount and number of solvents used to turn wood into pulp and then spin it into fibres. Lyocell manufacturing processes are highly innovative and specialised, presenting the main know-how for the organisation. The organisation's corporate strategy highlights sustainability. Hence, it has engaged in novel sustainability initiatives to promote circular economy through the use of recycled cotton. The organisation's branded viscose fibres are innovative and significantly more sustainable than traditional viscose, generating lower emissions and reduced water impact.

Organisation B's SC relationships differ across the different applications and can be described as:

- Long-term relationships: organisation B has long-term relationships with its upstream suppliers and direct customers across the different applications.
- Level of integration: There is high level of SC integration in the non-woven and industrial downstream SCs and a lack of integration in the TSC.
- Level of transparency and information sharing: there is good information sharing in non-woven and industrial applications. However, the TSC suffers from limited transparency and visibility, especially beyond the fabric manufacturers.
- High dependency on organisation B's fibres: due to the scarcity of specialised fibres and the capacity constraints of organisation B, there is a high dependency on its fibres by the downstream players.
- Level of power: The organisation has some power over the other SC players due to the scarcity of its fibre. However, the brands and retailers are still considered the most powerful parties as they decide on the types of fibres going into their garments.
- Level of trust: There are trust issues in the TSC. Organisation B must fight fibre counterfeiting. Brands and retailers require organisation B to verify that the end-garments contains their fibres.

Organisation B is highly influenced by government legislation regarding wood sourcing and manufacturing processes. The organisation's wood supply is compliant with the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) - two important certifications for sustainable forest management. Furthermore, it has over 30 different standards and certifications for its manufacturing processes, including

chemical and wastewater treatment. Organisation B is also influenced by other standards organisations in the textile industry including Textile Exchange for industry standards, Canopy for raw materials sustainability, and HIGG Sustainability index for TSCs' environmental impact.

In terms of market and customer demand, organisation B has developed a pioneer technology to re-use 30% of the pre-consumer waste and process it back to fibre in response to consumer demand for recycled content. The organisation also suffers from demand fluctuations in the TSC, exposing it to the bullwhip effect and affecting its ability to allocate its constrained capacity to meet the real demand. Finally, except for its blockchain solution, organisation B does not have any shared platform with its suppliers or customers but uses a centralised cloud-based ERP system internally.

6.2 Summary of the Key Challenges in Organisation B Textile Supply Chain

1. Lack of SC traceability and visibility

The organisation suffers from a severe lack of visibility in its downstream TSC, especially beyond the fabric makers. This affects the company's planning processes and capacity management.

2. Ensure fibre authenticity and fight counterfeiting

Organisation B uses novel technologies in its fibre production and seeks to protect this novelty and innovation against counterfeiting. Many SC partners claim the use of organisation B's sustainable fibres without guaranteeing the actual upstream link to their factories, exposing the TSC to greenwashing. Hence, brands and retailers require organisation B to verify their fibre in the final garments.

3. Customer education

Falling under the category of man-made fibres, organisation B's fibres are related to purely synthetic fibres such as polyester. Hence, the organisation needs to educate its customers about wood fibre production and its sustainable sourcing practices.

6.3 Mapping Organisation B's Downstream Textile Supply Chain

Figure 28 provides a high-level map showing organisation B's TSC configuration, which encompasses diverse clothing brands of different sizes. Two broad categories of apparel brands

use organisation B's fibres: First category consists of big brands with complex and large supply networks (hundreds to thousands of suppliers). This category usually uses a smaller proportion of organisation B's fibre compared to other fibres like cotton and polyester. However, such brands are keen on promoting their use of sustainable fibres. Generally, enabling traceability is more difficult in these gigantic types of supply networks. Second category includes highly sustainable and niche brands with less complex supply networks (in some cases, only a few main players). Apparel brands and retailers in this category may have a higher percentage of organisation's B fibre in their products, and it is relatively easier to implement traceability in their smaller supply chains. Organisation B has conducted several blockchain pilot projects in the two categories,, including:

1. Modal traceability pilot with Chinese TSC and Chicks.
2. Viscose traceability pilot with the Portuguese TSC for Armed Angels.
3. Lyocell traceability pilot with Korean and Indian TSCs for Mara Hoffman.
4. Lyocell traceability pilot with the Indonesian TSC for H&M.

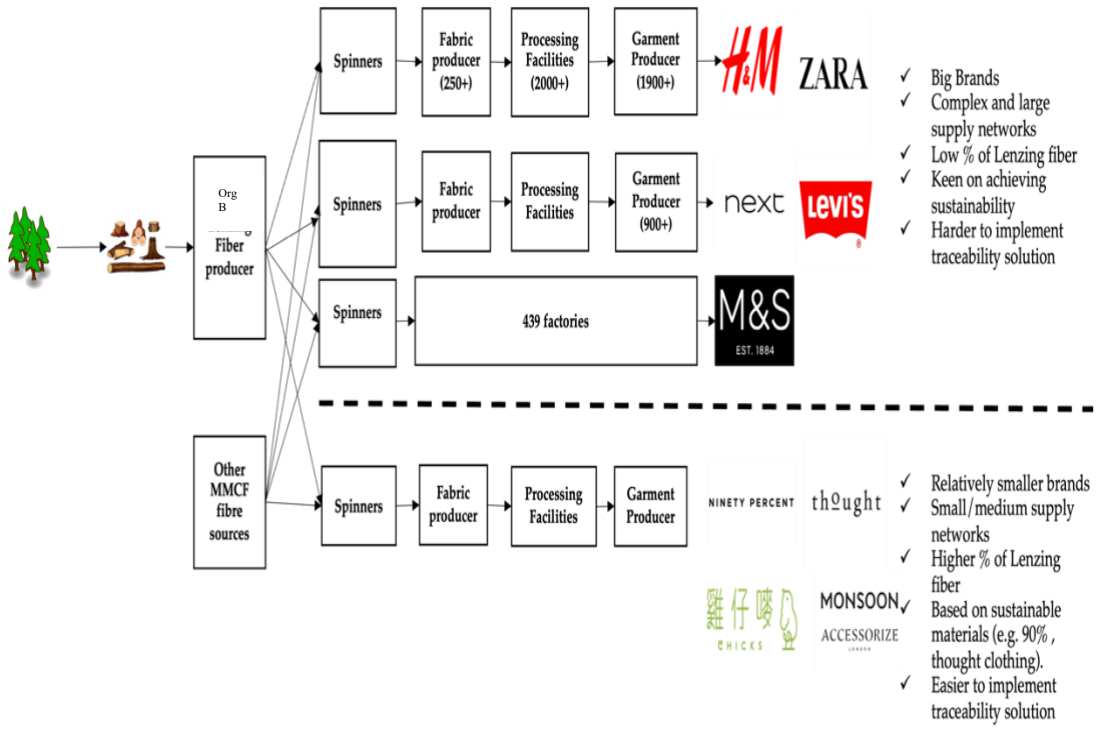


Figure 28. Categories of apparel brands of organisation B products.

6.4 Description of Organisation B's Blockchain Solution

Blockchain's capabilities to enable secure information sharing while maintaining data immutability and traceability made the technology appealing to organisation B. The company has collaborated with a blockchain solution provider that has developed a blockchain-based platform for fibre-to-retail traceability, named Solution-B (for the purpose of reporting in this thesis).

Solution-B a is cloud-based blockchain platform that uses Hyperledger Fabric and enables easy access and integration with other IT systems. It adopts the global GS1[15] standards to create fibre-to-retail traceability data standards for the textile and apparel industries. Solution-B is an easy-to-adopt solution that can track and trace any type of textile fibres. It captures fibre information from shipment transactions, invoices and purchase orders, and tracks the transported and produced fibre volume across the TSC using its patent-pending Fibercoin technology. Despite their name, Fibercoins are blockchain-based digital tokens representing the textile assets on Solution-B (e.g., Fibre, yarn, fabric, and/or garments) and are not linked to crypto-currencies. The link between the physical materials and Fibercoins is captured and validated through forensic audits for the physical textile products. Organisation B injects chemical tracers in its fibre to enable their identification. The company uses auditing companies to check its fibres at the different downstream SC stages.

The underlying principle of Solution-B is straightforward. A Fibercoin represents a fibre volume unit and allows fractional weights. Only fibre producers can create and send Fibercoins to other SC members equivalent to the physical fibre amount captured in the shipment transaction. Other SC partners can only transfer an equal or lower amount of Fibercoins than the total amount of physical fibre they possess. By tracking the flow of the limited Fibercoins through the platform, the fibre producer can know where its products are being used in the downstream TSC. Similarly, by receiving Fibercoins with finished garments, the brand or retailer can identify the origin and journey of their products.

Solution-B mirrors the physical flow of fibres in the downstream TSC and does not use mass balancing approach (i.e., an accounting principle that matches the inputs to a production process with the output to determine recycled content and is generally used by manufacturers to determine what percentage of their products is sustainable (Longo, 2021)). Solution-B captures the composition of each article/SKU and the average waste percentage at each

[15] https://www.gs1.org/standards

production stage in the TSC to calculate the amount of fibre produced, stored, and transferred across the supply chain.

One Fibrecoin represents 1 kg of fibre. For each shipment transaction that organisation B sends to a spinner, an equivalent amount of Fibercoins is created and transferred to that spinner. The platform then captures the details of yarn production at the spinner facility, including blend ratios, yarn ID, and average waste, and when the spinner sends a shipment of yarn to the fabric maker and/or garment producer, an equivalent amount of Fibercoins is calculated based on the production information and is transferred from the spinner to the yarn receiver. The platform captures this transaction and updates the Fibercoin account balances of both the spinner and the yarn receiver. The same process takes place at the other SC stages to ensure that the Fibercoin balances match the physical product amount. Solution-B captures all shipment transactions between the six main steps in the TSC (Figure 29). All Fibercoin transactions are recorded on the Solution-B platform, powered by blockchain, and are linked to the shipment transactions issued by the respective companies.

The use of Fibercoins keeps track of fibre volume throughout the TSC. No SC partner can claim the use of organisation B's sustainable fibres without their possession of equivalent Fibercoins. The platform can signal any mass transactions or discrepancies between the physical inventory and Fibercoin balances indicating the need for auditing. The platform also supports the cross-validation of transactions since, at each stage, the fibre receiver must confirm the physical quantities sent to them by the sender and its equivalent amount of Fibercoins.

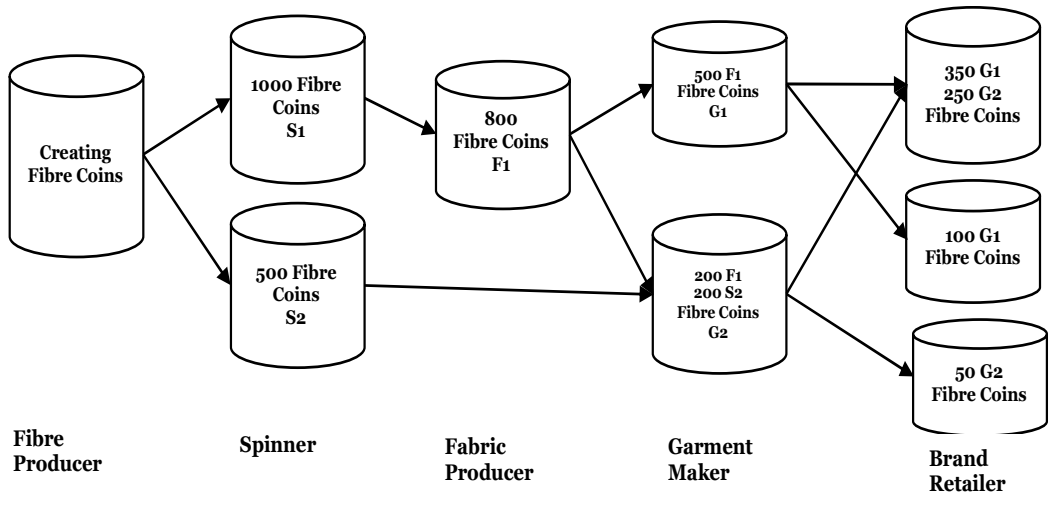


Figure 29. An illustrative example of Solution-B Fibercoins transfer across the textile supply chain

No sensitive or commercial data shared on Solution-B and a minimum amount of data is required to facilitate the targeted level of traceability which helped in engaging the different SC partners to share information. Furthermore, different access rights are given to the SC partners. Full SC visibility is granted to the brand retailers while organisation B gets to know the SC partners' location and their fibre inventory balances. Other SC partners between the fibre producer and brand or retailer are given limited visibility of the blockchain data, with access to only one step upstream and one step downstream their SC. The platform also captures and shares auditing reports and suppliers' certifications and uses smart contracts, namely Solution-B Pots, to validate the certificates, read PDF files and calculate inventory levels. Table 16 shows examples of the data shared and accessed by each SC partner in organisation B's pilot project.

Table 16. Examples of the data shared on the blockchain platform

	Input Data	**Access to Data**
Fibre Producer	▪ All outgoing transactions (shipment reference, purchase order, invoice, customer name). ▪ Fibre type ▪ Volume	▪ All SC partners' names, locations, and certifications ▪ Audits results across the supply chain ▪ Fibre coins inventory across the supply chain
Spinner	▪ Incoming and outgoing transactions (shipment reference, purchase order, invoice, customer/supplier name) ▪ Yarn ID ▪ Blend ratio ▪ Volume	▪ Incoming transactions from their suppliers ▪ Their audit information
Fabric Maker	▪ Incoming and outgoing transactions (shipment reference, purchase order, invoice, customer/supplier name) ▪ Fabric ID ▪ Blend ratio ▪ Volume and dimensions	▪ Incoming transactions from their suppliers ▪ Their audit information
Garment Maker	▪ Incoming and outgoing transactions (shipment reference, purchase order, invoice, customer/supplier name) ▪ Garment ID ▪ Blend ratio ▪ Volume and dimensions	▪ Incoming transactions from their suppliers ▪ Their audit information
Brand Retailer	▪ All incoming transactions (shipment reference, purchase order, invoice, supplier name) ▪ Garment ID ▪ Blend ratio ▪ Volume and dimensions	▪ All network members' names, locations, and certifications ▪ Audits results across the supply chain

6.5 Blockchain Application in Organisation B's Supply Chain

This section includes the company's value stream manager quotes in *italics* where relevant.

Organisation B has several motivations for blockchain adoption in its TSC, including:

- Product traceability across the TSC.
- SC visibility and mapping
- Ensure product authenticity and fight counterfeit
- Verify sustainability claims and fight greenwashing.
- Competitive advantage by being a pioneer in enabling traceability and adopting blockchain technology in the TSC.

Fibre producers and brands and retailers have more power in the TSC and the other SC partners are pressured to meet their demand. Therefore, to pilot blockchain, organsiation B has partnered with different brands and retailers.

"The power in the textile supply chain is split between the fibre producers and the brand and retailers and the split is in favour of the brand and retailers I would quote like 70-30… Everybody in the middle is squeezed so they operate back from the orders from the brand and retailers."

The first blockchain pilot was in its most sustainable fibres supply chain with a sustainable brand. The selection of the pilot SC was due to:

- The fibre brand is the most valuable and sustainable fibre in the organisation offerings, carrying the promises of the company. "*We went for the [X-for anonymisation] brand, because this is what is carrying the promise of what we do."* "*This is the highest sustainability product that we can get and exactly we wanted to pass on this confirmation to the to the consumers."*
- The retailer is a niche and high-end brand with high sustainability strategy. *"We're all looking for a partner who is very high on the list of exclusivity sustainability perceived given by the consumers."*
- The retailer has a simple supply chain. *"Brand X is a very high-end brand that has a relatively simple supply chain".*

- The selected supply chain is local to the blockchain solution provider. *"It was a very niche player in Hong Kong and also, Solution provider X is operating out of Hong Kong".*
- The brand retailer was willing to participate and meet the project deadline. "*The perfect brand image. The message to the consumer, the value chain players with less complexity but with high consumer prominence and somebody able to work fast on a tight deadline so we can be ready for the official announcement of the pilot."*

Prior to the pilot, organisation B had to educate its personnel about blockchain and the organisation's vision behind blockchain adoption.

"*Even though it's kind of a buzzword, blockchain, nobody or a very low percentage like 1% have actually some clue what it is and like 0% know how it works and how it can work for textiles. So, I mean this was a co-educational curve starting from zero*".

Getting everybody on-board was also challenging due to the lack of knowledge about blockchain and the internal reluctance to use inter-organisational systems.

"*The Beginning was like a top-down approach, so directly with the Board of Directors, Directors for Technical Support was relatively easy to bring them on board because they are seeing the big picture and the strategy behind. Then we started really pushing it down through the company into the different regions, business units, and this is what took us really like half a year until we get everybody on board. Very, very big challenge for adoption"*

However, the participant indicated that top management support was a key factor facilitating blockchain adoption.

"In our steering committee we have three out of five board members really pushing, and really willing to remove internal roadblocks, so it helps."

In the selection of blockchain, organisation B was clear about its business needs and the selection of blockchain came next as a potential technology meeting their requirements.

"The technology came as a second part because this was speeched by Solution-B provider, something specific catered for the fashion industry, something specifically starting from fibre producer and into the retailer. So exactly something that fitted us."

"*It was not like we need blockchain we need blockchain. Let's see how we can fit it".*

Organisation B was also willing to invest in the project.

"Investments, like every investment, of course, it's a challenge, but here wise I mentioned that the price tag was not that significant, or we didn't get any big problems here."

The blockchain provider designed the solution to enable fibre-to-retail traceability and identified the data sharing requirements at each SC stage. The different SC partners agreed on the proposed data.

"*It's a kind of an independent platform, it came as a part of the package because Solution-B provider has already done the due diligence and they have interviewed other value chain players… they have pretty much pre-defined the different data elements that we now see."*

The solution was easy to use, did not include any commercial or sensitive information and had minimum data requirements that encouraged its adoption.

"One of the selling points is that it's easy to use solution."

"It requires only the minimum amount of data that you can share."

Organisation B and the blockchain provider aim at developing an integrated solution where suppliers' certifications, materials flows and inventory levels are visible for both brand and retailers, and fibre producers.

"For the brands, have lesser systems to go to is a major one major selling point, and that's why we're trying to integrate as much as possible between Organisation B and Solution-B provider to offer endless solution to one system that could cater a bit more for their needs rather than vertical multiple different systems."

Organisation B uses a patented chemical tracer to identify its fibre in its downstream TSC.

"It's a chemical tracer exactly that is embedded inside of the fibres, and we are able to detect it at every step of the value chain."

In terms of the solution scalability, organisation B has been working on improving data flow with potential use of APIs, solving integration issues with existing systems, and tackling issues related to GDPR compliance.

"The technology related aspects because we get some back-and-forth issues with integration between Organisation B and Solution-B, we wanted to optimise data

exchange... However, this was not possible and still not possible due to GDPR compliance, lack of resources from Organisation B"

Nevertheless, organisation B's strategy include:

(1) Scaling the solution on its branded fibres of lyocell, modal and viscose brands but not on its commodity viscose fibre.

"This would be all of the branded offerings,..., we're not going to do it for a commodity viscose. First of all, because we don't have the physical tracer embedded inside. Second of all, because in the next 2 years we want to get out of the commodity viscose and get on sustainable viscose was that later generation power fibres."

(2) Targeting big brands with large volume of its fibres.

"The big brands definitely this is where we want to go because this is where we have economy of scale of us. More fibres are from Organisation B flowing through them."

(3) Working with smaller high-sustainable brands as they can be ambassadors and trendsetters on the adoption of new technologies and authenticating the use of sustainable fibres.

"The smaller brands. We are looking in these ambassadors like Reformation, Armed Angels which are really considered small but the later generations is looking at them like the trendsetters… these boutique brands are going heavy on more sustainable, embarking commute on new emerging technologies."

(4) Working with sustainability organisation, Canopy, to help identify those potential SC partners to adopt the blockchain solution.

"We use the Canopy ranking to help us in this. We want to reinforce the brands which are green on viscose and … we want to green up some of the guys which are not doing that great… we are offering helping hands and then the same time we will provide even a bigger competitive advantage to the guys who are already green on viscose"

(5) Besides their own downstream TSC, organisation B aims to form a blockchain consortium including other fibre producers to provide the end brand and retailers with a single solution for their entire supply network.

6.6 Case Study Analysis

6.6.1 Analysis of blockchain capabilities in addressing organisation B's supply chain challenges

1. Lack of SC traceability and visibility

Solution-B provides a robust and unified platform for all SC partners to manage their inventory, ordering, and shipment transactions. Organisation B can visualise the inventory levels and identify the fibre usage at the different downstream stages (Table 16). However, the platform partially addresses the business need for visibility and traceability since organisation B can only know the location of its fibre in the downstream TSC but not the actual material flows. Full visibility is only given to the brand and retailers under the current data structure and governance model.

Solution-B provides traceability at the firm level. It does not capture information of a particular product batch across the supply chain. This is mainly because the link between each SC partner's incoming and outgoing transactions is not established. Fibre blend ratio with other fibres is shared across the TSC to calculate the transfer of Fibercoins, but this does not indicate or guarantee which batches are being transferred.

2. Ensure fibre authenticity and fight counterfeiting

Soluton-B can indicate the content of organisation B's fibre in the final garments with the use of Fibercoins. At the end of the supply chain, brand retailers are assigned Fibercoins for every garment product that includes organisation B's fibres, thus ensuring it backward traceability. Without the possession of Fibercoins, brands and retailers cannot claim their use of organisation B's sustainable fibres. Organisation B use of chemical tracers and auditing companies ensures the validity of the blockchain data. Solution-B also integrates and authenticates all the suppliers' certifications across the supply in a single platform.

One key limitation of Solution-B is that it automatically calculates the Fibercoin inventory levels based on average expected waste percentage generated at each SC stage. Although it can be a close approximation to the actual value, variances can build up over time and result in inaccurate balances being recorded across the supply chain. This risks the solution's credibility and its data and provides potential opportunities for counterfeiting.

3. Customers' education about the organisation's sustainable fibres

Organisation B aims to educate its customers from brand and retailers and end consumers about its sustainable fibres. Solution-B enables fibre-to-retail traceability by tracking and providing information about the fibre, yarn and fabric blend ratios to the brand and retailers. End consumers can use a product barcode to access information about the SC journey of their garment pieces and about the products detailed information. However, this feature is not implemented in the blockchain pilots but is considered for the future.

6.6.2 Analysis of blockchain application area

Based on the characteristics of organisation B's fibres and downstream applications (Table 17), the TSC constitutes the majority of the organisation's products and is the most challenging. Therefore, the company started to experiment with blockchain in its TSCs to enable traceability, fight counterfeiting, and fibre authenticity. Non-woven applications are becoming an increasingly important business sector post the pandemic. Considering the SC characteristics of organisation B (e.g., relationships, configurations, and processing steps), the company could easily deploy blockchain in these supply chains to enable digitalisation, guarantee compliance to rigid regulations, and ensure the authenticity of products to fight increasing fraud in the market.

Table 17. Organisation B fibres - Applications analysis

	Textile Application	**Non-woven Applications**	**Industrial Applications**	**By-products**
1. Product Types	Viscose, Lyocell, Modal	Lyocell	Lyocell, Viscose	Vinegar, Sulphur
2. Product Characteristics	Various types of fibres with different properties Different designs and blends	Specialised fibre	Various types of fibres with different properties Different designs and blends	Bio-refinery products
3. Business Process Characteristics	Innovative and mature processes depend on the fibre Fast fashion environment	Innovative manufacturing processes	Innovative and mature processes depend on the fibre	By-products from fibre production
4. Supply Network Configuration	Multiple tiers (6 between the farm and brand retailer). Global and complex supply network.	Less number of tiers (4). Less players and controlled market.	Less number of tiers (4). Specific applications.	Less number of tiers

5. Supply Chain Relationships	Lack of integration. Limited information sharing and visibility. End retailers are more powerful. Contracts based on demand.	High integration. Long term contracts. Good relationships. High stability.	Infrequent Contractual or tender based.	Managed by a trading company
6. Demand Characteristic	High fluctuation. Difficulty in forecasting.	Stable and steady. Annual volumes divided monthly.	Based on available orders or tenders	N/A
7. Impact of Regulations	Highly impacted by government regulations and NGOs managing textile standards	Highly impacted by medical regulations	Depend on the application	Regulations related to waste management and use of chemicals
8. Key Challenges	Traceability and visibility Transparency Information Sharing Capacity constraints Demand Fluctuations	Capacity constraints	Securing business	Waste management
9. **Opportunities for Blockchain**	High	Low	Low	Low

6.6.3 Analysis of blockchain data

Three different types of information are shared on Solution-B (Table 16):

- Transaction information, e.g., shipment reference, purchase order, and invoices, which is added to the system either manually or through APIs for each transaction.
- Product information, e.g., product ID, volume, and blend ratios, which is used to calculate the equivalent amount of Fibercoins transacted or kept as an inventory.
- Organisations' certifications, e.g., audit reports and sustainability certifications. These certifications are added to each organisation's profile.

We analyse Solution-B data design and validity:

1. Blockchain solution data structure model

Solution-B provider pre-defined the solution's data structure model in compliance to GS1 global standards and the SC partners had to agree to it. The data model is role-based and requires the minimum possible data that enables fibre traceability at the organisation level. Organisation B requested the same level of visibility given to the brands and retailers, but the downstream players perceived it as a commercially sensitive information to be shared with fibre producers. The use of existing standards and the minimum data requirements are part of the solution design plan to encourage adoption and support scalability.

2. Blockchain solution data validity

The blockchain platform calculates Fibercoins inventory at each SC stage, triggering mass transactions for auditing and authenticating suppliers' certifications against fraud.

Solution-B is innovative in the use of Fibercoins, but it has two major shortcomings: First, there is no link between the digital Fibercoins and physical fibres. Organisation B identifies its fibres using chemical tracers. These tracers are only checked during the auditing processes. Fibre audits are conducted as part of the fibre verification process whenever the system triggers a mass transaction or upon requests from the brands and retailers. Audits reflect what is happening at the time of the audit but otherwise, there is no guarantee for data validity. Second, the blockchain solution relies on automated calculation of inventory balances. Waste is calculated based on a pre-defined average percentage and only the shipping transactions are captured in the platform. The amount of waste should be based on actual figures to ensure the accuracy of inventory balances across the SC and to eliminate the misuse of organisation B's fibres in any unauthorised manner.

6.6.4 Analysis of potential pathways for organisation B regarding blockchain adoption in its textile supply chain

Three main considerations were identified for organisation B regarding blockchain adoption in its TSC:

1. Have a clear blockchain governance model

There is no clear governance model for the traceability solution. In the current configuration, the blockchain provider is the one governing the blockchain solution and responsible for its uptime. Network members have to agree on the pre-defined data and access rights of the solution defined by the blockchain provider. The blockchain provider and fibre producers lease with the auditing company to verify the fibre content at the different SC stages when needed. Organisation B verifies its own fibre in final garments, but it aims to hire an independent laboratory to carry these verifications independently in the future. Finally, the organisation's work with Canopy will help in the development and sustainability of the developed solution and its governance model.

Having a clear governance model is crucial for solution scalability and for incentivising other participants to be part of the network. It is important to have a clear understanding of the roles and responsibilities of each network member, how the decisions are made, and

disputes are resolved, what rights each member has or should have, and what risks they need to consider. Considering the structure of the apparel industry, brand retailers are used to having the ultimate power over the supply network and would likely want to continue to exert control over the network. Blockchain adoption provides opportunities for every participant in the supply chain, from large organisations to SMEs, to have access to valuable information to improve their operations. Every participant has to address their requirements from the network and identify the value derived from their participation. Therefore, there must be a robust governance model to operate a blockchain-enabled supply chain.

2. Consider expanding the scope of traceability

The case study also highlights vital considerations regarding the level of SC traceability that organisations should aim for. In the TSC, higher levels of granularity will indicate traceability at the batch or garment unit levels. Enabling traceability at these levels would provide high assurance for the authenticity and sustainability of each garment piece and an access to detailed product information that can potentially improve the demand fulfilment process. However, it requires more resources and higher traceability costs. Therefore, it is important to consider the amount of value derived from different levels of traceability.

The level of SC traceability achieved by organisation B's blockchain solution meets its current needs. It ensures the authenticity of products, identifies their provenance and tracks their use in the downstream supply chain. However, there are opportunities to expand the traceability solution both horizontally across the TSC and vertically in terms of level of granularity.

Solution-B starts from the fibre producers and extends downstream to the brand retailer but does not include the upstream suppliers. Organisation B relies on the FSC and PEFC certifications of its suppliers to ensure wood sustainability in Europe. The certification process itself is costly and requires substantial resources (Murray *et al.*, 2019). Organisation B could consider extending its blockchain-enabled traceability system to the upstream origin of wood from forests. Besides wood traceability, blockchain can potentially transform the forestry industry by improving transparency and streamlining the documentation processes across the entire supply network (Murray *et al.*, 2019). It provides a secure way of capturing all the information related to upstream woodcutting, logging, and transportation, which can be used to certify its origin and prohibit illegal practices (Figorilli *et al.*, 2018).

Similarly, organisation B could trace its fibre at a higher granular level, e.g., the garment piece level. This level of traceability has been achieved in the blockchain pilot of Provenance that tracked a Martine Jarlgaard jumper across its UK-based supply chain (FIA, 2020). However, it would be very challenging to implement such a solution at scale considering the global, complex, and high-volume apparel supply networks.

3. Product identification technologies

Currently, organisation B uses embedding tracers in the fibre that can be checked in the auditing process at any SC stage. Additional techniques might be needed to enable traceability at a deeper level of granularity. Similarly, to enable upstream traceability, there is a need to identify fibre sources, including trees, logs, and pulps. Figorilli et al. (2018) developed a blockchain prototype for wood traceability across the SC using RFID, barcodes, and near-field communication (NFC) chips. The Chainwood project has also experimented with blockchain and IoT to trace pine, eucalyptus, poplar, and chestnut trees through production processes (Propopulus, 2020). Although these projects are in their embryonic stages, they show promise that technologies will be available that can support the traceability of raw materials for fibre production from forestry sources in the future. Figure 30 presents potential product identification techniques to be used at each cellulosic fibre SC stage to further enhance and extend product traceability across the entire tree-to-garment supply chain.

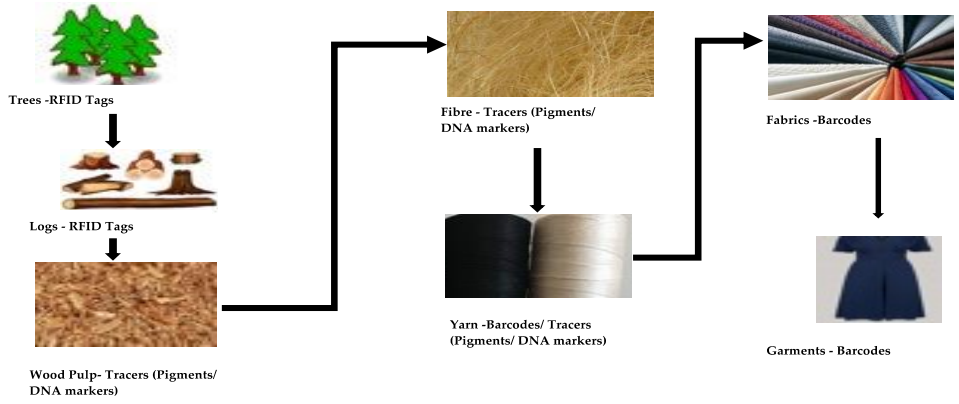


Figure 30. Examples of product identification technologies from tree to garment.

6.7 Case Study Discussion

This chapter has analysed blockchain application in an important sector where SC transparency, traceability, and sustainability are of great importance. Several blockchain applications are evident in the TSCs (Section 2.2.2.3). Two main motivations were identified - ensuring product authenticity and/or sustainability.

In this case study, organisation B adopted blockchain to enable fibre traceability in its downstream TSC to ensure its authenticity. The adopted blockchain platform enables the identification of the fibre source (i.e., the fibre producer) and the different processing stages it goes through until the final point of sale. The use of embedded tracers can identify organisation B's fibres in the end garment. However, it does not support SC traceability at a more granular level such as the batch level or the garment unit level. In its current configuration, the blockchain solution helps organisation B to improve its SC visibility and ensure the authenticity of their sustainable fibres in the final garments

This case study has provided important organisational considerations that facilitated blockchain adoption in organisation B's TSC, including clarity of business needs, top management support, internal organisation systems integration, and the organisation willingness to invest.

Several characteristics of Solution-B have made it successful not only in conducting several pilots within organisation B supply network but also with other fibre producers' SCs. First, the use of GS1 global standards provides a common language across the dispersed global network. Second, having minimum data requirements and the elimination of any sensitive or commercial data encourages the platform adoption. Finally, having a simple system design that is easy to use and can be integrated with other systems through APIs indicating less need for resources and investments.

Solution-B underlying blockchain technology supports secure information sharing between the dispersed SC partners and the provision of a single source of data, where participants can access, share, and validate their SC data and sustainability practices and certifications. Sharing sustainability-related information and certifications enables organisation B to ensure that their fibres are used in a sustainable manner. This is also important for brands and retailers who can identify, through the platform, all their upstream suppliers' credentials. The use of a third-party auditing company to validate the fibre content and captured SC data is crucial to ensure data

validity and to verify the link between the physical and digital worlds. We argue that external audits will constitute an important part of future approaches and standards that aim at enabling SC traceability using blockchain.

Forming a blockchain consortium is becoming an increasingly popular strategy for blockchain adoption in the supply chain. Organisation B aims at providing the end-brand and retailers with a single solution for all its upstream supply chains. Therefore, it plans to collaborate with other fibre producers to form a blockchain consortium that has a unified goal of promoting sustainable fibres. Both big brands and smaller niche brands are targeted players in this consortium due to the large volume big brands acquire, and the strong sustainability position of the smaller niche brands and the ease of adoption in their less complex and smaller SCs. Furthermore, the increasing engagement of standards organisation and non-government organisations (NGO) in different blockchain projects in the textile industry, e.g., Textile Exchange (Remington, 2019) and Canopy (this case study), indicates their important and supportive role in encouraging blockchain adoption in the broader textile and apparel industry

Chapter 7: Blockchain Adoption and Application in the Shipping and Maritime Logistics Supply Chain

This chapter analyses blockchain application in the shipping and maritime logistics supply chain. The shipping industry characteristics were described in Section 2.2.2.4.

7.1 Case Study Specific Supply Chain Characteristics

Organisation C is a leading shipping company with a global outreach in 130 countries. The company is vertically integrated and provides end-to-end logistics services, including ocean, rail and inland transport, customs brokerage, insurance and third- and fourth-party logistics.

Organisation C's shipping processes include multiple parties expanding through different countries and continents. They are manual and labour-intensive processes with enormous document handling and exchange, making them lengthy and costly processes. The shipping process and the number of parties involved vary depending on several factors, including the agreed terms and contracts, used services, customs and trade rules between the country of origin and destination, customer size and nature of cargo.

The SC relationships in organisation C's industry can be described as follows:

- Lack of trust in the industry as it has been subject to cyber-attacks and fraud especially in customs.
- Lack of collaboration and limited information sharing between the different parties in the shipping ecosystem.
- High competition in the industry since most customers use multiple carriers. This is even more for organisation C since it is vertically integrated, which increased its competition with other shipping partners besides ocean carriers, e.g., inland transport and logistics services.

Organisation C's operations are influenced by changes in regulations such as Brexit trade regulations and the International Maritime Organisation (IMO) 2020 that aims at reducing sulphur oxide emissions by cutting its content in the fuel oil (IMO, 2020).

Organisation C's customers demand visibility during cargo transport as delays can significantly affect their shipping costs. The organisation has developed several digital products for its customers, including third- and fourth- party logistics platforms for different customers'

segments. However, these systems provide limited visibility by connecting to INTTRA, one of the largest ocean shipping booking platform, that provides visibility to only 6 -8 standard industry milestones (INTTRA, 2021).

Organisation C has partnered with a blockchain provider to develop a blockchain-based platform, named Solution-C (for the purpose of reporting in this thesis) , that provides end-to-end visibility across the shipping processes and is currently open to the whole industry market. We analyse Solution-C in this chapter.

7.2 Summary of the Key Challenges in Organisation C's Supply Chain

1. Manual and labour-intensive processes leading to increased costs and inefficiencies. For example, organisation C has 90 people across the globe to manage one account, exchanging, printing, and scanning a large number of documents.

2. Data trapped in organisational silos. Within organisation C, many systems are used in isolation and data use is limited to specific applications. Generally, the shipping industry has a fragmented landscape of digital solutions used in silos and are not integrated for better transparency and visibility.

3. Lack of visibility on the end-to-end shipping processes, leading to poor planning and extra costs. This is especially for the other logistics services beyond the ocean carrier i.e., customs clearance, letters of credit issuance, and inland transport.

7.3 Mapping of the Shipping Processes

The international shipping and maritime logistics industry is the glue that connects the different actors across global supply networks (Ahmed and Rios, 2022). Maritime shipping is the main mode of transport for around 90% of the goods traded globally (OECD Ocean, 2021). To appreciate the complexity of shipping processes and the number of parties involved, we map and describe a general shipment scenario in Figure 31.

At a very high level, the shipping process starts with a booking confirmation from the ocean carrier based on the submitted booking request and shipping instructions. This process can be initiated by the exporter, importer, or a third-party logistics partner (3PL). Upon the receipt of empty containers, the cargo can be stocked at the ports or exporter's facilities. Once the containers are filled, the customs clearance processes start and are typically managed by the customs broker. Depending on the cargo and terms of contract, several certificates can be

requested, and cargo can be inspected. The customs processes also vary across countries. Once released from customs, the containers are then loaded onto the vessel. After the vessel's departure, the ocean carrier creates the original bill of lading (BOL). BOL is a legal contract that includes the cargo information and the agreed-upon terms and conditions between all the parties involved in the cargo transport (Irannezhad and Faroqi, 2021). BOL is the most important shipping document that acts as proof and title of ownership throughout the shipping processes, providing evidence that the shipper released the consignee's goods to the carrier for transport and enables the consignee to receive the cargo at the point of arrival. It also acts as official evidence of cargo information that can be referred to in the case of disputes and is important for the payment cycle between the sellers, buyers and their banks (Irannezhad and Faroqi, 2021). In cases when there is limited trust, BOL might be handled by a bank, which issues a letter of credit and ensures that payment is settled before enabling the importer to release the cargo (Tsiulin *et al.*, 2020).

Documentation is a key part of maritime transport (Papathanasiou *et al.*, 2020). On average 30 documents are exchanged to process one shipment (CargoSmart, 2018). Besides the significant number of steps and parties involved in the shipping process, these processes are mostly manual, requiring a tremendous amount of paperwork, and significant time goes into documents creation and exchange (Yang, 2019).

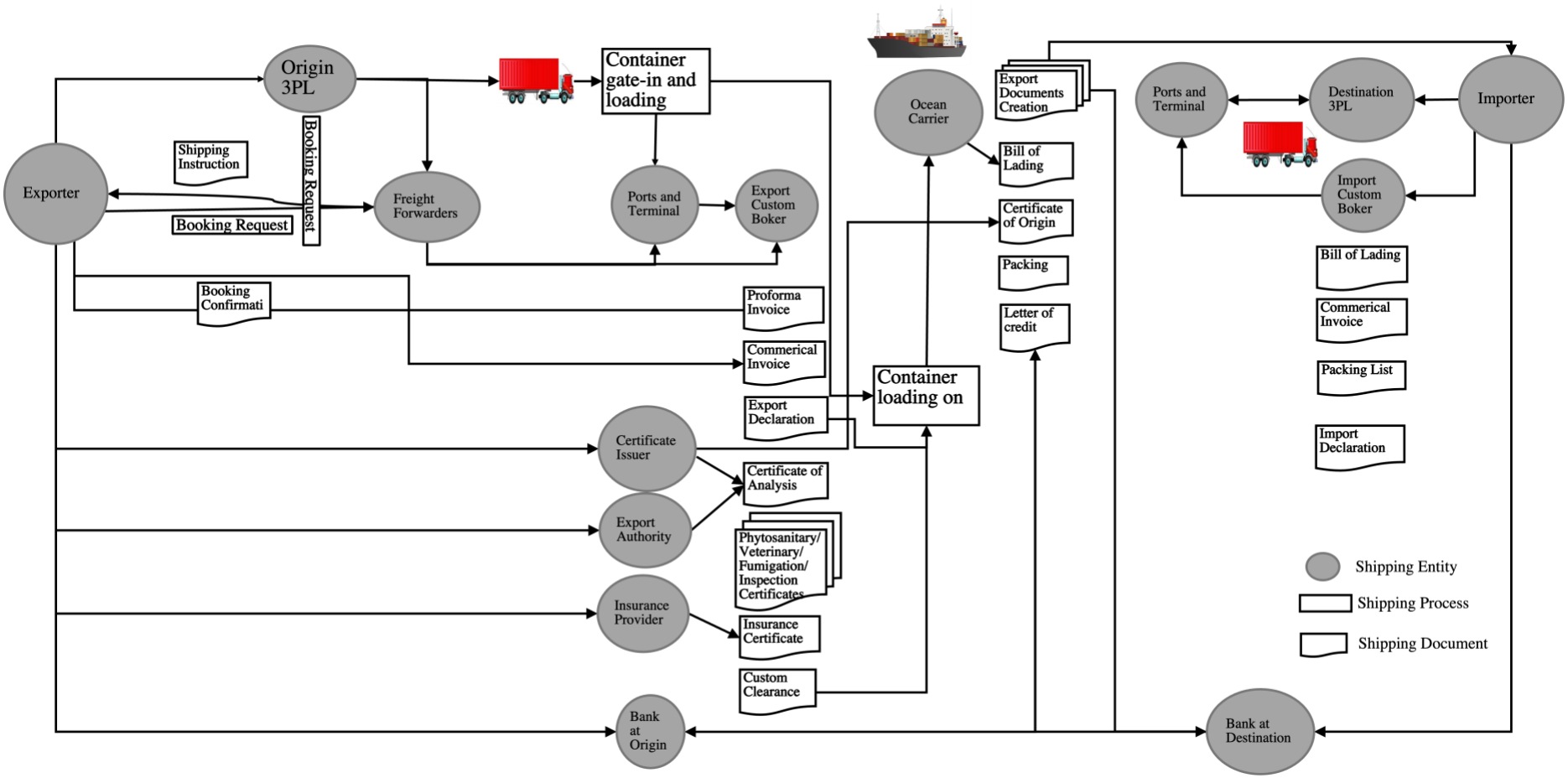


Figure 31. Overview of the shipping processes

7.4 Description of Organisation C Blockchain Solution

Solution-C is one of the largest blockchain-enabled digital platforms in the market that provides end-to-end visibility across all shipping processes. Starting with the booking confirmation, Solution-C enables every party in the shipment including shippers, freight forwarders, ocean carriers, customs authorities, ports and terminals and financial services to obtain visibility and track shipments events and documents at every stage of the shipping process based on their role in the shipment.

Transparency is at the core of Solution-C, and as an industry-wide solution, the company has published sufficient information to understand its architecture, integration process, and data permission model[16]. Solution-C has three layers: (1) the Ecosystem, which resembles the network members who provide, share and access data through Solution-C, (2) the Platform which is the medium where all these data is shared and accessed, and (3) the Marketplace which is an open platform that enables Solution-C and other parties to launch specific and customised applications on top of Solution-C.

In terms of governance, Solution-C has designed a detailed permissioned model that provides different access rights to relevant parties based on their role in the shipment. For standardisation and interoperability, Solution-C adopts the supply chain reference data model from the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT), which aims to develop standards for data requirements of all international supply and transport processes (Wessel and Heemskerk, 2017). The use of blockchain comes into play for ensuring the security, immutability and traceability of trade documents exchange.

Solution-C provides a rich data environment for all parties to utilise for continuous improvement. More than 130 shipping events can be captured on Solution-C including shipment, consignment, transport equipment, transport plan and other generic events (Soluton-C Documentation). We categorise Solution-C' events data into 5 categories: (1) estimated, planned and actual events for container filling, stripping and movement, (2) Customs inspection and release events, (3) Bill of lading creation and submission, (4) Cargo weight capturing, and (5) Transport equipment environment conditions.

Three different packages are provided for Solution-C' customers (Figure 32): (1) Essential package provides visibility to all shipping events and cargo movements, (2) Visibility package

[16] to maintain the anonymisation even used public sources are anonymised

includes essential visibility plus more analytical insights and functionality such as alerts and dashboards, and (3) Collaboration package includes all of the visibility plus document sharing capability. Solution-C users get to store the data in their own systems if they are connected with electronic direct interface (EDI) or APIs. The shipping events data remains in the Solution-C server for 180 days.

Features	Core Essential	Core Visibility	Core Collaboration
Transport Insight	✓	✓	✓
Continuous Data Improvement	✓	✓	✓
API Integration	✓	✓	✓
Shipment Manager		✓	✓
Notifications		✓	✓
Dashboards		✓	✓
Partner Access			✓
Document Sharing			✓

Figure 32. Solution-C Subscription Packages. Source: (Solution-C Pricing Document)

We briefly describe some of the key Solution-C use cases below:

1) **API Integration:** Solution-C uses open APIs to connect with its users, eliminating the need for additional hardware investments, IT resources and costs. Solution-C data can automatically feed into existing systems enabling users to have near real-time data access about their shipment. Access to the platform is controlled through federation authentication and data sharing is secured by a blockchain-based permission model (Solution-C Use Case Documentation).

2) **Customer Service:** The availability of all shipment data on a single platform in near-real time, saves an enormous amount of employees' time usually spent on manual shipments tracking. This time along with real-time data accessibility can enable better and timely customer service. Having access to estimated, planned, and actual shipping events can also improve shipping planning and logistics processes by proactively respond to changes in shipment schedules. This is especially important for freight forwarders and logistic service providers (LSP) competing in providing services (Solution-C Use Case Documentation).

3) **Customs Declaration:** Solution-C enables all participants to share shipment documents securely with the use of blockchain. Customs brokers can get access to the required shipment document as soon as they become available, which saves time and effort to assemble

all required documentation for customs declaration. Getting all the documents from a single source and tracking documents' updates reduces the potential errors frequently encountered in traditional lengthy and manual customs processes (Solution-C Use Case Documentation).

4) **Processing of letter of credit:** Issuing and processing of letters of credit are key bottlenecks in the shipping processes. These processes are time-consuming, expensive and demand high security. Solution-C provides a secure platform for information and document sharing by connecting directly to its customers' systems. By using Solution-C, authorised participants can access required documentation directly from its source, which expedites the letter of credit (LoC) processes, minimises errors and leads to better customers services. It can also prevent delays that result in additional costs of demurrage and detention (Solution-C Use Case Documentation).

5) **Verify bill of lading:** Solution-C can enable the instant verification of customers through the platform. The use of blockchain ensures documents' authenticity and traceability. Authorities can access all required documentation to verify customers and the originality of documents. In the case of financing requests, banks can instantly verify the bill of lading by directly connecting to Solution-C and accessing the latest published bill of lading to ensure its authenticity (Solution-C Use Case Documentation).

We present a summary of four case studies shared during the case study of organisations using the collaborative package of Solution-C and the measured benefits realised by each organisation in Table 18.

Table 18. Solution-C case studies. Source: (Internal Documents)

Case Study	Top Challenges	Application Area	Measured Benefits
1.Mid-size U.S importer of agricultural commodities from global markets	▪ Incomplete and unreliable visibility to empty containers availability ▪ Lack of visibility during transhipments and risks of cargo loss ▪ Time-consuming and costly paper-based bill of lading process that takes 4-5 days for documents handling and couriering and costs $30 in fees each time	Solution-C was deployed across 25% of container volume	▪ Real-time information on containers availability and dashboards and notifications alert the importer if any exceptions need action ▪ Use of electronic bill of lading saved the importer 4-5 days of processing time and $120,000 by avoiding courier fees
2. Large size European freight forwarder that ships over 30,000 containers monthly	▪ Employees spent most of their time fetching information from websites ▪ Inaccurate and inconsistent information that leads to poor customer service ▪ Poor visibility that leads to incorrect customer invoicing and incurring extra charges	60 internal employees accessed Solution-C	▪ Better customer service by being proactive in providing updates, reducing customer information request calls by 1.5 times ▪ No missed communications with customers ▪ Better visibility enabled faster and accurate issuing of invoices saving 2 days on average ▪ Use of electronic bill of lading for customers' invoicing and payment enabled faster payments
3. International coffee importer	▪ Supply chain delays forcing the importer to add extra 14 days to transit times ▪ Lack of visibility on container status ▪ Long time is spent on scraping carriers' website with no information on inland transport. ▪ Use of paper-based bills of lading is slow and was disrupted due to covid	Solution-C was deployed and accessed by carriers, truckers, terminals and exporters for 700 Brazilian containers	▪ Gained visibility into inland transport (24,000 events per year) ▪ Provided visibility improved communication and helped mitigating risks ▪ The importer moved from paper-based bill of lading to digital seaway bills saving processing time and courier fees for 50 shipment per month
4. Mid-size European distributor	▪ Almost 8 hours a week are spent on checking carrier websites ▪ Lack of visibility resulted in high demurrage and detention costs ($300,000 a year) ▪ Manual work results in error	Solution-C was accessed using open APIs and carrier data fed directly into the company's SharePoint	▪ D&D costs dropped to zero ▪ Getting data from the source using APIs eliminated manual errors and saved over 100 hours of administrative hours ▪ Better visibility led to better planning and scheduling as their viewing window extended from 1 or 2 weeks to 4 weeks

7.5 Blockchain Solution Adoption in Organisation C Industry

This section includes organisation C's solution expert and regional manager quotes in *italics* where relevant.

We summarise the main motivations of organisation C behind Solution-C development as:

- Desire to be a pioneer and leader in digital transformation.
- Opportunity to create a new revenue stream for the organisation.
- Reduce costs and risks and improve customer satisfaction level through improved visibility and efficiency, secured document sharing, and reduced costs.

Organisation C's shipping platform aimed at benefiting all participants in the shipping ecosystem. Customers are encouraged to use Solution-C to gain visibility over their shipping processes and enhance document sharing.

"Lack of visibility is the first stream that customers are looking for to solve and then they're looking at the document sharing."

The use of blockchain helped in addressing the security concerns by the shipping ecosystem.

"*This industry is very much interested in improving the IT security because we've been targeted, and we had several cyber-attacks."*

The platform supports secure document sharing using blockchain, capturing the interest of many parties including customs authorities.

"Customs have a big pain point which is fraud. So that is one of the drivers for them that is ... how do we protect and provide a portrait of the documentation? That's exactly what customs is interested in. That's the part of the concept that they really like about Solution-C and about blockchain."

Solution-C can result in 30% increase in productivity on average depending on the application.

"We calculate roughly around 30% in terms of increase of productivity. It will depend on the company, on how many documents they need to handle in shipments, but that is a rough calculation."

Solution-C also allows for better utilisation of resources by focusing on more value-adding activities such as increasing customer satisfaction and improving their experience.

"If I take all these transactional tasks from my people…, Where can I locate resources? Maybe more customer centric, a customer facing, commercial, something that requires people skills."

Solution-C' vision is to be an industry-wide shipping platform that provides end-to-end visibility on the shipping processes. This vision aligns with organisation C's strategy to be vertically integrated and have its different business units under one umbrella.

"It fits with our new strategy of becoming this global integrated of container logistics".

Organisation C clearly understood Solution-C' value proposition by providing an additional value not available in the market and using its data to reduce costs and generate profit.

"*The value proposition of Solution-C would be basically on two streams if we compared them to the rest of the products. One, how do we increase the winning ratio over the market competition? And second, how do we use in organisation C the cost to serve?"*

Several organisational factors have contributed to organisation C leading such an innovative and transformative endeavour. On top of these factors are top management support, internal organisation culture that supports innovation and digitalisation, willingness to invest, and flexible organisational structure.

"Top management support so organisation C is a company with a culture that is very innovative on its own."

"It required, somebody like organisation C to put this huge initial investment."

"We're used to have every two to three years a transformation, a big transformation in organisation restructuring."

Organisation C also perceived itself to have the power and the position in the market to lead such a transformation.

"We have the sort of the power to make it happen in terms of the network."

However, considering the highly competitive shipping market, having one organisation leading such an industry-wide transformation brought up many challenges. Hence, organisation C had to change Solution-C model from a joint venture to a collaborative model that gives other carriers similar rights to those of organisation C.

"We were a joint venture and then these conflicts sort of started we changed the model to a collaboration model."

Furthermore, the nature of the relationships in the shipping ecosystem presented another challenge in Solution-C development and adoption as the different parties can be competing in one supply chain while collaborating on the other one.

"*We are competitors as well, we could be collaborating in this supply chain, but in the other supply chain for another customer where the enemy and we are competitors.*"

There is also lack of information sharing and collaboration in the shipping industry.

"We don't have a very collaborative way of doing things in this industry."

There is also lack of standards for data sharing and different organisations can be using the same terminologies but mean entirely different things.

"They were not rules set to operate in a digital landscape in this industry, and that's another big challenge... We don't have a standard way of interpreting data, sharing data, collecting data we don't have standards on why do I want to share."

In addition to the challenging industry relationships, there is a lack of knowledge about blockchain in the shipping industry. Customers are either influenced by the hype around blockchain without fully understanding its technical aspects or are acknowledging the security of Solution-C because of blockchain.

"In this industry, there is not much knowledge around blockchain."

"So for some customers it's really like you give me more security… and for customers are that they feel that they are super ahead of the news and the market. They say yes, I know blockchain is the future but is still without understanding really what is the potential."

Despite all challenges, organisation C acknowledged the importance of including other shipping parties to ensure the integrity of the solution and maximise its value.

"The more network members that you have, the higher the integrity, the higher the value for everyone."

This is also driven by customers' requirements for a multi-carrier solution.

"Customers would not really want this solution only from one ocean carrier... They would like to have a multi carrier solution."

The concept of Solution-C is standard and flexible and can support different modes of transport as long as the transport object (i.e., containers, truck, etc.) can be uniquely identified.

"In theory without any ocean booking and ocean move, Solution-C could also provide visibility because the whole cost standard is a container but in theory is really a transport object."

Solution-C development was not easy. The organisation faced many challenges in its development and in bringing the necessary parties onboard to operationalise it. There was also an internal resistance to Solution-C, considering the variety of digital solutions already developed by the organisation. The main concerns were related to fear of jeopardising the value propositions of existing systems. There were also cultural differences between the two founders of Solution-C, in terms of investments, entrepreneurial spirit, and risks taking, limiting the development of Solution-C features.

Furthermore, despite that the Solution-C concept was standard, there were significant customisation requirements by the different customers that increased the length of Solution-C sale cycle and slowed down the adoption rate.

"It really is not a fast sales cycle, it is really long sales cycle because you need to understand all your customers set up and how do you put together a solution that will really help them in the best possible way."

Organisation C knew that Solution-C wide-scale adoption will take a long time as it is driving changes to existing business models. At first, organisation C started to integrate Solution-C with its internal systems to ensure data flow from these systems to Solution-C. Next, the organisation targeted ocean carriers and ports and terminals to join its platform.

"So that product introduction phase we knew that it was going to take long because it is a whole journey. But we decided to start with the low hanging fruits like ports and terminals and the carriers."

By engaging its vertically integrated business units, the organisation was able to demonstrate Solution-C value and encourage other shipping partners to join.

"We've been extremely successful in terms of integration, because we do have power over those decisions, at least within the organisation C Terminals Group…. so that is moving quite nicely."

Solution-C scalability strategy also aims at onboarding customs authorities and banks. However, considering the nature of these entities, the level of adoption varies across the different countries.

"Customs is like similar to banks. This reflects the culture of each country. Some customs authorities have approached us saying I'm interested in what you're doing... But then you have many other customs that we have approached because customers are interested in those locations and it is taking a few years for them to understand the concept, realise how this could fit their own ambitions and then to move to a face of integration and with many others is still part of the discussion."

7.6 Case Study Analysis

7.6.1 Analysis of blockchain capabilities in addressing organisation C's challenges

To gain further insights into the capabilities of the developed solution, we use SWOT analysis tool to analyse Solution-C capabilities as an industry solution, and as a solution within organisation C group. Considering that Solution-C is operational, the use of SWOT analysis provides additional insights about the opportunities and threats from the deployment of an industry-wide solution from the perspective of the organisation and the industry ecosystem. We discuss the SWOT analysis elements for each perspective next.

a) Solution-C as an industry solution

Figure 33 presents a SWOT analysis for Solution-C considering its internal strengths and weaknesses as a digital solution and the external opportunities and threats it faces from the shipping ecosystem and market.

1. Solution-C Strengths

Solution-C aims to connect the shipping ecosystem, presenting a powerful digital solution that could potentially transform the industry. The emergence of such platforms will play a significant role in bridging the gaps in the industry, reducing inefficiencies, enabling shipping data standardisation and fostering collaboration. Solution-C provides access to a rich data environment by capturing more than 130 shipping events, enabling unprecedented levels of visibility that goes beyond the ocean carriers. Flexibility and ease of integration are key strengths of Solution-C. The use of open APIs enables quick and near real-time integration with existing systems without additional investments. The platform can incorporate different modes of transport (e.g., rail), and different types of organisations regardless of their size, location, and existing systems. The use of blockchain for secure trade document exchange and traceability ensures the reliability and security of Solution-C.

2. Solution-C Weaknesses

Solution-C success relies on its adoption by as many participants in the shipping ecosystem as possible to provide rich data and end-to-end visibility. Participants incur costs to use Solution-C, which influence the solution adoption by the mass ecosystem participants.

Solution-C has no control over the data accuracy and validity at the beginning of the process (e.g., shipping events). The platform mirrors what the different participants have in their systems and is, therefore, subject to the GIGO principle. However, the platform has a

sophisticated permission model that controls who shares what information and with whom, holding each participant accountable for the data they provide. It also operates with a continuous data improvement focus, where data performance is constantly monitored, and actions are taken with each network member as the primary source to improve data accuracy, timeliness, and business logic.

Solution-C key technical weaknesses include the immaturity of the underlying blockchain technology used for shipping document tracking and management. Although it holds great promise for improving shipping processes (Lambrou *et al.*, 2019), it can still be a weakness to use a continuously evolving technology like blockchain, as the underlying technology for an industry-wide solution. Another technical challenge is the integration of Solution-C with legacy systems, which may not necessarily work with open APIs. Finally, Solution-C is maintained and developed by a single IT company, which subjects Solution-C to have a single point of failure.

Solution-C development started in January 2018, and the solution has been evolving since then, incorporating feedback and lessons learned. Solution-C governance model changed from a joint venture to a collaboration model including other giant players as part of the "Solution-C Collaboration Board". Further changes in the governance model can take place with the development of Solution-C (e.g., launch of Solution-C marketplace). Changes in governance models need to be managed carefully and effectively (WEF, 2020) to avoid serious drawbacks.

3. Solution-C Opportunities

Solution-C has the potentials to become an industry-wide digital solution, especially by having most major ocean carriers part of it (i.e., Maersk, MSC, and CMA-CGM, Hapag Lloyd and ONE). Solution-C can enable the creation of a shipping industry-wide digital repository, connecting all participants in the global shipping ecosystem in a single platform. Having a shared digital Global Trade Identity has been recommended by the World Economic Forum as a key facilitator for logistics processes digitalisation (Jensen, 2020). It reduces costs and resources required for identifying, verifying and managing multiple digital identities.

Solution-C marketplace provides a platform where innovative solutions are available to the whole shipping network. The availability of such platforms encourages the development of innovative solutions, benefiting the industry as a whole. Solution-C promotes the digitalisation and automation of shipping processes, potentially transforming the whole shipping industry, and resulting in higher performance and efficiencies.

4. Solution-C Threats

Solution-C is subject to several threats including the availability or future development of competing solutions affecting the mass adoption of Solution-C. Furthermore, it faces the risks of technological developments that can make it obsolete and of exposure to cyber security risks. These risks also hold for the use of emerging blockchain technology.

Other risks include conflicts and disputes between Solution-C board members that might affect the success and sustainability of the solution. There must be a clear conflict and dispute management process agreed upon by all board members to sustain the solution. Finally, for Solution-C to be a global industry solution, it will have to fit in with the complex regulatory frameworks of the different countries. Lack of supportive regulations and standards can inhibit or delay the digitalisation of shipping and logistics processes.

b) Solution-C as an organisation C solution

Figure 34 presents a SWOT analysis for Solution-C as an organisation C's solution.

1. Solution-C Strengths

Organisation C's strategy is to be the global integrator for container logistics in the industry. The company has undertaken several mergers to realise its strategy. Solution-C supports the organisation strategy by enabling the integration of its different business units and services. The majority of organisation C's systems provide only limited visibility over ocean shipping. Solution-C extends beyond the ocean carriers and provides rich data environment across the entire shipping ecosystem that can help the organisation to continuously improve its internal operations and leverage the capabilities of its existing systems. Solution-C is also a new revenue stream for organisation C as a founding partner owning the royalties of the solution.

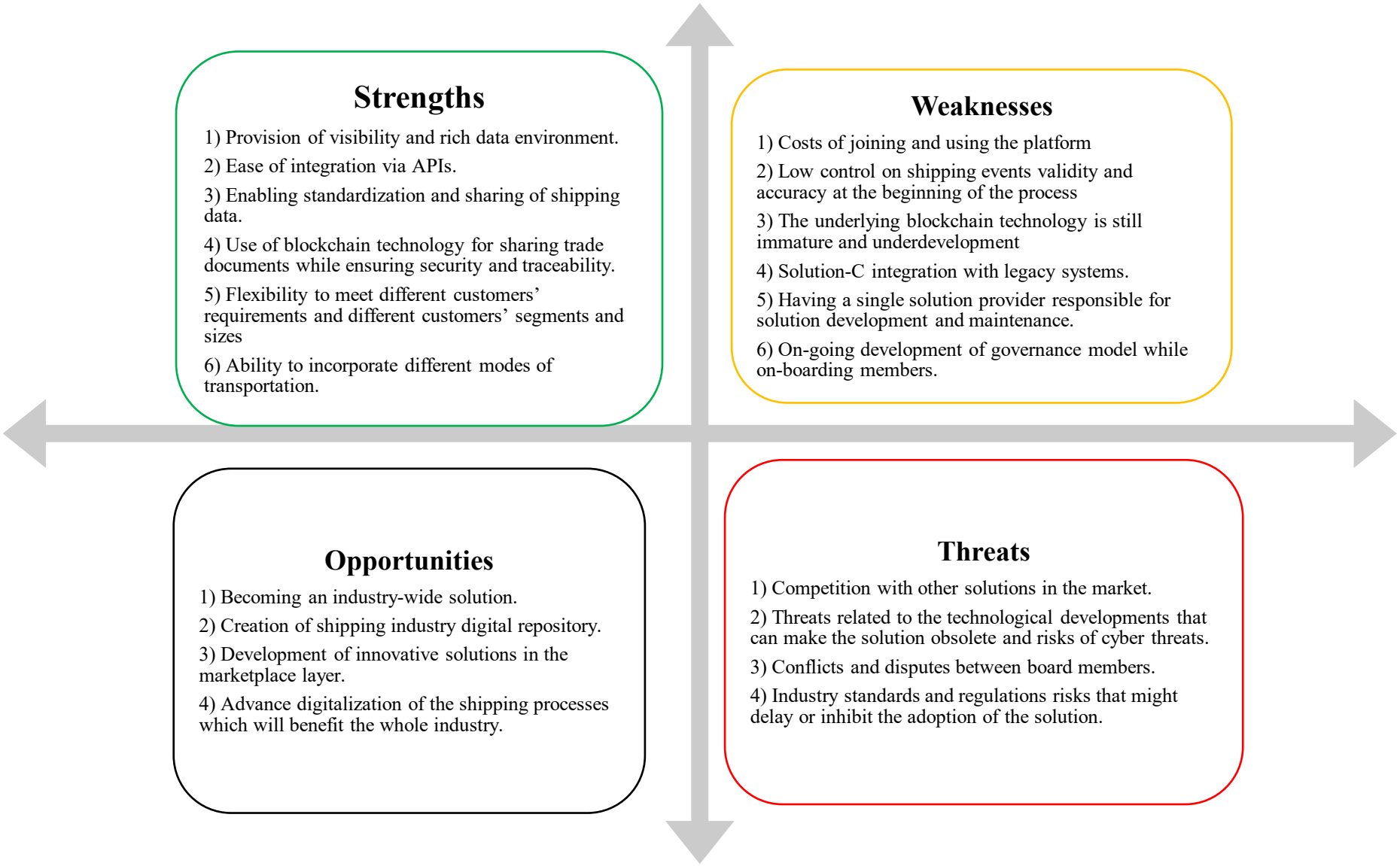


Figure 33. SWOT analysis for Solution-C as an industry solution

2. Solution-C Weaknesses

One of the key weaknesses of Solution-C for organisation C is that it is not yet fully integrated with its other systems or business units, preventing the organisation from obtaining the full potential of the solution. Moreover, since the solution has changed its governance model to a collaborative mode, organisation C has the same rights as any other ocean carrier and will incur costs to access Solution-C data. This might delay or risk its ability to realise its return-on-investment (ROI) on the initial investment.

3. Solution-C Opportunities

With Solution-C, organisation C has the opportunity to be a pioneer in developing innovative solutions and exploit their advantages prior to their release in the market. The marketplace holds great promise to promote innovative solutions and generate new revenue streams for the organisation. Solution-C may also provide organisation C with an opportunity to capitalise on the rich environment data to optimise its logistics services and other digital solutions.

4. Solution-C Threats

Organisation C is subject to several risks related to Solution-C. Despite that Solution-C can be considered a rich data source for the organisation, it might jeopardize the value proposition of the other organisation's products if they are not appropriately integrated. Other digital products within organisation C focus on logistics execution and provide limited visibility. Solution-C provides visibility to more than 134 shipping events, which can also help and inform logistics execution. Therefore, it would be beneficial to expedite the integration process to avoid devaluation of the existing products and services.

The collaboration model provides organisation C and other ocean carriers the same rights in Solution-C, including a right to sell the platform to their network and a share in the company. That means other ocean carriers can also obtain profits from Solution-C. This poses the risk of them outgaining organisation C despite being the platform's founder. The Solution-C governance model is still evolving with the system's evolution and the onboarding of major ocean carriers. Despite having these changes to support the solution scalability, it raises risks related to weakening organisation C's position in Solution-C.

Finally, Solution-C success highly relies on the number and variety of parties adopting the solution to maximise its value and also increase the number of transactions to maximise its profit. Failure to achieve this is a live threat that organisation C has to avoid.

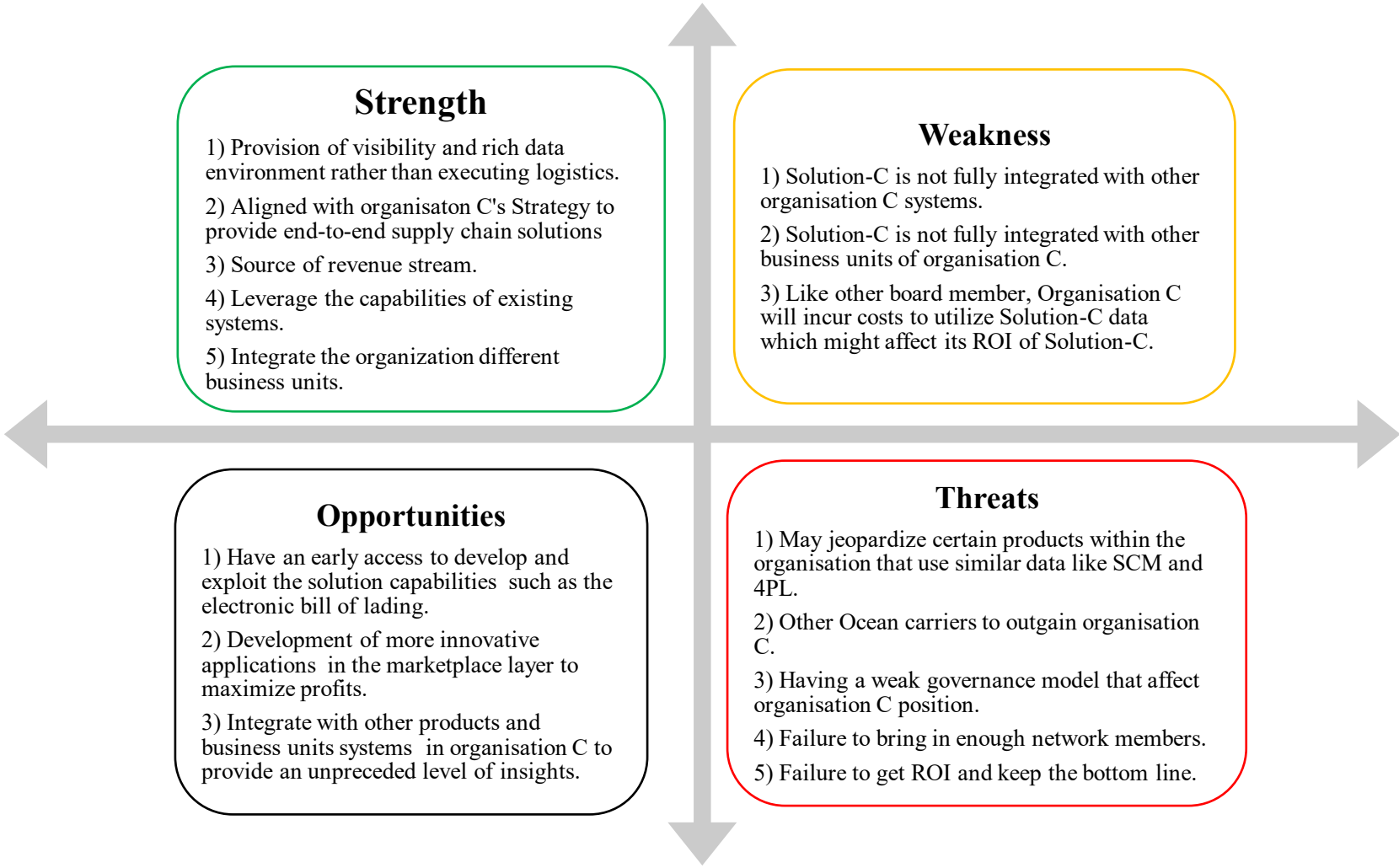


Figure 34. SWOT analysis for Solution-C as an organisation C solution

7.6.2 Analysis of blockchain application area

The blockchain application area within Solution-C falls under the document sharing capabilities. All the shipping events captured in Solution-C are stored in the solution provider cloud platform while the hashes of the shipping documents are stored on the blockchain. The case study participant explains it below.

"We basically have two streams within the Solution-C model: The cloud and this is where we store all the data. We don't use blockchain to gather or store any shipment data when it comes to container milestones. When it comes to document that's where we use blockchain and we have the Hyperledger fabric and the solution provider controls all of that."

"When we store documents in the Hyperledger fabric. We don't really store the document; we store the hash only and the hash is sort of the fingerprint of the document. The hash is the only part that is stored in the blockchain and when we need to see that document, then we're going to retrieve the hash from the blockchain, and it will populate the document itself. That's how it works. Everything is handled and managed by the solution provider."

Figure 35 presents an example of the document sharing interface in Solution-C. When selecting a new document, the platform compares and verifies the document hash (i.e., document ID) with the one stored in the blockchain to ensure its immutability. It also supports the tracking of documents versions when they are amended or changed.

The configuration of Solution-C and its use of blockchain highlights important considerations regarding the type of data to be stored on blockchain. Shipping documents handling and exchange is a manual, costly and lengthy process that requires high security, making it a common pain point in the industry. Most major players in the industry had cyber-attacks in the past that raised several concerns regarding digitalisation in this area. Blockchain has emerged as a technology that promotes security, immutability and traceability of digital records, which makes it an attractive technology to address these outstanding challenges. Blockchain supports the digitalisation of shipping documents management while maintaining its security and traceability to ensure it is only accessed by authorised parties. Blockchain also provides the flexibility to have different access rules for the different parties (Pedersen *et al.*, 2019). This is another important characteristic of blockchain that is key for shipping documents since different parties require different documents to carry their activities. Using blockchain, Solution-C has developed a solid permissioned model that gives network members different access rights based on their role in the shipment.

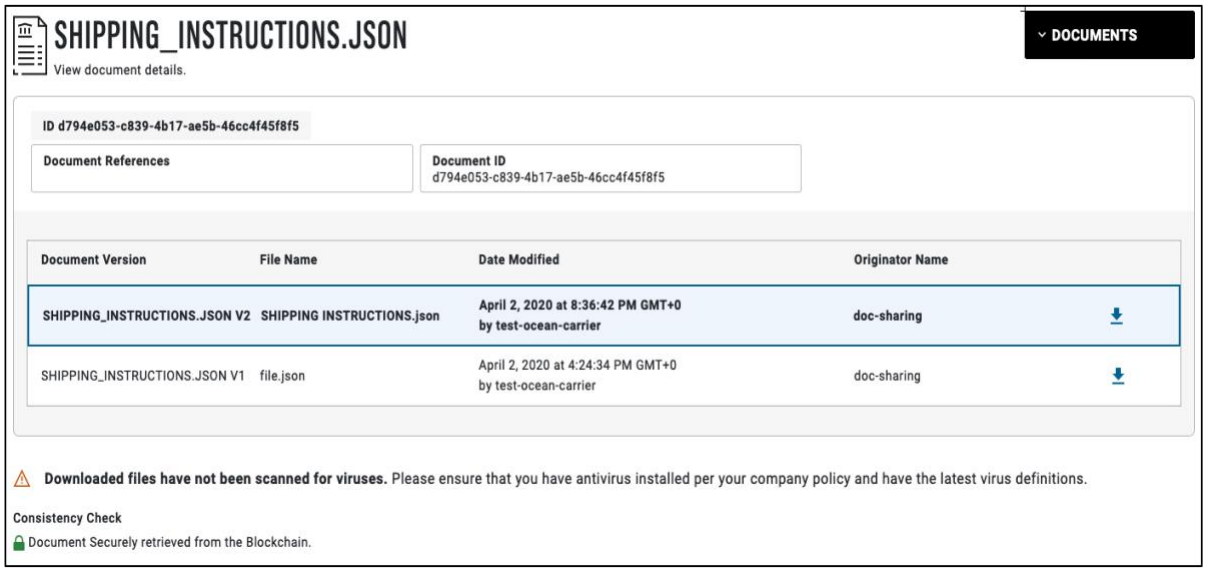


Figure 35. Example of Document sharing interface on Solution-C. Source: (Solution-C Documentation)

7.6.3 Analysis of blockchain data

There are two types of Solution-C data shown in Figure 36. Shipping events data is stored in the cloud while the shipping documents' hashes are stored on the blockchain.

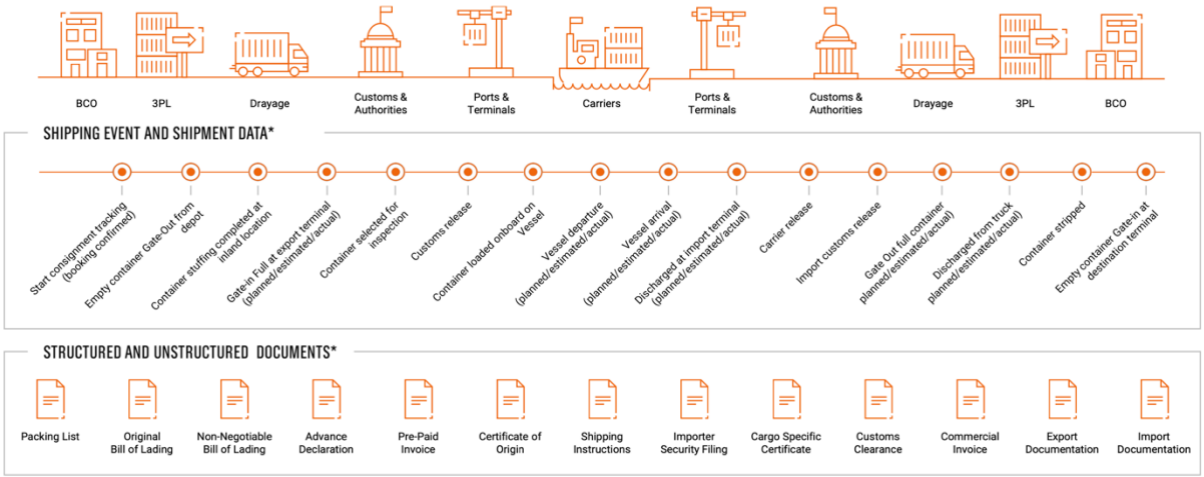


Figure 36. Solution-C Data Sharing Specification. Source: (Solution-C Documentation)

We analyse the type of insights that can be derived from Solution-C data in Table 19. We identify 8 main benefits that can be derived from Solution-C data including (1) Shipping processes optimisation, (2) Secure trade documents exchange, (3) Intelligent transportation, (4) Container utilisation management, (5) Container weight reporting, (6) Streamline customs processes, (7) cargo safety and security, and (8) Better SC planning and management.

Table 19. Analysis of Solution-C data

Type of Data	Examples	Potential insights from the data
1. Identification Data	transport equipment reference, transport object cargo type, consignment reference, and shipment reference	▪ These data are essential for tracking and to differentiate the cargo and containers
2. Container stuffing and stripping information	Container Stuffing/stripping start and end time	▪ Information about transport object stuffing and stripping can be used to identify and improve inefficiencies ▪ Containers information can help increase containers utilisation efficiency.
3. Container Movement information	- Loading and discharge on/from truck/rail/Barge/vessel - Departure and arrival of Loading and discharge on/from truck	▪ Information regarding the transportation scheduling can help improve transportation planning. ▪ If information related to the exact routes is captured along with scheduling information, selected routes can be optimised for all modes of transport. ▪ Optimising transportation routes will reduce lead times, costs and emissions.
4. Cargo release from customs/carriers /Terminals	Transport Equipment Inspection Events	▪ Information regarding the custom inspection process help identify problem areas for future improvements. ▪ Provide a reliable system for inspection process documentation. ▪ Provide a reliable source of information for customs and importers/exporters about the inspection process, inspected containers, loading and unloading during inspection, etc.
5. Bill of lading issuance	BL Number/issued/surrendered	▪ Expediate related processes
6. Cargo Weight	Cargo Weight Submitted	▪ Accurate provision and protection of containers weight. ▪ Less time and cost for providing this information. ▪ Provides additional assurance to the cargo owners.
7. Transport Equipment Environment Conditions	Temperature set point/ Humidity updated/ CO_2 updated	▪ Monitor and improve the environmental impact of vessel transportation. ▪ Provide valid and tamper-proof information about the condition of cargo transportation. ▪ With smart contracts, CO_2 emissions can be automatically calculated and standardised for products movements.

7.7 Case Study Discussion

The case study has investigated blockchain application in the shipping supply chain based on an analysis of one of the most prominent industry-wide solutions. Learning from pioneers in technologies like blockchain can help better understand the technology and its implication similar to how Toyota was studied to better understand, adopt, and implement lean practices (Ferdows, 2018).

The shipping industry has longed for a reliable solution that improves visibility and efficiencies, especially in handling trade documents, which has been a critical bottleneck responsible for most delays and costs in the shipping processes. The multiple cyber-attacks that hit many top ocean carriers have raised concerns about the security of digital solutions (Cimpanu, 2020), potentially hindering the digitalisation of trade documents. The emergence of blockchain as a technology that provides a secure medium for information sharing while ensuring data immutability, privacy, and traceability, has made it a very attractive solution to underpin and leverage the digitalisation of shipping processes.

Solution-C has by far been a pioneer in providing an operational blockchain-enabled digital solution that extends beyond the ocean carrier is to overcome the existing challenges in this industry. It provides a very rich data environment that serves different parties. This data can be analysed using different analytics tools including Business Processes Modelling, Six Sigma, Total Quality Management (TQM) and Cause-Effect Analysis to derive valuable insights and establish continuous feedback to improve shipping and logistics business operations (Feibert *et al.*, 2017).

Several organisational factors played important role in the decision-making, adoption and scalability of Solution-C. Organisation C's culture and support for innovation and digital transformation has facilitated their willingness to invest in blockchain. The desire to become a pioneer in the market to provide end-to-end visibility matches the organisation's strategy of being the global integrator of containers logistics. Further, the power and position of the organisation in the market influenced the scalability of the solution.

The case study also provided interesting empirical insights into the areas for blockchain application in the shipping processes. It validates the use of blockchain for permanent immutable and traceable records such as the shipping documents rather than changing and transactional data such as the shipping events data, indicating that the type of data affects the use of blockchain. Therefore, we argue that traditional systems can provide similar visibility

over the shipping events area while blockchain platforms can solely be used for sharing and managing shipping documents.

The SWOT analysis helped analyse the developed solution from two different perspectives as an industry wide solution and as organisation C's solution. It has revealed important considerations regarding the development of industry-wide solution including its governance model, market competition, integration issues, and impact of technological developments. Having a collaborative model is essential for the sustainability of an industry-solution. Furthermore, it is important to consider the interoperability of the platform with other solutions in the market. Having a pool of technology experts developing the solution rather than a sole entity will enforce its interoperability and prevent the development of new form of siloed platforms in the industry. As with Solution-C, most identified elements in the SWOT analysis will be relevant to other blockchain-based solutions in the industry.

The implications of having a blockchain network for the entire shipping industry go beyond the technology's technical capabilities to include development of standards for data sharing and interpretation, promoting trust within the industry and collaboration between the different parties. All of these will reduce significant burden for the customers who usually work with multiple carriers.

Besides Solution-C, several organisations ranging from ocean carriers (MSC, 2021), ports and terminals (The Maritime Executive, 2020), and major logistics service providers (Ledger Insights, 2020b), are also investigating blockchain application to optimise the shipping processes. The availability of multiple platforms raise additional concerns including the use of several platforms, the interoperability between different platforms and potential implications of platforms competition (Rietveld and Schilling, 2021). These are all important areas that are recommended for future research.

Chapter 8: Cross-case Studies Analysis

In this chapter, we provide cross-case study analysis guided by the research questions.

8.1 The Influence of Industry Characteristics on Blockchain Applications in the Supply Chain

Table 20 summarises the different industry characteristics identified for each case study and provides, where evident, examples of reported blockchain applications in practice. These characteristics include SC configuration, product, business processes, industry standards and regulations, and market and customers' demand characteristics.

The four investigated industries comprise of complex and global supply networks with multiple parties involved and major SC transparency, traceability, and visibility challenges. The product characteristics also varies across the industries. Automotive batteries are complex products, of high value, and with high sustainability concerns and quality requirements. The automotive leather is mature product, of high grade and must meet high quality requirements, while the textile fibres vary in terms of materials used, sustainability and quality.

The business and manufacturing processes characteristics range from being highly controlled, technology advanced and sensitive manufacturing processes in the automotive battery industry to a manual, labour-intensive and mature manufacturing processes in the automotive leather and textile and apparel industries. However, all these processes have high social and environmental impact raising several concerns. The shipping processes vary depending on cargo, industry and agreed upon shipping terms. They involve significant documents management, largely paper-based and labour-intensive processes with high impact on performance and shipping costs.

Different standards and regulations exist in the case study industries. There are increasing collaborative efforts to tackle the sustainability issues of automotive batteries sourcing, manufacturing, and recyclability, such as the GBA (Global Battery Alliance, 2021). The leather industry is influenced by the meat industry standards and legislations related to use of chemicals and animal by-products. The textile industry is largely influenced by non-profit organisations actively working on tackling the social and environmental issues related to

apparel production, e.g., Canopy, Textile Exchange. The shipping industry expands across countries with different trade rules, customs requirements, and jurisdictions.

The market and customers' demand characteristics are important in all four industries. The growing market of EVs impact the automotive battery supply chains and consumers are demanding battery sustainability, improved performance and competitive prices. In the leather industry, consumers are aware of deforestation issues and are increasingly demanding leather provenance and sustainability. The fast-paced apparel supply chains are exposed to changing demands and high sustainability concerns related to garment manufacturing and sourcing. In the shipping industry, the market is very competitive as customers can be working with multiple carriers, and they are demanding better visibility, performance, and reduced costs of shipping processes.

The different industry characteristics have influenced blockchain application areas. In the automotive battery, cobalt is a key battery material with high sustainability concerns. Organisation A like other OEMs has put cobalt on top of battery materials for SC tracking using blockchain to ensure its ethical sourcing, e.g., Volvo Cars (2019). In the leather industry, there is on-going project initiated by UNECE (2021) investigating the potential of blockchain in improving transparency and traceability in the textile and leather supply chain, but organisation A is a pioneer in experimenting with blockchain to enable leather traceability and ensure its sustainability. Several fibre producers have engaged in blockchain projects to tackle the traceability and sustainability issues in the supply chain including organisation B, C&A Foundation (2019) and Chargeurs (2018). Shipping document management has been a popular area for blockchain application in the shipping processes by organisation C, Cargo Smart (2018) and MSC (2021) .

Table 20. The case studies' industry characteristics and blockchain application areas

Key Industry Characteristics	Automotive Battery	Automotive Leather	Textile Fibre Supply Chain	Global Shipping and Maritime Logistics
SC Configuration	- Complex and multi-tier supply network. - Raw materials are concentrated in certain countries.	- Global, complex, and multi-tier supply network with large number of players.	- Global, complex, and multi-tier supply network with large number of players.	- Multiple and dispersed parties involved in the shipping ecosystem.
Product Characteristics	- High value and complex product. - Most battery materials are scarce and have strict quality and technical specifications.	- High quality requirements. - Mature product.	- Various types of natural and synthetic fibres. - High sustainable, social and environmental impact.	
Business Process/ Manufacturing Characteristics	- High sustainability concerns related to battery manufacturing and recyclability - Controlled manufacturing processes.	- Manual and labour-intensive manufacturing processes. - High social and environmental of leather manufacturing.	- Manual and labour-intensive manufacturing processes. - High sustainability concerns of textile and apparel production including child labour.	- Manual and labour-intensive processes. - Lengthy and costly processes. - High security requirements for documents exchange. - Variable processes depending on cargo, industry, and country.
Industry Standards and Regulations	Increasing collaborative efforts from the industry to tackle the sustainability of the battery manufacturing and material sourcing such as GBA.	Influenced by meat industry legislations e.g., EU legislations for use of chemicals, environment impact, and use of animal by-products.	Pressure from standards organisations and NGOs to tackle the environmental and social issues related to textile and apparel production.	The shipping processes are affected by the customs regulations, trade laws, and financial regulations.
Market and Customers Demand	- Growing market share for electric vehicles and batteries. - Demand for battery sustainability. - Demand for competitive prices and performance for batteries to compete with internal combustion vehicles.	- Demand for sustainability. - Demand for provenance.	- Fast-paced environment. - Changing customers' demands. - Demand for sustainability of garments and their manufacturing.	- Demand for visibility. - Demand for efficiency. - Demand for security.
Blockchain application areas in the industry supply chain	To ensure the ethical sourcing of Cobalt. e.g., Volvo cars (2019).	The case study is the first to implement blockchain in the leather industry.	Textile fibre traceability and sustainability. E.g., C&A Foundation (2019)	Shipping document management. E.g., Cargo Smart (2018) and MSC (2021)

Table 21 presents the key characteristics influencing the selected blockchain application areas in the four case studies. The SC configuration characteristics influenced the selection of blockchain application areas in all four case studies. Organisations sought for blockchain application in the more complex supply chains to tackle different SC challenges such as lack of transparency (e.g., automotive battery), traceability and sustainability issues (e.g., leather and textile case studies). Product and business processes characteristics also played a big part in the selection of blockchain application area. The high-value, necessary use, and high sustainability concerns of cobalt in automotive batteries have put it at the top of blockchain application areas in organisation A's battery supply chain. Similarly, the automotive leather has high sustainability concerns. Hence, organisation A was interested in leather traceability to identify its provenance and ensure its sustainability. Organisation B wanted to protect its innovative and differentiated fibres and manufacturing processes from counterfeit in the downstream complex textile supply chain. Finally, documents management is a high value-adding business process with high security requirements in the shipping industry and can significantly influence the shipping costs and efficiency. These characteristics made it a top application area for blockchain to help improve the shipping processes' efficiency.

Industry standards and regulations played a different role in each case study. In the battery industry, an increasing number of initiatives such GBA and Battery Passport are looking into tackling the sustainability issues of battery sourcing and manufacturing. MOBI is a blockchain consortia that aims to develop standards for blockchain adoption in the automotive sector (MOBI, 2022). Organisation A was closely following the work of these organisations to understand emerging industry standards. Some members of organisation A leather pilot project were also members of the UNECE project. Organisation A was keen on understanding the current and emerging legislations for traceability and environmental impact to decide upon the best blockchain application areas in its battery and leather supply chains. Organisation B has the support of existing standards organisation, Canopy, to better plan the scalability of its blockchain solution, which is also developed based on existing global GS1 standards for data sharing across the supply chain. Standards and regulations in the shipping industry strongly affect the shipping processes and their requirements. Different authorities such as banks, customs and trade organisation can be involved the shipping processes and these authorities differ between countries and might have different requirements. Organisation C adopted UN/CEFACT supply chain reference model to enable data standardisation and define data sharing requirements.

Last but not least, the market and customer demand characteristics have a strong role in directing business operations and strategic decisions, including those related to blockchain adoption. Organisation A indicated that both its investors and customers are interested in getting assurance of the sustainability of cobalt used in the vehicle battery. The organisation has also been frequently questioned by its customers and NGOs about the provenance and sustainability of its leather. Organisation B acknowledged the increasing consumer awareness and demand for the sustainability of apparel products. It has also frequently been asked by its customers from brands and retailers to verify their fibres in the final garment. Finally, international shipping customers have longed for a solution that provides them with visibility into the shipping processes to improve their efficiency and reduce costs.

Table 21. Case study application area characteristics

Case Study Characteristics	Org A Automotive Battery	Org A Automotive Leather	Org B Textile Fibres	Org C Shipping and Maritime Logistics
Blockchain Application Area	Upstream cobalt supply chain	Upstream - From farm to Tannery	Downstream - from fibre producer to brand and retailers	Shipping documents – exporters to importers
SC Configuration	Complex, global and large supply chains			Multiple and globally dispersed parties involved.
Product Characteristics	Main battery component Difficult to track. High sustainability concerns	High sustainability concerns.	High value products. Sustainable fibres. High authenticity concerns	
Business Process/ Manufacturing Characteristics	High social and environmental impact of cobalt mining	High social and environmental impact of tanning processes	Innovative and sustainable manufacturing processes	High value processes. Inefficient processes. High security requirements
Industry Standards and Regulations	Pressure from standards organisations and NGOs regarding cobalt sustainability	Pressure from NGOs to ensure leather sustainability and/or stop using leather.	Support from standards organisations for blockchain adoption in the supply chain.	Countries trade regulations affect the shipping processes requirements
Market and Customers Demand	Increasing customers and investors demand for cobalt sustainability	Customers demand for leather sustainability and provenance.	Customers demand for fibre authenticity and sustainability.	Highly competitive market. Demand for visibility into the shipping processes.

8.2 The Main Motivations for Blockchain Adoption and Selection of Application Area in the Supply Chain

This section identifies and analyses the main motivations for blockchain adoption and application in the four case studies. We differentiate between three types of motivations: (1) blockchain technology selection, (2) blockchain adoption in the supply chain, and (3) selection of blockchain pilots' application areas and SC partners.

8.2.1 The main motivations for selecting blockchain technology

The main identified motivations for selecting blockchain in the four case studies were the security, transparency, traceability, immutability and verifiability of blockchain solutions. These motivations were mainly related to the nature of the data stored on the blockchain and needed to be shared between multiple dispersed parties.

Despite the variable knowledge about blockchain across the different participants in the case studies, they all referred to existing trust issues in their supply chain which require data security and immutability, and the need to enforce information sharing to improve transparency, and to maintain traceable records for products information across the supply chain. These needs can be addressed by blockchain considering its core capabilities and inherited architecture, including its distributed ledger that promotes transparency and information sharing among the blockchain participants, and the use of cryptography and timestamping that secure the blockchain data, enable its traceability and support its immutability.

In the four case studies, the different organisations were dependent on a third party blockchain provider to develop, implement and maintain the blockchain platform. Blockchain solution providers have the necessary expertise that might be missing within the organisation and represent a neutral and independent partner controlling the blockchain platform rather than having it controlled by any SC partners.

The case studies have also shown that blockchain is not necessarily the best technology for all types of SC data. Organisation A has invested in E2open[17], a cloud-based SC planning and management platform to manage orders scheduling and delivery information with their suppliers but was interested in using blockchain to only provide provenance and sustainability-related information about cobalt and leather used in its vehicles. Similarly, organisation B uses

[17] https://www.e2open.com/

Blue Yonder[18] SC planning and management platform to manage its production and capacity planning information while the blockchain solution was separately applied to track fibres usage in the downstream supply chain. Finally, organisation C shipping solution captures shipping execution events data and stores them on the solution provider centralised cloud, while shipping documents are shared and stored on the blockchain platform. Therefore, the need for blockchain comes when the data has to be shared, secured, immutable, traceable, and verifiable which is directly satisfied by the core capabilities of blockchain.

8.2.2 The main motivations for blockchain adoption in the selected supply chain

Table 22 summarises the main motivations for blockchain adoption in the supply chain across the four case studies. There are similar motivations for blockchain adoption in the four case studies. Improving SC transparency, traceability and visibility are main motivations for blockchain adoption across the four case studies. Ensuring the sustainability of products are key motivations in the automotive industry case studies for the battery and leather supply chain while ensuring the authenticity of the textile fibres and fighting counterfeiting are one of the main motivations for the textile and apparel case study. Quality assurance was a main motivation in the automotive battery and textile case study to ensure the quality of the battery raw materials by guaranteeing the consistency of raw materials sourcing and manufacturing processes, and to verify the final garment specifications claims, respectively. SC optimisation, improved efficiency, and better risk management were key motivations in the automotive and shipping case studies enabled by the improved transparency and level of SC information sharing. Different additional motivations were behind blockchain adoption in the shipping industry case study where organisation C aimed to adopt blockchain to enable secure documents management to reduce costs, generate a new revenue scheme, and improve customer satisfaction levels. By enabling leather traceability and identifying provenance, organisation A also aimed at providing its customers with better leather options.

Finally, gaining competitive advantage and being a pioneer in digital transformation and blockchain adoption were common motivations for implementing blockchain in the automotive leather, textile fibres, and shipping case studies.

[18] https://blueyonder.com/

Table 22. The main motivations for blockchain adoption in the four case studies.

Main motivations for blockchain adoption in the supply chain	Org A Automotive Battery	Org A Automotive Leather	Org B Textile Fibre	Org C Shipping and Maritime Logistics
Traceability and provenance	✓	✓	✓	✓
Transparency	✓	✓	✓	✓
Sustainability	✓	✓		
Supply Chain Visibility	✓	✓	✓	✓
Quality Assurance	✓		✓	
Supply chain optimisation and efficiency		✓		✓
Product Authenticity			✓	
Risk management and reduction	✓			✓
Costs reduction				✓
Customer Service		✓		✓
New Revenue Stream				✓
Competitive Advantage		✓	✓	✓

8.2.3 The main reasons behind the selection of blockchain application areas and supply chain partners

Table 23 summarised the main reasons for the selection of blockchain application area and supply chain partners in three case studies omitting the first one that has not piloted the technology.

Three main application areas for blockchain were evident in the case studies. The first application area is for *product tracking and traceability* across the supply chain, evident in the automotive leather and textile case studies. The second application area is to *improve business processes*, including the shipping industry where blockchain is applied to improve the efficiency and security of shipping document management. The third application area is to *provide customer service* which is evident in the automotive leather case study where organisation A aimed to provide its customers with improved leather options and in the shipping case study where organisation C aimed at providing better customer service to improve their satisfaction level.

In the selection of blockchain pilot application areas, organisation A worked with two abattoirs, a local leather tannery and a local blockchain provider to investigate the application of blockchain in the upstream leather supply chain. Organisation B partnered with a local

blockchain provider and a high-end and niche fashion brand. Organisation C partnered with a leading blockchain provider and started the pilot within its own shipping line and ports and terminals.

There are common characteristics of the selected blockchain application areas in each case study. Organisation A and B started with local simple supply chains with limited number of players who are willing to engage in the project. Organisation C started with its own companies in its vertically integrated supply chain. Each of the three organisations worked with SC partners that were aligned with in terms of strategy and motivations.

The blockchain pilot application areas are important for the success of the project. Pilots are meant to provide a better understanding and a proof of concept. They help determine the fundamental requirements for blockchain adoption, evaluate its capabilities and expected benefits, and identify the requirements and challenges for its scalability in a wider and more complex supply chains.

Table 23. The main reasons behind the selection of the blockchain application area and supply chain partners in the case studies

Main motivations for blockchain pilot application area	**Org A Leather**	**Org B Textile Fibre**	**Org C Shipping and Maritime Logistics**
Simple and Less Complex Supply Chain	✓	✓	✓
Local Supply Chain	✓	✓	
Internal processes			✓
Vertically integrated SC partners			✓
Willingness to participate	✓	✓	✓
Alignment in motivations	✓	✓	✓
Alignment in business strategy	✓	✓	✓

8.3 The Key Pre-requisites and Inhibitors for Blockchain Adoption and Deployment in the Supply Chain

8.3.1 The key pre-requisites for blockchain adoption and deployment in the supply chain

Table 24 summarises the key pre-requisites for blockchain adoption. These pre-requisites were identified in each case study as critical requirements/inhibitors for blockchain adoption in the supply chain. Those pre-requisites were stressed upon by the case study participants and were directly affecting the organisations' ability to adopt the technology. All pre-requisites were acknowledged in the four case studies. We use the (✓) sign to indicate its achievement in the case study while the (X) sign indicates it is challenging. Most of the pre-requisites were not attainable in the battery case study, hindering the organisation for adopting blockchain. Having a clarity about the purpose and scope of blockchain application area and product identification were main challenges in the leather blockchain pilot project, hindering the scalability of the solution. On the other hand, organisation B successfully achieved all pre-requisites and was able to implement several blockchain pilots while organisation C's developed industry-wide solution relies on its use by all necessary parties in the shipping processes. We discuss the main pre-requisites below.

Table 24. The key pre-requisites for blockchain adoption in the supply chain across the four case studies

Key pre-requisites for blockchain adoption in the supply chain	**Org A Automotive battery**	**Org A Automotive Leather**	**Org B Textile Fibre**	**Org C Shipping Processes**
1. Clarity of purpose for blockchain adoption and scope of application	X	X	✓	✓
2. Knowledge about the supply chain	X	✓	✓	✓
3. Establishing an agreement among the SC partners on the use of blockchain and on blockchain data.	X	✓	✓	✓
4. Inclusion of all necessary parties in the blockchain solution	X	✓	✓	X
5. Establishment of a data governance model	X	✓	✓	✓
6. Identification and linkage of assets stored on the blockchain to create a SC digital twin	X	X	✓	✓

1. Clarity of purpose for blockchain adoption and scope of application

Organisation A selected the cobalt supply chain as a potential application area for blockchain. However, it was not clear about the potential value of blockchain adoption in its battery supply

chain, which affected its adoption decision. In contrast, organisation A aimed at implementing blockchain to identify leather provenance and started investigating blockchain application in the upstream supply chain. However, the project team struggled to define the optimal level of leather traceability they should aim for, which affected the scalability of the developed solution. Organisation B had a clearly defined business need to ensure the authenticity and traceability of its innovative fibres. Hence, it was mainly interested in its branded fibre and in traceability in the downstream supply chain and was successful in implementing several pilots. Blockchain was specifically applied in the shipping document sharing part of organisation C industry-wide operational shipping solution.

2. Knowledge about the supply chain.

Most blockchain SC applications are private permissioned blockchain networks, requiring the knowledge about each of the participants that need to join the network. The lack of SC knowledge of organisation A was a major roadblock hindering its ability to adopt blockchain in its battery supply chain. However, the organisation had better knowledge about its leather suppliers and sourcing regions, which facilitated their engagement in the leather blockchain pilot project. Organisation B has partnered with the brand and retailers to identify and bring the middle parties on board. In organisation C shipping platform, knowledge about the different parties involved in the shipping processes is crucial to ensure that only authorised parties have access to the shipping data and documents.

3. Establishing an agreement among the SC partners on the use of blockchain and on blockchain data.

In the automotive battery case study, organisation A was aware of the importance of bringing all relevant SC partners to agree and invest in the blockchain solution. They realised that their current SC relationships would not support such an agreement and are gradually trying to change their contractual relationship terms and conditions. However, in their LSC, organisation A was able to bring its leather suppliers onboard and agree on experimenting with blockchain to identify leather provenance. Organisation B's blockchain provider had undertaken all the necessary groundwork to define the data sharing requirements across the downstream TSC from the fibre producers to the brands and retailers. When joining the blockchain solution, all the SC partners must agree on data sharing requirements. Finally, the blockchain-enabled shipping platform developed by organisation C aimed at providing a

platform for secure document sharing. Hence, any shipping partners interested in using the platform must be willing to share and access these documents through the platform.

4. Inclusion of all necessary parties in the blockchain solution.

Different parties can be crucial in the blockchain solution depending on its purpose and scope of application. To ensure cobalt sustainability, organisation A realised the need to involve all its SC partners from the mining to the Tier 1 battery manufacturers. Similarly, in its LSC, organisation A and the project team was able to map the upstream LSC and decide and reach to the necessary SC members to be part of the project. Hence, two abattoirs were onboarded in the project. Organisation B's participants indicated the importance of not only including all SC partners but also all the necessary participants within the organisation from top management to the people carrying on the operational work. For organisation C to realise its vision of developing an end-to-end logistics solution, it is required to include all parties involved in the shipping processes which is an ongoing challenge.

5. Establishment of a data governance model

The data governance model is the set of rules that control data access and sharing rights between the different parties. This were major concerns raised in organisation A case studies due to existing high resistance in information sharing. Similarly, there is high competition among the shipping partners in the shipping industry and, hence, high reluctance to share information. Organisation C acknowledged the importance of developing a strong data sharing permission model to ensure the security and privacy of the platform and its data. In the automotive leather case study, the project team identified data requirement at each SC stage and addressed the importance of having a reliable data validation and verification method to ensure that the data is captured and shared properly. The team has suggested the potential use of external auditing to ensure blockchain data validity. The blockchain solution adopted by organisation B relied on minimum data sharing requirements and various data access rules given to the different SC partners based on their value chain position.

6. Identification and linkage of assets stored on the blockchain to create a SC digital twin

Asset identification is a key pre-requisite to ensure that the associated blockchain data is valid and representing the real world. It enables the creation of the SC digital twin using blockchain and is strongly influenced by the product characteristics and manufacturing processes. Organisation A acknowledged the need to identify and link batteries to their components across the supply chain to enable traceability. The organisation's participants considered it to be a

very complex endeavour to identify the bill of materials across the multi-tier battery supply chains and establish the physical and digital links between the products at the different SC stages.

In the automotive leather case study, leather identification and traceability throughout the tanning processes and in the downstream LSC were one of the main challenges in the project. The project team investigated different identification methods to support the development of a blockchain-enabled traceability solution. Organisation B used embedded physical tracers to identify its fibre physically in the final garment products. An equivalent amount of fibre coins was also created on the digital blockchain solution equal to the physical fibre volume transferred between the different SC partners. Having digital and physical identifiers was crucial to ensure the authenticity of fibre. Organisation C solution stores a unique identification for each shipping document on the blockchain to keep track of documents versioning and sharing and to ensure the security and validity of the shared documents.

8.3.2 The key inhibitors for blockchain adoption and deployment in the supply chain

Table 25 summarises the key inhibitors for blockchain adoption and deployment in the four case studies using (✓) sign for challenges identified in each case study. Different challenges were evident in each case study.

Table 25. The key inhibitors for blockchain adoption and deployment across the four case studies.

Key inhibitors for blockchain adoption in the supply chain	Org A Automotive Battery	Org A Automotive Leather	Org B Textile Fibre	Org C Shipping Processes
SC partners unwillingness to participate and share information.	✓	✓		✓
Costs of required investments across the supply chain for product identification and use of blockchain	✓	✓		
Conflicts of interest among the SC partners.	✓			✓
Lack of financial incentive		✓		
Blockchain solution integration issues with existing systems.		✓	✓	✓
Blockchain data compliance issues with GDPR		✓	✓	
Inability to mandate adoption across the supply chain.	✓			
Current business processes are incompatible with traceability		✓		
Cultural differences	✓			✓
Lack of standards for data sharing		✓		✓
Immature understanding of blockchain technology	✓	✓	✓	

1. SC partners unwillingness to participate and share information

Blockchain application requires collaboration among the different SC partners to put in the necessary resources and share required information. Organisation A identified that suppliers' unwillingness to share information about the upstream battery supply chains as one of the major challenges faced by the organisation. This challenge was also faced in the automotive leather blockchain pilot project when one of the abattoirs was not willing to share information about their CO_2 footprints and energy use, affecting the ability to calculate and track CO_2 emissions across that specific supply chain. Information sharing is a key challenge in the fragmented shipping industry as it is perceived commercially sensitive. Organisation C has worked on promoting information sharing to encourage blockchain adoption.

2. Costs of required investments across the supply chain for product identification and use of blockchain

This was a major concern for organisation A in its battery and leather supply chain. It received government funds to experiment with blockchain in the LSC. However, these concerns remained when considering the scalability of the developed solution.

3. Conflicts of interest among the SC partners

Conflicts of interest can be a significant inhibitor for establishing the necessary agreements and collaboration to adopt blockchain-enabled SC solutions. Organisation A's plan to assemble battery packs in-house has increased the resistance of its tier 1 suppliers to share information about their supply chain. Conflict of interest was one of the main challenges faced by organisation C since shipping customers usually work with multiple carriers.

4. Lack of financial incentive

The lack of financial incentive was a major challenge highlighted in the automotive leather case study as it is considered a by-product of the meat industry, resulting in lack of interest and financial incentive from key players - the abattoirs - in enabling leather traceability.

5. Blockchain integration issues with existing information systems

The integration of blockchain solutions with existing information systems was a common challenge in all three case studies. All developed solutions have the option of systems integration using open APIs but still struggle to integrate with legacy systems.

6. Blockchain data compliance issues and GDPR

GDPR provides different rights to the data subject, including their right to restrict information processing and erase their data (GDPR, 2021). Issues related to data compliance with GDPR have been raised in two case studies, including the automotive leather project as part of identifying and storing leather provenance information such as farm names, locations, etc. Similar issues were faced in the textile case study in determining what data to store on the blockchain and how to deal with data compliance issues.

7. Inability to mandate blockchain adoption across the supply chain

The position and power of the leading organisation can strongly influence their ability to mandate blockchain adoption in their supply chain. Organisation A considered itself as a small player in the automotive industry compared to other large OEMs, hindering its ability to mandate adoption across its battery supply chain. Organisation A has a stronger position in its LSC and was able to bring together its leather suppliers and tier 1 assemblers to engage in the blockchain project.

8. Current business processes are incompatible with traceability

This was a main challenge in the automotive leather case study related to the identification of leather during the tanning processes. In the pilot project, leather hides were processed in order, tagged and retagged with ear tags before and after each tanning process to maintain their traceability. However, this identification process is not feasible nor scalable.

9. Cultural differences

Cultural differences were a key challenge in organisation A's battery supply chain, affecting their communication and information sharing. It was also evident in between organisation C and the blockchain solution provider, creating some challenges in the development of the blockchain platform.

10. Lack of standards for data sharing

The lack of standards for data sharing was a key challenge in the automotive leather blockchain project as the project team struggled to identify the optimal level of traceability and data requirements across the leather supply chain. Organisation C has also indicated that the lack of common industry standards for information sharing has been a great challenge for developing an industry-wide solution as the organisation has to work on developing these standards with its customers and other shipping partners.

11. Immature understanding of blockchain technology.

There were variable levels of blockchain understanding across the different case studies. Organisation A had a specialised team enabling digital transformation within the organisation. However, there was a limited or no knowledge about blockchain in the functional departments. Organisation B indicated that promoting and educating the different management levels within the organisations about blockchain was an initial challenge they had to overcome to encourage blockchain adoption. Organisation C indicated that the lack of knowledge about the blockchain was not an issue as the company partnered with a leading blockchain provider.

8.4 The Key Factors Influencing Management Decision-making, and the Adoption and Scalability of Blockchain in the Supply Chain

8.4.1 The key factors influencing management decision-making regarding blockchain adoption

The case study organisations made different decisions about blockchain adoption. Organisation A decided not to adopt blockchain in its battery supply chain but implemented a blockchain pilot in its leather supply chain. Organisation B implemented several blockchain pilots in its downstream textile supply chains and started planning for the solution's scalability. Organisation C developed an industry-wide shipping platform that is open to the entire shipping ecosystem. Table 26 summarises the key factors affecting the organisation's management decision-making regarding blockchain adoption where (X) represents when the factor was negatively evident and (✓) when the factor was positively evident. Almost all factors were negatively evident in organisation A battery supply chain while most factors were positively evident in the other three case studies. We discuss these factors below.

1. Clarity of business needs

Having a clear and defined business need is one of the key factors that influenced the decisions made by the different organisations. One case study participant from Organisation A noted regarding blockchain, *"We have got a solution looking for a problem (Senior Project Manager)"* Organisation A struggled to define their exact need for blockchain since they are meeting current legislation requirements in their battery LSC to gain a competitive advantage. Organisation B was clear on its business needs to ensure fibre authenticity in the final garments and improve SC visibility and the blockchain solution met the organisation requirements. Organisation C business need was to develop an end-to-end shipping digital solution to improve the international shipping processes. Hence, they partnered with a leading technology provider expert in blockchain applications.

Table 26. The key factors influencing management decision-making regarding blockchain adoption

Key factors affecting the decision making regarding blockchain adoption	Org A Automotive battery	Org A Automotive Leather	Org B Textile Fibre	Org C Shipping Processes
Clarity of business needs	X	✓	✓	✓
Clarity of purpose and value proposition of blockchain adoption	X	X	✓	✓
Top management support	X	✓	✓	✓
The leading organisation's power and position to encourage adoption	X	✓	✓	✓
Nature of SC relationships, including	X	✓	✓	X
Long term relationships	X	✓	✓	✓
Willingness to information sharing	X	✓	✓	X
Willingness to collaborate	X	✓	✓	X
Willingness to invest	X	✓	✓	✓
Alignment with business strategy	✓	✓	✓	✓
SC partners willingness to participate and share information	X	✓	✓	✓
Alignment in the SC partners motivations	X	✓	✓	✓
Type and amount of required blockchain data	X	✓	✓	✓
Final decision	Do not adopt blockchain	Conduct blockchain pilot	Multiple pilots	Solution commercialisation

2. Clarity of purpose and value proposition of blockchain adoption

This was a key factor influencing the decision to not adopt blockchain in organisation A battery supply chain and not being able to decide the optimal level of blockchain-enabled traceability in its LSC. Organisation B was able to identify the value from blockchain adoption through improved visibility and fighting counterfeit in its downstream TSC. Similarly, organisation C saw the marketing opportunity from being a leader in digital transformation and from providing its customers with a solution that reduces costs and improves efficiency and productivity. Additionally, the platform provides a new revenue stream for the organisation.

3. Top management support

Top management support is crucial for blockchain adoption in the supply chain as digital transformation and inter-organisational decisions are usually made by top management. This was a key challenge within organisation A as there was a lack of management support and SC perspective within the organisation management. During the second case study and the blockchain pilot, organisation A went through an internal restructuring that introduced a new

cross-functional department to support SCM. This has encouraged the implementation of the blockchain pilot in its LSC. Organisation B's top management support was a key reason behind blockchain adoption. The organisation's Board of Directors are advocates of digital transformation and supported the project. Organisation C also highlighted the company's top management support for innovation and digital transformation as one of the main reasons behind its continuous development of innovative digital solutions.

4. The leading organisation's power and position in the supply chain

The position and power of the leading organisation in its supply chain influenced its ability to encourage adoption. Organisation A perceived itself as a small player in the automotive industry and considered the more powerful position of its Tier 1 suppliers to lead such an initiative. However, in the automotive leather, organisation A had a stronger and more powerful position since it is one of the biggest consumers of automotive leather.

Similarly, organisation B is a leading producer of an innovative and sustainable MMCF in the textile industry which gives it a strong position in its supply chain. Moreover, the organisation partnered with end-brand and retailers who have the ultimate power in the network. Finally, organisation C has a strong position in the shipping industry, and it is vertically integrated, which helped the organisation develop and encourage adoption of its developed blockchain solution.

5. Nature of SC relationships

The SC relationships characteristics strongly influence the decision making for blockchain adoption in the supply chain. Organisation A has contractual short-term relationships with its battery suppliers and lacks information sharing and collaboration in the supply chain but in its LSC, organisation A has long-term partnerships with its leather suppliers and already a good level of information sharing and collaboration. This has influenced the organisation's decision to adopt blockchain in the leather supply chain rather than the battery supply chain. Organisation B has good relationships with its direct customers and end retailers but lacks visibility on the other downstream intermediary players who are also controlled by the end brand and retailers. Partnering with the end brands and retailers has facilitated blockchain adoption across the supply chain. Organisation C initially considered adopting the solution within its own group of companies whom it has the power to influence. Then the organisation made the solution open to the rest of the industry.

6. Willingness to invest

Organisation A was concerned about investment requirements to enable traceability in its battery supply chain. The organisation has secured government funds to experiment with blockchain in its LSC. Organisation B and C were willing to invest in the blockchain solution once the value propositions and benefits were identified.

7. Alignment with business strategy

In all case studies, the considerations regarding blockchain adoption was related to the overall business strategy. Organisation A has an overall strategy of vehicle sustainability and hence aimed at investigating blockchain adoption to ensure the sustainability of its battery and leather as they are considered critical commodities for the organisation. Organisation B wanted to protect its novel technologies and ensure that their name is not misused in anyway while organisation C's vision is to be the global integrator for container logistics. All these supported their decision to investigate and adopt blockchain.

8. SC partners willingness to participate and share information

This is one of the key factors affecting the decision-making regarding blockchain adoption and application area in the automotive leather and textile fibre case studies.

9. Alignment in the SC partners motivations

Alignment in the motivations among the SC partners is a key factor that encourages blockchain adoption and the selection of the application area. The conflict of interests in organisation A battery supply chain has raised concerns about the suppliers' willingness to share information. In the automotive LSC, organisation A shared the same motivations with its leather suppliers to ensure leather sustainability and identify its provenance. Similarly, organisation B planned to engage with brand and retailers who are also keen on ensuring the sustainability of their garment products. This was crucial in their selection of their partners in the pilot projects and the development of their blockchain scalability plans. Organisation C aimed at tackling common pain points in the shipping industry through its developed solution to benefit the entire shipping ecosystem.

10. Type and amount of required blockchain data

This was highlighted in the automotive leather and textile fibre case studies. In the leather case study, the project team addressed the impact of the type and amount of data required on the investment requirements across the supply chain and on the willingness of the SC partners to participate and share information. Organisation B also indicated that the minimum data

requirements and the lack of any sensitive or commercial information in the blockchain platform were key factors affecting their decision regarding the solution adoption.

8.4.2 The key factors influencing the adoption and scalability of blockchain in the supply chain

Table 27 summarises the main factors affecting blockchain adoption and scalability in the supply chain in the three case studies (excluding the battery case study since they did not adopt blockchain), where (X) represents when the factor was negatively evident and (✓) when the factor was positively evident. We classify these factors into technical, organisational and external factors.

a. Technical factors

- Blockchain solution configuration

The blockchain solution configuration plays an important role in its adoption. In the leather blockchain pilot of organisation A, the blockchain platform was configured to provide visibility to the leather journey from the farm to the tannery. The platform had a user-friendly interface with clear selection of data capture points and data entry options. Organisation B indicated that their blockchain solution is easy to adopt with a user-friendly interface. Organisation C's solution provide different services for the shipping ecosystem such as automated workflows for customs processes and bill of lading which meets the different customers' requirements.

- Development of blockchain solution based on existing data standards

The blockchain solution adopted by organisation B is based on GS1 global data standards, supporting its adoption in the global textile supply chain. Organisation C solution was based on UN/CEFACT supply chain reference model enabling data sharing in the shipping industry.

- Blockchain maturity and scalability

Several concerns were raised regarding blockchain's maturity across the different case studies. Organisation A indicated the immaturity of blockchain applications in the automotive industry as an inhibitor for its adoption. Organisation C indicated that the developed solution is evolving with changes in the shipping ecosystem and the underlying technology. This was identified as a weakness to their solution.

Table 27. The key factors influencing the adoption and scalability of blockchain in the supply chain

Key factors affecting the adoption and scalability of blockchain in the supply chain		Org A Automotive Leather	Org B Textile Fibre	Org C Shipping Processes
Technical Factors	Blockchain solution configuration	✓	✓	✓
	Development of blockchain solution based on existing data standards	X	✓	✓
	Blockchain maturity and scalability	X	X	X
	Blockchain solution flexibility and adaptability	✓	✓	✓
	Blockchain data input and integration methods	X	X	X
	Blockchain governance model	X	✓	✓
Organisational Factors	Level of digitalisation in place	X		X
	Product characteristics and consistency across the different supply chains	X	✓	
	Business processes characteristics and consistency across the different supply chains	X	✓	X
External Factors	Availability or development of industry standards for data sharing across the supply chain	X	✓	X
	Support from regulatory bodies, standards organisations, and NGOs to develop and adopt blockchain in the supply chain	✓	✓	✓

- Blockchain solution flexibility and adaptability

Organisation B's blockchain solution has a simple and easy to grasp concept and is fibre agnostic, supporting its implementation across different types of fibres and its scalability. Organisation C's solution must accommodate the different nuances within the shipping ecosystem as different customers can have different requirements, and their shipping processes can vary. Therefore, it has to be flexible and adaptable to encourage wide-scale adoption.

- Blockchain data input and integration methods

The blockchain solution integration with existing information systems is a key factor affecting its adoption and scalability. All three developed blockchain solutions provide different options for data input methods, including open-APIs and manual data input.

- Blockchain governance model

Organisation A, B and C solutions providers were responsible for the blockchain solution governance. However, collaboration between the different participants in accessing and sharing SC data is necessary for the solution adoption and scalability. Organisation C changed its governance model form a joint venture to a collaborative model to encourage the adoption of its solution by other major ocean carriers.

b. Organisational factors

- Level of digitalisation in place.

Blockchain is a digital technology and hence it is influenced by the level of digitalisation adopted in the organisations using the technology. This was relevant in the leather case study since the manufacturing processes are mature and low technology, raising major considerations regarding leather identification and blockchain data capture. It also affected the ability of the different parties to adopt organisation C shipping platform.

- Product characteristics and consistency across the different supply chains

This is important for SC traceability as products might be identified differently, affecting the solution data capture points and input methods. In the leather case study, individual hides had to be tracked throughout the multiple tanning processes, while in the textile case study, the fibre producer can physically identify their fibres during the auditing processes.

- Business processes characteristics and consistency across the different supply chains

This is similar to the product characteristics, the manufacturing processes can influence the blockchain solution configuration, data capture points and input methods. The leather tanning processes characteristics makes it difficult to maintain hide traceability and identification while the textile fibre manufacturing processes enabled product identification and traceability. The difference in shipping processes between countries, sectors, and customers has raised high customisation requirements for the blockchain solution to support its adoption and scalability.

c. External factors

- Availability or development of industry standards for data sharing across the supply chain.

Organisation A highlighted the lack of standards for SC traceability as a key challenge for leather traceability. Organisations B and C solutions were developed on existing standards to ensure wide adoption.

- Support from regulatory bodies, standards organisations, and NGOs to develop and adopt blockchain technology in the supply chain.

Organisation A stressed the need for legislation to enforce compliance through blockchain adoption in the battery industry. The organisation was able to secure government funds to support its investigation of blockchain in enabling leather traceability. Having a support from standards organisations and NGOs is a key part of organisation B blockchain solution scalability plan where the organisation is working closely with Canopy organisation to identify the other sustainable SC partner to adopt its solution. Organisation C is keen on engaging customs authorities and banks in its solution to optimise the shipping processes.

Chapter 9: Blockchain Use Cases and Executive Workshop Analysis

This chapter presents the results of two studies aimed to validate and complement the case studies findings and support research findings generalisation: First, a qualitative analysis of reported blockchain use cases to identify the motivations behind blockchain adoption, the different application areas and the key industry characteristics influencing blockchain adoption and application in the supply chain (Section 3.3 describes the research methodology and the selected use cases for analysis). Second, an executive workshop that investigated the motivations, inhibitors, and requirements for blockchain-enabled SC traceability (Section 3.4 describes the workshop design and questions).

9.1 Analysis of Reported Blockchain Use Cases in Practice

9.1.1 Industry motivations for blockchain adoption in the supply chain

Table 28 presents the motivations emerged from Nvivo analysis and their frequency of citation across the six sectors. Enabling traceability (mentioned in 72% of the 50 cases) and improving transparency (68%) are the top two motivations for blockchain projects across all industries.

The results also indicate how the main motivations vary across industries. For example, customer service and sustainability are the dominant motivations identified in the automotive and textile industries, while cost reduction is a major motivation in the shipping and logistics industry. Likewise, improving efficiency and security are frequently identified in the aerospace, shipping, and pharmaceutical industries, while ensuring product quality and risk management are among the most frequently cited motivations in the food and beverage and pharmaceuticals industries. Ensuring product authenticity is among the top three motivations in the textile and clothing industry. We present and discuss each identified industry motivation based both on this study and the case studies in the next chapter.

Table 28. Main industry motivations for blockchain adoption in the supply chain (n = 50)

Main Motivations - Emerged Themes	Examples of coded cases [Use case No][19]	Frequency of coding						
		Total	Automotive (15)	Aerospace (6)	Food and Beverages (8)	Textile and Clothing (9)	Shipping and Logistics (6)	Pharmaceutical (6)
Traceability	Porsche [15]	**36**	**5**	**4**	**8**	**9**	**4**	**6**
Transparency	U.S Cotton Trust [49]	**34**	**5**	**4**	**7**	**8**	**6**	**4**
Efficiency	AIA [21]	**26**	**3**	**6**	**3**	**3**	**6**	**5**
Customer Service	JLR [13]	**20**	**8**	**-**	**5**	**4**	**1**	**2**
Security	Maersk Group [22]	**20**	**6**	**3**	**2**	**1**	**5**	**3**
Sustainability	Ford Motors [7]	**16**	**6**	**-**	**2**	**8**	**-**	**-**
Risk Management	Tech Mahindra [41]	**13**	**-**	**-**	**4**	**2**	**3**	**4**
Authenticity	Arianee Consortium [44]	**12**	**2**	**-**	**3**	**5**	**-**	**2**
Quality	Walmart [29]	**12**	**-**	**1**	**4**	**3**	**-**	**4**
Cost Reduction	MSC [27]	**11**	**1**	**2**	**-**	**2**	**6**	**-**
Visibility	E-live Stock Global [33]	**8**	**-**	**1**	**4**	**1**	**-**	**2**

[19] Table 11

9.1.2 Blockchain application areas in the supply chain

The academic literature does not provide detailed evidence on specific blockchain application areas in the supply chain beyond the high-level motivations influencing blockchain adoption. The analysis revealed further insights into the specific types of blockchain applications in practice (Table 29). Three main application areas can be identified:

1) Blockchain application for improved product tracking and traceability

Around 72% of companies reported using blockchain to track product information, including most cases in the automotive, textile and apparel, and food and beverage industries. Two different perspectives emerged:

- *Product tracking and traceability across the supply chain*: Most applications applied blockchain to capture, track and trace specific information about a product across its supply chain. Importantly, three different types of information are tracked. First is *product provenance and sourcing information*, e.g., to ensure products sustainability (Volvo [6] and C&A Foundation [47]). Second is *product-related environmental impact information*, e.g., CO_2 emissions (Mercedes-Benz [8]). Third is information related to *product transportation and storage conditions* e.g., to ensure product quality and safety (Modum [36]).
- *After-sales product tracking*: This application area was evident in the automotive industry for the tracking and traceability of vehicle data and its subsequent use in mobility and vehicle servicing applications (Lamborghini [2] and Volkswagen [11]).

2) Blockchain applications to enable, support, or improve specific business processes

66% of the companies in our sample use blockchain to improve specific business processes in two ways:

- *Automation of business processes,* e.g., the automation of manual SC finance processes (Hyundai [1]) and of quality checks with the use of IoT and smart contracts (Modum [36]).
- *Digitalisation and optimisation of business processes*, e.g., the digitalisation of shipment document handling processes (Cargo Smart [24]), engine data management in aerospace industry (Block Aero [18]), and suppliers' contracts management (Mercedes-Benz [9]).

3) Blockchain application for an enhanced customer experience

Improving the customer experience is a dedicated goal for blockchain in several industries (16 reported use cases), e.g., customer reward schemes in the automotive industry (Daimler AG

[14]), providing customers with information about a product to guarantee its authenticity and/or provenance (LVMH [42] and Carrefour [31]), and providing customers with e-leaflets to access drug-related information and ensure its authenticity (Pharmaledger [38]).

Table 29. Main application areas for blockchain in the supply chain (n = 50)

Main Blockchain Application Area- Emerged Themes	**Frequency of Coding**						
	Total	**Automotive (15)**	**Aerospace (6)**	**Food and Beverages (8)**	**Textile and Clothing (9)**	**Shipping and Logistics (6)**	**Pharmaceutical (6)**
Product Traceability	36	11	2	8	9	1	5
Business Process	33	8	6	1	7	5	6
Customer Experience	16	8	-	2	3	1	2

9.1.3 Industry characteristics influencing blockchain supply chain applications

Five principal industry characteristics that influence blockchain applications in the supply chain were derived from the analysis (Table 30): *product characteristics*, *business processes characteristics*, *supply network configuration characteristics*, *industry standards and regulations*, and *market conditions and customer demands*.

1. Product characteristics

The product characteristics influence blockchain application areas. High value and innovative products potentially justify the investment and effort required to adopt blockchain (e.g., automotive batteries and high-end luxury products). High risk (e.g., food products), safety-critical (e.g., aircraft parts and drugs), and high social and environmental impact (e.g., textile products) products are seizing on potential blockchain solutions as organisations seek to ensure the authenticity, quality, traceability and/or sustainability of these products, e.g., LVMH [42] and Hugo Boss [43] for high-end products; the SITA MRO Blockchain Alliance consortium [20] for aircraft parts traceability and verification; and Walmart [29], MSD [37], and Volkswagen [5] for tackling products' social and environmental impact.

2. Business and manufacturing process characteristics

Blockchain's core capabilities have made the technology attractive for improving business processes with high security and performance requirements, e.g., shipping document management (Port of Rotterdam [25]) and aircraft asset data management (Block Aero [18]). For blockchain applications in manufacturing industries, it is important to consider the

manufacturing process characteristics to address traceability (e.g., mixing), sustainability (e.g., CO_2 emission and waste management) and regulatory requirements (e.g., testing and verification requirements), e.g., Mercedes-Benz [8,9].

3. Supply network configuration characteristics

The size, complexity and geographical dispersion of the supply network are important aspects influencing both engagement in blockchain solutions and targeted application areas. These factors are addressed in multiple blockchain use cases, including BMW [3] and SITA MRO Blockchain Alliance [20]. Many organisations initially experimented with blockchain on a smaller or local supply chain before its implementation at scale, e.g., C&A Foundation [47].

4. Industry standards and regulations

Standards and regulations operating in a sector may support or inhibit blockchain adoption and vary across the different industries (Hughes, 2020; Wang *et al.*, 2016). Regulations to provide proof of product provenance are increasingly prevalent in many industries. For instance, the food industry has stringent food safety and quality regulations. Organisations in this industry are interested in applying blockchain to improve product traceability and recall processes e.g., Carrefour [31] and Walmart [29]. Other industry examples include the MSD [37] project with the USA FDA, investigating blockchain use for drug traceability to comply with the DSCSA regulations. Mandated industries like aerospace have stringent regulations regarding their manufacturing processes that encourage blockchain application to streamline product verification and maintenance processes e.g., Block Aero [18]. Standards organisations and NGOs also play an important role in blockchain adoption in the textile and apparel industry as they are actively engaging in blockchain projects, e.g., U.S Cotton Trust [49].

5. Market and customer demand characteristics

Customer requirements can be a powerful driver for organisations' investments. The analysis identifies a wide spectrum of customer demands that have been considered in several blockchain projects across the different industries, including demand for performance (Lamborghini [2]), demand for security (ALIBABA and China Merchants Ports [23]), demand for authenticity (Arianee [44]), demand for provenance (Carrefour [31]), and demand for sustainability (C&A Foundation [47]).

Table 30. Main industry characteristics influencing blockchain applications in the supply chain (n = 50)

Industry Characteristics	Identified Characteristics	Examples [Use case No]	Frequency of coding						
			Total	**Automotive (15)**	**Aerospace (6)**	**Food and Beverages (8)**	**Textile and Clothing (9)**	**Shipping and Logistics (6)**	**Pharmaceutical (6)**
Product Characteristics	**Total**		33	7	4	8	8	-	6
	High social and environmental impact	Cobalt [4,5,6]	14	6	-	2	6	-	-
	High-Value Product	Wine [34]	10	2	3	3	2	-	-
	Safety-Critical Product	Drugs [41]	10	-	1	4	-	-	5
Business Process Characteristics	**Total**		19	3	6	1	1	5	3
	High BP value adding	Certification process [44]	9	1	3	-	-	4	1
	Impact on performance	Documents management [22,24,26,27]	14	1	6	1	-	4	2
	Social and Environmental Impact	Beef production [32,33]	3	2	-	-	1	-	-
Supply Network Configuration Characteristics	**Total**		9	2	2	2	1	1	1
	Geographical Expansion	Global [3]	4	1	-	1	1	1	-
	SC complexity	High complexity [20]	7	2	1	1	1	1	1

	Supply network size	Large size [25]	3	-	2	-	1	-	-
Industry Standards and Regulations Characteristics	**Total**		20	2	3	4	5	2	4
	Compliance to existing standards and regulations	OECD [6]	13	2	1	2	3	1	4
	Development of industry-wide standards	Shipping standards [22]	3	-	1	1	-	1	-
	Support for technological developments	DSCSA [37]	4	-	1	1	2	-	-
Market and Customer Demand Characteristics	**Total**		24	5	-	7	7	2	3
	Demand for authenticity	Luxury items [44]	14	2	-	6	3	0	3
	Demand for performance	Shipping process [24]	3	1	-	-	-	2	-
	Demand for provenance	Food products [29]	10	-	-	6	4	-	-
	Demand for security	Drugs information [38]	5	1	-	1	1	1	1
	Demand for sustainability	Textile products [47]	9	2	-	1	5	1	-

9.2 Summary of the Executive Workshop

This section presents the findings of an executive workshop conducted at the end of the blockchain pilot project in the leather supply chain (LSC) (Please refer to Section 3.4 for detailed information about the workshop design and participants). We include participants quotations in italics where relevant.

9.2.1 The main motivations, most interested stakeholders and existing certification and regulatory schemes for enabling traceability in the supply chain

The first group answers were presented by the Innovation and Sustainability Director (Leather Supplier)[20]. The group identified the main drivers for SC traceability, including:

1. Financial Incentives. The group highlighted financial incentives as a key driver for enabling traceability in the supply chain. The supply chain is not comprised of the main value-adding partners only. There are certification bodies, NGOs, financial institutions, and investors who rely on SC information to evaluate it and invest in it. The group indicated that traceability systems can generate information that can be used for SC verification and validation to meet lender expectations, ensure the SC credibility, and encourage investments and pension funds.

"Credibility, authenticity is required before - it's not just the end consumer decides to buy a product that everyone else decides to invest in."

2. Identification of product provenance. As it is an increasingly important requirement from customers, investors, and regulatory bodies.

"How do new products prove provenance? Or how do we prove the provenance of different or new products compared to the old ones?... you never see that kind of investor-related information presented for those products."

3. Respond to customer demand and strengthening the brand position. The group highlighted brand vulnerabilities as a key driver for traceability that can be pushed upstream the supply chain.

4. Improving SC Transparency. Traceability can help in exposing SC practices and improve transparency. The group discussed the importance of defining the purpose of traceability and the type and level of information you would like to expose in the supply chain.

[20] All quotes in this section are of the presenter

In the LSC for example, it might be to ensure that the hide did not come from an area of deforestation, and/or the animals/farmers were treated properly.

5. Sustainability. The fifth driver for SC traceability is to capture sustainability information, e.g., carbon footprint and life cycle analysis (LCA). The group highlighted the increasing interest of organisations in reducing carbon footprints and conducting LCA for their products. They identified the growing use of carbon currencies to manage, exchange and reduce carbon emissions across the SC. With the growing use of electric vehicles, the group predicted the transfer of carbon emission amounts generated from end vehicles to the manufacturing of their parts and subcomponents.

"We're going from a system where cars used to have an emission which came out of the tailpipe to now being an emission which is in manufacturing. We need to know the LCA, the product, to produce the embedded footprint of the car rather than tailpipe emissions. The whole metric has changed."

6. Responsible sourcing. This is achieved by knowing the stakeholders involved in the SC.

The group identified the main value-adding SC partners as key stakeholders required to achieve traceability (i.e., abattoir, tannery, etc.). The group also noted the global leather SC challenges and the very large number of parties involved, including agents and sub tanneries. They also considered certification bodies, NGOs, financial institutions, and investors as important stakeholders, requiring SC traceability information to validate and verify it.

"You've got the certification bodies, the NGOs, financial institutions, investors, who are relying on the information that's being presented from that supply chain."

Regarding existing schemes in support of traceability, the group mentioned that there are many certification schemes that imply traceability but none of them actually measure or verify traceability, e.g., the ISO standard for LCA. However, the Leather Working Group is the only scheme that guarantees some degree of traceability.

"There's lots of them, but the certification schemes that are out there don't actually measure traceability. They imply traceability, so when you have an ISO standard, for example, for a lifecycle analysis, it implies the fact that you know where the material comes from, because you can work out the footprint of it. But it doesn't actually verify traceability of the material that goes into your product."

9.2.2 The main inhibitors, resisting stakeholders and operational challenges that hinders traceability in the supply chain

The second group answers were presented Senior Manager (first NGO)[21]. The group identified the main challenges for enabling traceability in the LSC, including:

1. Supply chain complexity. Both in terms of the number of SC tiers and actors.

2. Degree of motivation and investment from the industry. The group indicated that traditionally, most traceability systems are in the beef industry due to the human consumption component of the value chain and leather being perceived as a by-product. This might affect the industry's willingness to pursue leather traceability.

3. Costs of required investments to enable traceability: The group considered cost to be a big inhibitor in terms of (1) financial and economic costs, (2) opportunity costs associated with the best next alternatives, (3) resources, time required and management burdens for the management and maintenance of the traceability system, and (4) level of appropriate traceability, which affects the number and range of parties involved and the level of collaboration, partnership and coordination required for traceability. The group indicated that the level and complexity of traceability can be affected by the size of the problem that traceability is trying to solve.

The group argued that many stakeholders can be included/excluded in a traceability system depending on the selected level of traceability and the complexity of the traceability methods. They identified the key factors that can make any stakeholder reluctant or resistant to participate in a traceability solution:

- **Imbalance between the level of incentive and the amount of information and effort required.** The group provided an example of the automotive LSC seat assembler where a single seat can be made of approximately 30 different hides. Enabling traceability of each hide going into a seat would require signification time, efforts and administrative chores.

"The unwillingness of the resistant typically, will arise when you have some, you know, an asymmetry or imbalance between, sort of, the, the level of incentive or the reward, the

[21] All quotes in this section are of the presenter

recognition and, sort of, the amount of information or the level of effort required to participate in this type of traceability".

- **When the SC actor is ignorant of their problems:** The group recognised that some actors might not be willing to participate in a traceability system because it will expose problems in their operations or supply chains.

"Any actor who may sort of be considered as having sort of these uncertain unobservable problems, may be unwilling to, sort of, lean in, and maybe there might be some resistance in terms of their willingness to participate."

- **SC actors perceive traceability as exposing vulnerabilities or good practices:** The group considered traceability a double-edged sword that can expose vulnerabilities and/or good practices. Hence, how the stakeholders perceive traceability will affect their willingness to participate in the traceability solution.

- **Who is paying for the traceability solution?** The cost of developing and maintaining the traceability system can be significant depending on the selected level of traceability. Not all stakeholders will be willing to invest in traceability unless there are clear benefits that exceed the costs.

- **Who is regulating and verifying the traceability solution?** The group considered this as a key factor affecting the stakeholder's willingness to participate in traceability, e.g., if the traceability system is mandated by government such as the cattle traceability scheme in the UK, it will enforce participation. Otherwise, participants might be reluctant to participate.

The second group identified several operational challenges that can inhibit SC traceability, including (1) Having trust issues between the different actors, (2) Required level of collaboration and partnership to enable traceability, (3) Data availability issues, (4) Lack of governmental support to the development of traceability systems, (5) Lack of standardised operational approach in the sector, (6) Lack of standards for appropriate level of traceability in the sector, (7) Inability to define the amount of traceability information that effectively answer the traceability problem, and (8) Need for an established validation process for traceability that improves trust in the shared data.

9.2.3 The main costs and benefits for enabling SC traceability

The third group answers were presented by the Managing Director (Second NGO)[22]. The group identified and listed the costs and benefits from enabling SC traceability as presented in Table 31.

Table 31. Supply chain traceability costs and benefits

SC Traceability Costs	SC Traceability Benefits
▪ Costs for setting up the traceability system. ▪ Integration costs of the traceability system with existing systems. ▪ Auditing costs for the traceability system. ▪ Resources and personnel costs required for managing and enabling the traceability system. ▪ Research and development costs. ▪ Potential drop in efficiency at the first stages of implementation, especially when new processes are introduced to enable traceability.	▪ Provenance and that it can be the sole purpose of traceability. ▪ Quality assurance from having visibility and knowledge about the SC members, materials, and processes. ▪ Increase in market share by having a competitive advantage and demonstrating traceability to customers. ▪ Brand strengthening and reputation. ▪ Improved risk management through better visibility. ▪ Better reporting, increased trust and awareness which can positively influence investors. ▪ Responsible sourcing and ethics by showcasing good practices and ethical behaviour. ▪ Public relation and marketing boost by capitalising on the good practises. ▪ Setting standards by being a leader and a pioneer in enabling traceability and demonstrating how it should be down. ▪ Building close partnerships across the supply chain that could increase confidence and willingness of the different SC partners to invest as they are assured of continued business and future relationships.

The third group also indicated that every SC partner would incur some costs to invest in the traceability infrastructure. This cost can be perceived differently by the SC partners depending

[22] All quotes in this section are of the presenter

on their profit margins. They mentioned that research has proven that consumers are willing to pay extra for sustainable products so ultimately the end customer is the one paying for traceability. However, the increase in prices is not usually transmitted upstream the SC to support the traceability investment incurred by the SC partners which affect their incentive to support traceability. Referring to the LSC, the group suggested that the demand for traceability comes ultimately from consumers, brands and OEMs and goes backwards in the SC. The abattoirs are the least interested partners in enabling leather traceability and/or investing in leather identification technologies as they will sell their product anyway, raising the need to incentivise them to do so. Leather tanneries would have to pay them more to get traceability at the abattoir and this would be reflected on their customers' margin and so forth until the price is raised for the end consumer.

In terms of who benefits the most, the group indicated that everyone benefits including consumers from having more trust in their products, and the society and planet benefit from improved SC traceability and transparency by encouraging good behaviour. They mentioned that the benefits might not be equal among the SC partners. From a quality perspective, it might benefit the SC partners responsible for ensuring products' quality and providing that assurance to the downstream partners. From a commercial perspective, the brands and OEMs benefit the most from traceability as they are the one who ultimately pay for their upstream traceability costs. Finally, the group stressed the need to define what you really want from traceability in order to specify its costs and benefits.

9.2.4 The main business processes, technical, integration and governance challenges from blockchain enabled traceability in the supply chain

The fourth group answers were presented by the Project Manager (OEM). The group discussed several traceability implications on some business processes, including:

- **Sourcing process.** Having a traceability system might help tackle some of the sourcing issues by ensuring product quality and provenance. However, it can also raise challenges in the traditional cost-driven sourcing processes and enforce its optimisation by better understanding product sources and traceability.
- **Customers offering processes.** By realising higher levels of traceability, organisations ought to consider the additional value they are providing to their customers. They need to better understand the customer demand and what value proposition is presented to them.

- **Strategic planning processes.** SC traceability leads to the accumulation of large amounts of data that must be analysed and combined in the SC strategic planning processes. Data analysis and utilisation is a further challenge from having higher level of traceability.
- **Continuous exposure of vulnerabilities and bad practices.** SC traceability will expose bad practices and poor processes across the supply chain. The SC partners have to plan their response to this exposure.
- **Level of trust in the supply chain.** Considering the SC complexity and need for granularity, traceability can be aimed at different levels at the different SC stages. In the automotive LSC, the group indicated that higher granularity can be targeted at the upstream SCs of the tanneries who are potentially the trust point in the supply chain while traceability downstream the tanneries can be driven by the OEM value proposition.
- **Compliance to emerging standard and regulations.** Organisations ought to comply with existing and emerging regulations regarding traceability requirements and technologies.
- **Adoption of complementary technologies.** Enabling SC traceability can encourage the adoption of certain supportive technologies affecting current business processes.

The fourth group identified the key technical and integration challenges related to blockchain adoption for SC traceability as follows:

- Lack of knowledge about blockchain and its value proposition.
- Continuous development of blockchain technology for traceability.
- The ability to measure traceability costs versus ensuring sustainability
- Cost of solution scalability in a feasible way.
- Understanding the current capabilities of existing systems across the SC and their agility to support integration.
- The security and commitment of suppliers regarding the use of the traceability system.

The fourth group also considered the issues of GDPR and data accessibility for the governance of the traceability system. They considered the solution configuration to be modular enabling different access rights to the different SC partners depending on the type of data and who they want to share it with. Referring to the automotive LSC, they indicated that leather tanneries can share their upstream data with multiple OEMs. However, the OEM will only have access to its own SC data. They also stressed the need to ensure data security and

protection from being misused by any SC partner. Therefore, there is a need for data segmentation considering the customer and user of the blockchain traceability system. This configuration would be developed and governed by the blockchain provider.

9.2.5 The optimal level of traceability in the leather supply chain

All the four groups were asked to identify the optimal level of traceability in the LSC:

- The first group indicated that business-to-business traceability is sufficient considering back-stage work is done and there is an independent certification body to verify the credibility of the traceability system to provide a guarantee to the customer in a simple way.

"Business-to-business detail granularity is essential to be able - for the final brand - to be able to present something simple to the consumer, without having to give them all of the level of detail that goes in through that supply chain (Innovation and Sustainability Director)."

The group also stressed the importance of having an accreditation scheme for traceability systems to ensure their credibility and suggested that it can be facilitated by blockchain.

- The second group indicated that the level of traceability depends on its purpose and can be affected by the SC complexity. *"It depends on what you want to solve for and what you want to prove (Senior Manager)."* Referring to the LSC, they indicated the importance of having traceability at the farm and/or individual animal level considering the upstream SC complexity and how the cattle move across multiple farms during their lives. They considered available identification techniques such as RFID and ear tags to enable higher level of traceability along with blockchain that enables traceability information accumulation across the supply chain.

"Blockchain offers from our perspective, the ability to basically layer - stack up all of the different data sets and criteria certifications, labelling schemes at different nodes in the value chain, and then capture those and move those with the product as they move through different levels of processing, as they move between continents and countries and different companies (Senior Manager)."

The group also stressed that end-consumers are not looking for the details of higher levels of traceability but rather to know that they can trust the companies they are buying from and they are doing the work they are claiming to do.

- The third group indicated that organisations should aim at 100% traceability across the supply chain. However, they acknowledged the practicalities of implementing traceability systems and how they differ across different sectors, countries, and continuants.

"We said the vision is 100% traceability. That's what we've got to be aiming for (Managing Director)."

They referred to existing traceability schemes in Europe and America that support higher level of traceability and the lack of similar systems in some of the high producing low-income countries in Africa or Asia. They highlighted the relation between the level of traceability in the meat and leather industries when leather is a by-product of meat compared to the required levels of traceability for leather coming from exotic species.

- The fourth group indicated that higher level of traceability and granularity should be aimed at the highly variable areas of the SC such as the direct and indirect cattle supply to the abattoirs. From that stage downwards, the group suggested traceability at a relatively lower level of granularity at the batch level.

"Where we identify there being a higher need for granularity is actually in that indirect supply area where you're looking at what's going into the tannery. So identifying that actually, you need higher granularity in the first instance… From then on, it becomes less about tracking individual components and tracking batches instead. So essentially, to answer it is that in that indirect, highly variable area, that's actually probably where you'd want most transparency and tracking (Project Manager)."

They also indicated that changing the perspective from enabling traceability for sustainability to use it in planning and live tracking, raises the need to evaluate the benefits and costs of having such a tool and might require different levels of traceability. They suggested to start by having a low level of granularity while investigating and gaining better understanding of the benefits of going deeper.

9.2.6 Summary of the workshop findings

The workshop provided important considerations regarding the drivers, requirements, inhibitors, and main factors influencing SC traceability systems implementation. The workshop groups had some agreement but diverse views on the optimal level of traceability, highlighting the need for more research to investigate this important topic. We discuss and compare the workshop findings along with the empirical findings from the case studies and the academic literature in the next chapter.

Chapter 10: Discussion

The case studies provided empirical evidence and an in-depth understanding of the main motivations, pre-requisites, and challenges for blockchain adoption and application in the supply chain. They also enabled the identification of the main inter-organisational and intra-organisational factors that play a crucial role in the decision-making, deployment and scalability of blockchain SC solutions. The case studies' findings were complemented with the growing academic and practice literature and an executive workshop that presented additional empirical insights into the prominent area of blockchain-enabled SC traceability.

This chapter provides detailed answers to the research questions and proposes new conceptual and decision frameworks based on the research findings. Section 10.1 summarises the main motivations for blockchain adoption and the key industry characteristics influencing blockchain adoption and applications in the supply chain in. Section 10.2 presents comprehensive lists of the main pre-requisites and challenges influencing blockchain adoption in the supply chain. Section 10.3 identifies the main factors influencing the decision-making, adoption, and scalability of blockchain in the supply chain. Section 10.4 presents a decision framework that guides the decision-making regarding blockchain adoption and the selection of potential application areas in the supply chain. Section 10.5 discusses in more detail one of the most targeted application areas for blockchain, which is enabling supply chain traceability in Finally, Section 10.6 identifies the different theoretical perspectives that can be adopted to advance blockchain-SCM research.

10.1 The Main Motivations and Key Industry Characteristics Influencing Blockchain Adoption and Application Areas in the Supply Chain

This research revealed specific sectoral characteristics and motivations that influence blockchain applications areas in the different industries. We summarise our research findings in the first conceptual framework that takes a cross-industry lens to blockchain adoption in the supply chain in Figure 37. The left-hand side of the framework presents the main industry motivations driving organisations to adopt blockchain in their supply chain. Each identified motivation can be related to an existing industry challenge motivating blockchain adoption (e.g., tackling lack of transparency, limited traceability, known inefficiencies or high costs). The right-hand side of the framework presents five industry characteristics and their key sub-

characteristics identified from our research work, including the internal characteristics of a specific industry's supply chain (i.e., SC configuration, product and business processes) and the external environment (i.e., industry standards and regulations, government standards and regulations, sustainability requirements and market conditions). Both the industry motivations and inherent sectoral characteristics influence the specific SC challenges and the application area targeted by blockchain.

The framework provides several contributions to the academic literature by empirically validating some of the identified motivations in the literature from a cross-industry perspective and by addressing the literature gap in investigating the influence of industry characteristics on blockchain adoption in the supply chain. We discuss the elements of the framework next.

10.1.1 The main motivation for blockchain adoption in the supply chain

The main motivations identified from the cross-case studies and the practice literature analysis provide some affirmative evidence to the motivations proposed in recent academic literature reviews, including Jardim et al. (2021), Treiblmaier et al. (2022) and Wang et al., (2019) such as transparency, traceability, product authenticity and sustainability. However, our analysis also highlights additional important motivations, including customer service, risk management, and product quality assurance which were evident in the case studies and the practice literature analysis. Furthermore, improving efficiency and SC optimisation is a further important motivation apparent in our analysis but were infrequently discussed in the literature. From our combined findings, we summarise the top ten motivations for blockchain adoption in the supply chain below.

1. Transparency

Blockchain can provide transparency through its distributed ledger that allows all the nodes in the network to have access to an exact copy of the database and thereby ensure a single source of truth (Lashkari and Musilek, 2021; Treiblmaier, 2020). In the supply chain, this can lead to improved SC transparency and visibility through enhanced information sharing and SC knowledge. Improving transparency is one of the most acknowledged benefits of blockchain adoption in the academic literature (Aras and Kulkarni, 2017; Cole *et al.*, 2019; Jardim *et al.*, 2021; Kamble *et al.*, 2020; Kshetri, 2018; Maull *et al.*, 2017; Viriyasitavat and Hoonsopon, 2019), one of the main motivations for blockchain adoption in all four case studies (Table 22), and the second most cited motivation across all the sectors in the reported use cases analysis (Table 28).

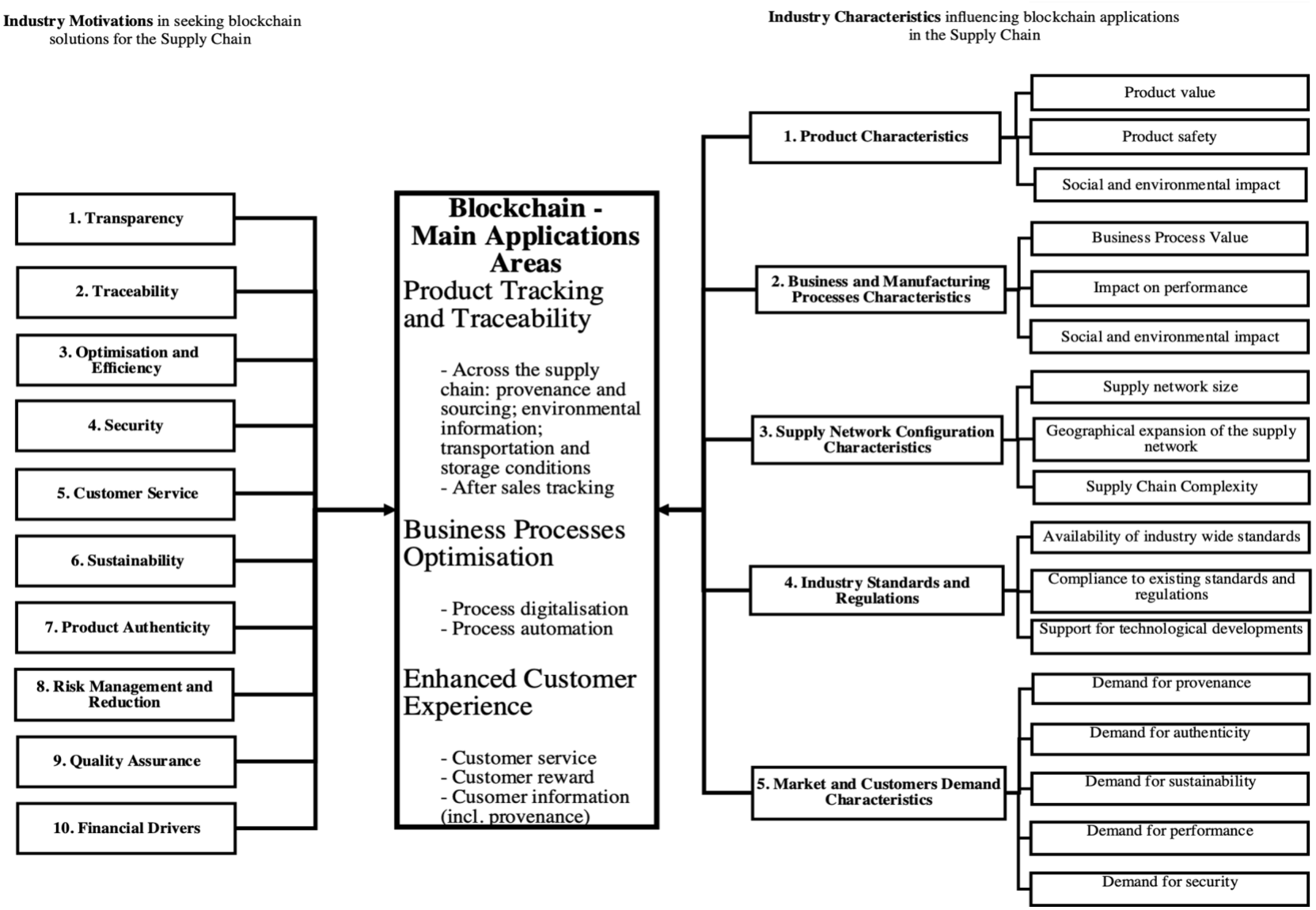


Figure 37. A conceptual framework the main motivations, application areas and industry characteristic influencing blockchain adoption in the supply chain

2. Traceability

The immutable chronological record of transactions makes blockchain a potentially valuable technology for traceability. Blockchain adoption to enable SC traceability has been investigated by academics in almost every industry (Table 2). In the case studies, enabling SC traceability had been a significant motivation for blockchain application in all case studies (Table 22). It was also the most cited motivation in the practice literature analysis (Table 28). Blockchain application for SC traceability is discussed further in Section 10.5.

3. SC optimisation and efficiency

Blockchain can support business processes and SC optimisation by improving information sharing, eliminating intermediaries, and enabling process digitalisation and automation with the use of smart contracts. All of these can positively impact operations and SC performance and efficiency (Casino *et al.*, 2019; Queiroz *et al.*, 2019). Blockchain can also add more capabilities to existing platforms and be combined with other technologies to improve business performance, including IoT, RFID, and cloud manufacturing (Christidis and Devetsikiotis, 2016; Viriyasitavat and Hoonsopon, 2019). SC optimisations and efficiency were also evident in the case studies (Table 22), and the reported use cases analysis (Table 28).

4. Security

Blockchain provides a technical solution that improves SC security and ensures the reliability of shared information in real-time (Glaser, 2017; Wang, Han, *et al.*, 2019). Blockchain and smart contracts can enforce policies and procedures in the system through automation and digitalisation (Queiroz *et al.*, 2019). Enabling security underpins almost all blockchain applications as it is the technology's most powerful attribute. Blockchain's security was one of the main motivations for selecting the technology in all four case studies (Section 8.2.1) and was strongly evident in the reported use cases (Table 28).

5. Customer service

Every business seeks to meet customer requirements, expectations and demands. There is an increasing demand for provenance and authenticity (Wang, Han, *et al.*, 2019), and a rising awareness regarding sustainability issues, stimulating many businesses to invest and demonstrate their sustainable practices (Kayikci *et al.*, 2020; Mayyas *et al.*, 2019). Although not recognised as an important driver for blockchain adoption in the academic literature, the analysis of use cases highlights customer service as the fourth main motivation for blockchain adoption (Table 28) and it was also evident in the case studies (Table 22).

6. Sustainability

The trusted system provided by blockchain helps ensure SC processes' integrity. For example, using blockchain in the sourcing processes enables organisations to assert their commitment to sustainable practices (Kshetri, 2018; Saberi *et al.*, 2019). Sustainability has been recognised as a primary motivation for blockchain application in the two automotive case studies (Table 22), and many reported use cases in automotive, food and beverages, and textile and apparel industries (Table 28). Sustainability has also been recognised as the main motivation for blockchain adoption in the academic literature across different industries (Cole *et al.*, 2019; Feng *et al.*, 2020; Park and Li, 2021).

7. Product authenticity

Blockchain can help guarantee products authenticity by verifying their provenance and movements across the supply chain, which is valuable for all SC parties, including customers who are increasingly demanding assurances for product provenance and authenticity (Agrawal *et al.*, 2021; Kayikci *et al.*, 2020; Malik *et al.*, 2018; Wang, Han, *et al.*, 2019). In addition, fighting counterfeit goods is a major challenge in several industries. Hence, the use of blockchain to prevent counterfeiting has been recognised in multiple sectors, including food (Bechtsis *et al.*, 2019), automotive (IBM, 2018), and pharmaceutical (Tseng *et al.*, 2018). Ensuring product authenticity was a main motivation for organisation B. Similarly, authenticity was evident in the reported use cases for high value and safety-critical products in the automotive, textile and apparel, and pharmaceutical industries (Table 28).

8. Risk management and reduction

The use of blockchain can help overcome or mitigate SC risks (Mann *et al.*, 2018). The immutable distributed ledger enables all relevant SC parties to access information in almost real-time, which can potentially help in mitigating the bullwhip effect, one of the most recognised SC risks (van Engelenburg *et al.*, 2018; Jardim *et al.*, 2021; Pournader *et al.*, 2020). Blockchain can also reduce cybersecurity risks by making it impractical to hack the system and relatively easy to identify false participants (Glaser, 2017; Li and Zhou, 2020). Risk management and reduction with blockchain were highlighted in organisation A's battery supply chain and organisation C shipping solution. Risk reduction was also a main identified motivation in the reported use cases analysis (Table 28).

9. Quality assurance

Ensuring product quality is a significant motivation for blockchain applications, especially when non-conformance can have substantial social, environmental or economic impacts. This is particularly important in pharmaceuticals and food and beverages industries, where the use of inferior products can affect the health and safety of consumers (Cole *et al.*, 2019; Kayikci *et al.*, 2020; Wang, Han, *et al.*, 2019). Quality assurance was highlighted in the automotive battery and textile case studies and the reported use cases (Table 28).

10. Financial drivers

Many researchers have anticipated the potential financial gains from blockchain adoption by eliminating intermediaries (Cole *et al.*, 2019; Kamble *et al.*, 2020; Saberi *et al.*, 2019), facilitating SC finance (Choi, 2020; Pournader *et al.*, 2020; Tsiulin *et al.*, 2020), and enabling automation and digitalisation (Queiroz *et al.*, 2019). However, there is limited evidence about the amount of savings attainable from blockchain adoption in the academic and practice literature.

Different financial drivers have been highlighted for organisation C, including opportunities for generating new revenue streams and reducing costs. Table 18 presents real measured benefits from adopting Solution-C. The executive workshop also identified several financial drivers from blockchain-enabled traceability, including providing investors with reliable information.

It must be noted that there can be other motivations not covered in the framework pursued by the different organisations. For example, motivations such as SC visibility and competitive advantage were highlighted in the analysis but are not included in the framework. We argue that visibility is strongly linked to and falls under achieved traceability and transparency through blockchain. This argument aligns with Sodhi and Tang (2019). Improving SC visibility was a strong motivation for blockchain adoption evident in the case studies (Table 22), referring to blockchain-enabled transparency and traceability. However, visibility was scarcely cited in the practice literature analysis compared to transparency and traceability (8 cases).

The other motivation is to gain a competitive advantage. We argue that competitive advantage cannot be an industry-wide motivation but rather an organisational one. If the whole industry uses blockchain, it becomes more of a business-as-usual practice rather than a competitive one. This opportunity to gain a competitive advantage is currently available due to the limited but growing use of blockchain. However, it will reduce when using blockchain is more normalised. Organisations who are interested in investigating and adopting blockchain in their supply chain

are proud to call themselves "*pioneers*", "*leaders*", "*first blockchain implementation*", etc. These types of statements were evident in 10 reported used cases. It was also apparent in the three blockchain case studies where organisations A (leather case study), B and C desired to be leaders in their industry and gain a competitive advantage by adopting blockchain.

10.1.2 The main application areas for blockchain in the supply chain

Three inter-related application areas for blockchain in the supply chain have been identified in the combined research findings, including:

(1) Tracking and traceability of products information across different SC stages: Blockchain has been mostly implemented to enable product tracking and traceability within different supply network configurations and industries. Different motivations might lead to blockchain application in this area, such as ensuring authenticity, sustainability, and quality. Many scholars investigated blockchain applications to enable product traceability in the supply chain (Table 2). It was also the main application area in the automotive leather and the textile case studies (Table 22) and numerous reported use cases [2, 4,36,48].

(2) Improvement of business processes: Many researchers anticipated blockchain potential in transforming business processes (Christidis and Devetsikiotis, 2016; da Cruz *et al.*, 2020; Dolgui *et al.*, 2020; Xu *et al.*, 2019), and developed different prototypes for assessing the implication of blockchain adoption in specific processes (Abeyratne and Monfared, 2016; Schyga *et al.*, 2019). Practitioners have also been experimenting with blockchain to improve their business processes, including organisation C, which implemented blockchain to improve shipping documents management. It was also evident in numerous reported use cases [1,9,18,24,36][23].

(3) Customer experience enhancement: The use of blockchain to directly enhance the customer experience is the third identified application area for blockchain. It differs from the second application area in that it includes the customer either as a recipient of the blockchain service or as a user of the blockchain solution. Examples include using blockchain to provide customers with information about the product history and origin details or to secure the communication platforms used by the customers. Improving customer experience was targeted by organisation A and C and was evident in numerous reported use cases [10, 14,31,42,38].

[23] Use case numbers in Table 11

10.1.3 The key industry characteristics influencing blockchain adoption and application in the supply chain

This research has identified specific industry characteristics influencing blockchain adoption and application in the supply chain. Table 32 summarises the empirical findings, highlighting the idiosyncrasies of each industry together with the main blockchain application areas, relevance to the case studies, reported use cases and supporting academic literature.

The automotive industry is characterised by its extensive, complex, and globally dispersed supply network and manufacturing processes subject to high-quality standards and restricted regulatory requirements related to the materials used and manufacturing processes, including health and safety, environmental and social impact. The industry is highly influenced by developments in technology and digitalisation, including the emerging trends of mobility services and car-sharing, which has made the automotive industry more than just providing a physical mode of transport (IBM, 2018). Therefore, blockchain has been applied in various use cases in the automotive industry, from enabling product traceability across the supply chain, improving business processes including vehicle data management, securing customers data, and improving emerging mobility services. Similarly, the aerospace industry is characterised by a complex supply network with dominant competitive players, complex products, sophisticated technologies, and sensitive information and financial flows. Hence, blockchain has been applied mainly to support product traceability and improve engine data management processes (Aerospace Industries Association, 2019).

The shipping and logistics industry is one of the first industries that acknowledged the potential of blockchain to transform its business processes. The shipping processes are primarily manual, labour-intensive, and paper-based processes that highly affect shipping costs and performance (Zhou, Soh, *et al.*, 2020). The industry is also influenced by global trade and customs regulations that differ across countries. Blockchain enable the development of a secure and real-time data sharing platform among the different shipping partners, which can help tackle the industry's significant challenges.

Governments are responsible for establishing policies and regulations and enforcing compliance with them whenever it is related to public health and safety. These regulations vary across the different industries. The nature of the products in the food and beverages industry justifies the standards and regulations imposed in the sector to protect public safety. Besides governments regulations in the food and beverage industries, consumers are also more

concerned about the sources of products, forcing retailers to engage in sustainability programs with their suppliers and invest in traceability technologies. Blockchain has been widely implemented in this sector to enable product traceability across the supply chain, improve the efficiency and effectiveness of product recall processes, and improve customer experiences by providing them with information on product sourcing and provenance.

Like the food industry, governments are intensively involved in regulating the pharmaceutical industry and are expected to monitor every step of the drug supply chain (Tseng *et al.*, 2018). Product counterfeit and quality issues are paramount in this sector (Singh *et al.*, 2020; Sylim *et al.*, 2018). Therefore, blockchain-enabled traceability is also appealing in this industry. Finally, the textile and apparel industry is one of the most mobile industries in the world with mature manufacturing processes and high sustainability concerns related to its product raw materials and manufacturing processes (MacCarthy *et al.*, 2016). The industry faces significant pressure from consumers and standards organisations to improve the SC sustainability. Blockchain has mainly been applied to ensure product sustainability by enabling product traceability to assure end consumers and standard organisations.

The influence of industry characteristics on the different motivations for blockchain adoption is evident from the analysis of the different blockchain consortia that have emerged in specific industries to collaborate in developing blockchain solutions to tackle common challenges and pain points (Ahmed and MacCarthy, 2022). For instance, the Mobility Open Blockchain Initiative (MOBI) aims to develop blockchain solutions to improve mobility services and SCM in the automotive sector (MOBI, 2022). The MRO Blockchain Alliance seeks solutions for aircraft parts traceability and asset management in the aerospace sector (SITA, 2020). In maritime logistics, TradeLens is focused on improving the efficiency of shipping processes and enabling secure shipping documents exchange (TradeLens, 2020), which are acknowledged challenges in the sector. The IBM Food Trust blockchain solution enables food traceability across the supply chain (IBM Food Trust, 2020). Mediledger focuses on drug traceability and compliance with the US Drug Supply Chain Security Act (DSCSA) (Mediledger, 2019). The Arianee consortium strives to develop standards for the digital certification of luxury goods to fight counterfeit products (Arianee, 2022).

Table 32. Characteristics influencing blockchain projects in six industries

Industry	Main Application Areas	Main Industry Characteristics	Relevance to case studies	Examples of Reported Blockchain Projects [Use case No]	Relevant Academic Literature
1. Automotive	Mobility services (Customer Experience)	▪ Highly innovative ▪ Technology-focused ▪ Improved customer experience		JLR [13] Daimler AG [14]	Fraga-Lamas and Fernández-Caramés, (2019); Singh and Kim, (2018)
	Automotive battery (Product Traceability)	▪ Complex supply network ▪ High social and environmental concerns related to raw materials and manufacturing processes ▪ OECD Guidelines for ethical sourcing of minerals	Organisation A battery case study	Ford Motors [4] Volkswagen [5] Volvo [6]	Chohan, (2021); Mann et al. (2018) Fraga-Lamas and Fernández-Caramés, (2019); Kuhn et al. (2021)
	Automotive leather (Product Traceability)	▪ Complex supply network ▪ High social and environmental concerns related to raw materials and manufacturing processes ▪ Pressure from sustainability organisations (i.e. Better)	Organisation A leather case study		
	Vehicle data management (Business Process)	▪ Subject to tampering and fraud ▪ Manual and scattered information ▪ Lengthy verification process		Hyundai [1] Lamborghini [2] Mercedes-Benz [9]	Abbade et al. (2020); Chen et al. (2020); Demir et al., (2019)
2. Aerospace	Aircraft parts tracking (Product Traceability)	▪ Complex supply networks ▪ High-quality standards requirements ▪ Regulated manufacturing processes ▪ Required product certification by regulations (back to birth) ▪ Stringent requirement for engine maintenance, repair, and overhaul (MRO) processes ▪ High-security requirements for MRO transactions records.		SITA MRO Blockchain Alliance [20] Block Aero [18]	Eryilmaz et al. (2020) ; Ho et al. (2021); Wang and Li, (2019)
	Aircraft engine maintenance record (Business Process)				Aleshi et al., (2019); Schyga et al. (2019)

3. Logistics and Shipping Industry	Shipping data management (Business Process)	▪ Manual Paper-based processes ▪ Lengthy and costly processes (Letter of credit processes) ▪ Compliance with customs regulations	Organisation C case study	Cargo Smart [24] Port of Rotterdam [25]	Chang et al. (2019); Loklindt et al., (2018); Tsiulin et al., (2020); Yang, (2019)
4. Food and Beverages	Products traceability across the supply chain Product recall (Business Process) Product Story (Customer Experience)	▪ Different levels of complexity ▪ High sustainability concerns related to product sourcing and use of chemicals ▪ Stringent regulations regarding food safety		Carrefour [31] Walmart [29]	Bechtsis et al. (2019); Malik et al. (2018); Shingh et al. (2020); Tian (2017)
5. Pharmaceutical industry	Drugs traceability and monitoring across the drug supply chain (Product traceability)	▪ Complex supply network ▪ Highly regulated industry ▪ High-quality standards requirements ▪ Stringent regulations regarding drug safety and traceability (DSCSA)		Pharmaledger [38] Merck [37] Modum [36]	Singh et al. (2020); Sylim et al. (2018); Tseng et al. (2018)
6. Textiles and Apparel	Products traceability across the supply chain (Product Traceability/Customer Experience)	▪ Complex supply network ▪ High social, ethical and environmental concerns related to raw materials and production processes ▪ Pressure from sustainability organisations (i.e. Textile Exchange, Canopy Planet)	Organisation B case study	Martine Jarlgaard [46] C&A Foundation [47]	Agrawal et al., (2021); Bullón Pérez et al. (2020); UNECE (2021)

10.2 The Main Pre-requisites and Inhibitors for Blockchain Adoption and Deployment in the Supply Chain

The variety of case studies in terms of sectors and stage of blockchain adoption provided a comprehensive understanding of the main pre-requisites and inhibitors for blockchain adoption and deployment in the supply chain. The automotive battery case study included an organisation that is interested in investigating the potential of blockchain but due to its specific SC characteristics, it decided not to adopt the technology. However, other OEMs were able to apply blockchain in the same supply chain. The automotive leather case study was the most longitudinal and started when the organisation was only investigating blockchain, developing a business case, engaging with other SC partners, securing funds, and implementing a blockchain pilot. It provided rich and practical insights into the actual blockchain adoption considerations and challenges in the supply chain. The textile case study included an organisation with a number of pilots with leading brands and retailers and at the stage of planning the scalability of the blockchain solution in its broader supply network. Last but not least, the fourth case study included an industry-wide shipping platform developed by a leading organisation that is operational. We discuss the main pre-requisites and inhibitors identified.

10.2.1 The main pre-requisites for blockchain adoption in the supply chain

The same set of pre-requisites for blockchain adoption in the supply chain was identified across all case studies despite their variety (Table 24). These pre-requisites enabled blockchain adoption in the automotive leather, textile, and shipping case studies, and inhibited the adoption in the automotive battery case study. They include:

1. Clarity of purpose for blockchain adoption and scope of application

Prior to blockchain adoption, organisations ought to clearly define the purpose of blockchain adoption and its scope of application. This purpose should be derived from the organisation's business needs and existing SC challenges. Although it may seem a straightforward pre-requisite, with the hype that has accompanied blockchain, organisations can be tempted to conduct blockchain pilots without first establishing an in-depth understanding of what they need to/can with blockchain. Hence, many organisations experimented with blockchain, but limited solutions have been implemented at scale (Aich *et al.*, 2019; van Hoek, 2019a; Wamba and Queiroz, 2020). Organisation A struggled to define the required level of leather traceability enabled by blockchain which was a fundamental challenge for solution implementation.

Industry characteristics can influence blockchain's purpose and application area. Product and business processes characteristics need to be considered when defining the SC data capture points. Mapping the SC configuration help identify the required participants in the blockchain solution. Industry standards and regulations can support and guide data sharing requirements. Meeting the customer and market demand requirements can drive blockchain adoption. All these factors were relevant in the different case studies and have influenced blockchain's purpose and application area in the supply chain.

2. Knowledge about the supply chain.

Many organisations lack detailed knowledge about their supply chain evident by the Covid-19 pandemic and the associated disruption in many organisations, supply chains and business operations. Rising consumers awareness about end-product social and environmental impacts has also forced organisations to manage and be responsible for their extended supply chains. Hence, SC knowledge is crucial for effective SCM, risk management, and meeting regulatory, market and consumer demand. Blockchain has emerged as a potential technology connecting the globally dispersed and complex supply chains and supporting information sharing through its decentralised and distributed ledger. Having transparency and traceability as the top identified motivations for blockchain adoption indicates the increasing interest of organisations in knowing their supply chain.

Despite its importance, the lack of SC knowledge has not been discussed in the blockchain-SCM research. Most announced blockchain projects included a small number of stakeholders and are limited to specific SC stages. However, to fully realise the potential of blockchain in developing end-to-end SC solutions, organisations must know their SC configuration and engage all necessary parties in the blockchain system. SC knowledge is also crucial for the deployment and scalability of blockchain solutions. It helps identify the required partners and informs the solution design processes. Knowledge about the supply chain was a key determinant for organisation A's ability to adopt blockchain in its battery supply chain and for identifying the requirements for the blockchain traceability solution in its leather supply chain.

SC knowledge is necessary beyond the SC partners to industry partners and competitors when aiming to develop industry-wide solutions. Organisation B worked with a standard organisation to identify the potential industry partners interested in promoting their sustainable products to join their blockchain platform. Organisation C collaborated with other ocean carriers to encourage the adoption of their solution by the broader industry ecosystem.

3. Establishing an agreement among the SC partners on the use of blockchain and on blockchain data.

Establishing an agreement on using blockchain and shared data is a critical requirement for blockchain adoption (Babich and Hilary, 2020). This is particularly important in permissioned blockchain networks commonly used in SCM applications. Blockchain enables multiple parties to access, transact, and validate transactions as data sharing is supported by distributed ledger and agreement is enforced by blockchain consensus mechanisms (Aras and Kulkarni, 2017; Christidis and Devetsikiotis, 2016; Lashkari and Musilek, 2021; Treiblmaier, 2020).

Establishing agreement and collaboration is not an easy task and may significantly delay blockchain adoption. The complexity and global nature of businesses magnify the efforts required to establish such agreements where SC partners operate in various countries with different regulations, laws and institutions (Kshetri, 2018). In the leather case study, the project team of four organisations needed four months to establish an agreement on the blockchain pilot before the commencement of the project. During the project, some SC partners refused to share certain required information, which limited their participation in the developed solution.

4. Inclusion of all necessary parties in the blockchain solution

Including all necessary SC partners in blockchain solutions is crucial for realising the full potential of blockchain (Jović *et al.*, 2019; Sternberg *et al.*, 2021). The number and type of parties required in a blockchain solution differs depending on its purpose and application area. For example, to enable product traceability across the supply chain, all SC partners involved in the product's manufacturing and/or delivery have to share product information. Identifying product's origin might require different SC partners than those aiming for after-sales product tracking. Some researchers proposed blockchain solutions that involve external organisations and regulatory bodies to govern and monitor the blockchain data, e.g., Sylim *et al.* (2018) and Tseng *et al.* (2018) in the pharmaceutical industry. Other standard organisations in the textile industry were engaged in blockchain projects such as US Cotton Trust Protocol (2021) and Fashion for Good (2019). The variety of members in the emerged blockchain consortia such as Pharmaledger (IMI, 2020), also proves the importance of including all relevant stakeholders to develop blockchain and its wide-range applications (Ahmed and MacCarthy, 2022).

5. Establishment of data governance model

Data sharing, privacy and disclosure have been significant concerns for organisations across different industries when adopting blockchain (Agrawal, Koehl, *et al.*, 2018; Choi *et al.*, 2020;

Feng *et al.*, 2020; Kamble *et al.*, 2020; Saberi *et al.*, 2019). Therefore, developing a data governance model that sets the rules for blockchain data sharing and accessibility is crucial. It has to be aligned with the initial agreement on blockchain use and data sharing. Consensus mechanisms and cryptography used in permissioned and private blockchain networks, support having different access rights for different participants in the network (Pedersen *et al.*, 2019). By having an agreed-upon data governance model, the blockchain network participants can trust that their data is not misused and is accessed only by authorised parties. This encourages blockchain adoption and improves trust in the supply chain (Feng *et al.*, 2020; Lim *et al.*, 2021).

The data governance model differs depending on the nature of shared data shared and SC relationships and the level of trust and transparency between the different network participants. Various data governance models were developed in each case study with different data access rules for the network participants.

6. Identification and linkage of assets stored on the blockchain to create a SC digital twin

Creating a SC digital twin is crucial for blockchain adoption and for accurately representing the physical world. Otherwise, the use of blockchain systems would neither be credible nor valuable. Digital twin creation involves three aspects: a physical object, its digital or virtual representation, and the nature of connections between the two and between the digital twins (Srai *et al.*, 2019). The creation of the SC digital twin and what it represents depend on the purpose and scope of blockchain and the agreement among the SC partners on data sharing and identification requirements. Individual organisations, departments, participants, products, locations, and equipment can all be uniquely identified in the blockchain to represent the physical world. We discuss the different identification levels in more detail in Section 10.5. Several technologies and product identification techniques have been used in the supply chain, such as GPS, cloud computing, RFID, QR code, and sensors that enabled product data collection across the supply chain (Davies and Wang, 2021; Kshetri, 2018). Combining these technologies with blockchain can facilitate the creation of a SC digital twin and ensures the reliability and integrity of blockchain solutions (Feng *et al.*, 2020; Lim *et al.*, 2021).

Many researchers anticipated the potentials of combining blockchain, smart contracts and IoT to transform current business models (Aich *et al.*, 2019; Buccafurri *et al.*, 2017; Christidis and Devetsikiotis, 2016). Different products require different identification techniques depending on their nature and composition. Asset identification can require additional investments, and

therefore it might affect the organisations' willingness to adopt and deploy blockchain systems (Agrawal, Sharma, *et al.*, 2018; Kamble *et al.*, 2020; Lopes *et al.*, 2021; Saberi *et al.*, 2019). The leather case study is a good example where product identification represented a significant challenge for leather traceability at a high level of granularity.

To ensure the blockchain SC digital twin validity, some organisations conduct auditing. This step is found to be crucial to ensure blockchain data integrity and validity (Alles and Gray, 2020). In the case studies, organisation B and other SC partners involved in the blockchain solution worked with an independent auditing company to audit mass transactions triggered in the system. The auditing reports are then shared among the SC partners.

10.2.2 The main inhibitors for blockchain adoption and deployment in the supply chain

Most identified inhibitors for blockchain adoption in the supply chain in the case studies have been highlighted in the academic literature (Table 4). However, our research provides empirical validation to key inhibitors as well as new aspects not considered in the literature, including SC complexity and size, lack of SC knowledge, fragmented organisational structure, organisation's inability to mandate adoption, and issues related to the creation of SC digital twins. We categorised identified inhibitors into four categories: intra-organisational, inter-organisational, technical, and external inhibitors (Figure 38). A similar classification was adopted by Saberi *et al.* (2019). We discuss each category below:

a. Intra-organisational inhibitors for blockchain adoption

Several intra-organisational factors hindering blockchain adoption in the supply chain were identified, including lack of management support (Lopes *et al.*, 2021; Saberi *et al.*, 2019), which was evident in the battery case study. The organisational structure can also present a challenge for blockchain adoption as it affects the level of integration within the organisation necessary to establish internal agreement. Organisation A had a fragmented, functional and siloed organisational structure limiting its ability to develop consensus on using blockchain or leading its adoption within its extended battery supply chain. It can also result in internal resistance to adopt blockchain and undertake necessary changes to existing business models (Kamble *et al.*, 2020; Lopes *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020), and in the perception of blockchain jeopardising existing systems and roles within the organisation, which was faced by organisation C.

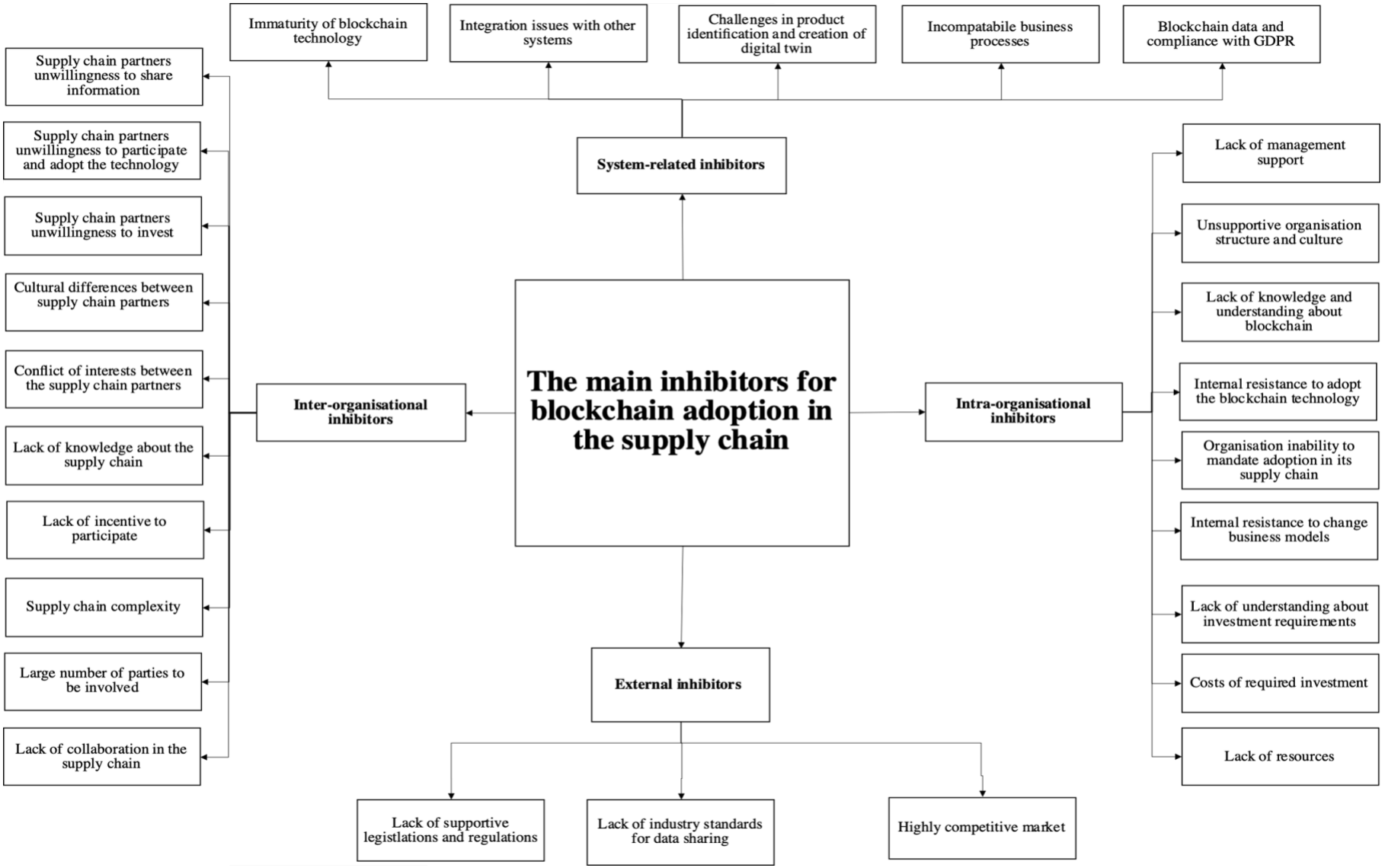


Figure 38. The main inhibitors for blockchain adoption in the supply chain

Lack of knowledge about blockchain is a main inhibitor for blockchain adoption in the supply chain (Caldarelli *et al.*, 2021; Kamble *et al.*, 2020; Kurpjuweit *et al.*, 2021; Wong *et al.*, 2020), especially among decision-makers within the organisations. It also leads to a lack of trust in the technology and hinders its adoption (Babich and Hilary, 2020; Rogerson and Parry, 2020). The organisations that were successful in implementing blockchain usually partner with a blockchain technical partner to bridge the knowledge gap of the technology e.g., organisations A, B, and C.

Another new inhibitor identified is the inability of the focal organisation to mandate adoption and establish an agreement to adopt blockchain. Not every organisation that wishes to adopt blockchain has the necessary resources, influence and power to lead and develop partnerships for blockchain adoption (e.g., the battery case study). Instead, these organisations usually seek to join already established blockchain consortia or partner with more powerful players to lead the adoption endeavour. The lack of understanding of investment requirements, availability of resources, costs of investments are all critical concerns for organisations, hindering their willingness to adopt blockchain (Feng *et al.*, 2020; Kamble *et al.*, 2020; Kayikci *et al.*, 2020; Kurpjuweit *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020; Wong *et al.*, 2020).

b. Inter-organisational inhibitors for blockchain adoption

These are related to the SC characteristics and nature of SC relationships, including the unwillingness of SC partners to adopt blockchain and share required information (Kamble *et al.*, 2020; Lopes *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020). Participating organisations can be reluctant to disclose information about their products or operational practices (Agrawal, Sharma, *et al.*, 2018; Choi *et al.*, 2020; Rogerson and Parry, 2020; Saberi *et al.*, 2019). Having a conflict of interest among the SC partners and a lack of clear incentive for participating are also main inhibitors for blockchain adoption (Lopes *et al.*, 2021; Saberi *et al.*, 2019; Wang *et al.*, 2020). Cultural differences can also hinder blockchain adoption, leading to problems in communication and coordination in the supply chain (Queiroz *et al.*, 2021; Saberi *et al.*, 2019).

The SC complexity and size are noted inhibitors for blockchain adoption in our empirical research but are not acknowledged in the academic literature. Most conceptual blockchain research highlight the potential of blockchain in transforming supply chains considering its inherited decentralisation that supports information sharing through the fragmented supply chains (Cole *et al.*, 2019; Kamble *et al.*, 2020; Wamba and Queiroz, 2020; Wong *et al.*, 2020). Many organisations have piloted blockchain on a small scale. Therefore, the issue of SC

complexity and size will get more prominence when organisations aim to scale their solution in their broader supply networks. This is particularly important for permissioned blockchain platforms where participants must be identified and engaged in the blockchain solution depending on their role and position in the supply chain and for the effectiveness of the data governance model. The lack of SC knowledge is another related inhibitor for blockchain adoption in the supply chain.

Finally, blockchain adoption may require the SC partners to invest in and acquire resources to support data sharing and accessibility requirements. If the SC partners are unwilling to undertake the necessary investments, it can be a significant challenge hindering blockchain adoption. Rogerson and Parry (2020) suggested that consumers will need to pay a premium price to fund blockchain adoption across the supply chain. It was also highlighted by participants in the executive workshop.

c. Technical inhibitors for blockchain adoption

These are related to the immaturity of blockchain (Agrawal, Sharma, *et al.*, 2018; Miehle *et al.*, 2019; Wamba and Queiroz, 2020; Wang and Li, 2019), the ongoing developments to tackle blockchain security, privacy, interoperability and scalability concerns (Babich and Hilary, 2020; Jović *et al.*, 2019; Kamble *et al.*, 2020), blockchain integration with existing systems (Clohessy *et al.*, 2019; Kayikci *et al.*, 2020; Lopes *et al.*, 2021; Queiroz *et al.*, 2019; Wang *et al.*, 2020), and blockchain data compliance with standards and regulations such as GDPR (Feng *et al.*, 2020; Jović *et al.*, 2019; Kamble *et al.*, 2020; Kshetri, 2018; Wang *et al.*, 2020).

Other inhibitors include the inability to create a valid SC digital twin that meets the purpose of blockchain use, including critical issues related to product identification requirements and incompatibility of business processes. These issues were strongly evident in the leather case study where the nature of the tanning processes hinders the identification of individual hides and their traceability to their origin. The inability to create a SC digital twin will inevitably raise concerns regarding blockchain data validity and system credibility. Ensuring data validity is essential for blockchain adoption (Agrawal, Sharma, *et al.*, 2018; Babich and Hilary, 2020; Caldarelli *et al.*, 2020; Kamble *et al.*, 2019, 2020).

d. External inhibitors for blockchain adoption

The external inhibitors for blockchain adoption include the lack of regulatory support and guidance, which was discussed in the literature (Feng *et al.*, 2020; Jović *et al.*, 2019; Kamble *et al.*, 2020; Kshetri, 2018; Saberi *et al.*, 2019; Wang *et al.*, 2020), and was also evident in the

case studies. The lack of industry standards for data sharing and blockchain adoption is another key challenge (Babich and Hilary, 2020; Feng *et al.*, 2020; Jović *et al.*, 2019; Wang *et al.*, 2020). However, this challenge is increasingly addressed by the emerging industry-wide blockchain consortia aiming to develop required standards e.g., Arianee (2020) and Pharmaledger (IMI, 2020). The lack of regulations and standards for blockchain adoption and the data sharing can have significant implications on the scalability and interoperability of blockchain solutions, hindering its development and wide-scale adoption.

Finally, blockchain adoption can be a major challenge in highly competitive markets where there is less collaboration, conflicts of interests and limited information sharing between the network participants (Saberi *et al.*, 2019). Consequently, it was one of the main challenges faced by organisation C that forced the organisation to convert its blockchain-enabled platform to have a collaborative model to encourage adoption.

10.3 The Main Factors Influencing Blockchain Adoption and Deployment in the Supply Chain

Many factors influencing blockchain adoption in the supply chain were identified dispersedly in the literature (Table 3). However, most academic research is conceptual and focuses on the technical features of blockchain, with limited empirical research investigating the factors influencing blockchain adoption from a SCM perspective. The different blockchain deployment stages of the case studies enabled the identification of various factors influencing the management decision-making regarding blockchain adoption, and the actual adoption and scalability of blockchain in the supply chain. We categorise these factors into intra-organisational, inter-organisational, technical factors and external factors, and discuss them next.

10.3.1 The factors influencing management decision-making regarding blockchain adoption in the supply chain

In the cross-case analysis, we identified and discussed the main factors that influenced the decision-making of the different organisations regarding blockchain adoption along with the final decision of each organisation (Table 26). These factors facilitated the organisations' decision to adopt blockchain in the leather, textile and shipping case studies and not to adopt it in the battery case study. We summarise these factors in Figure 39 and discuss them next.

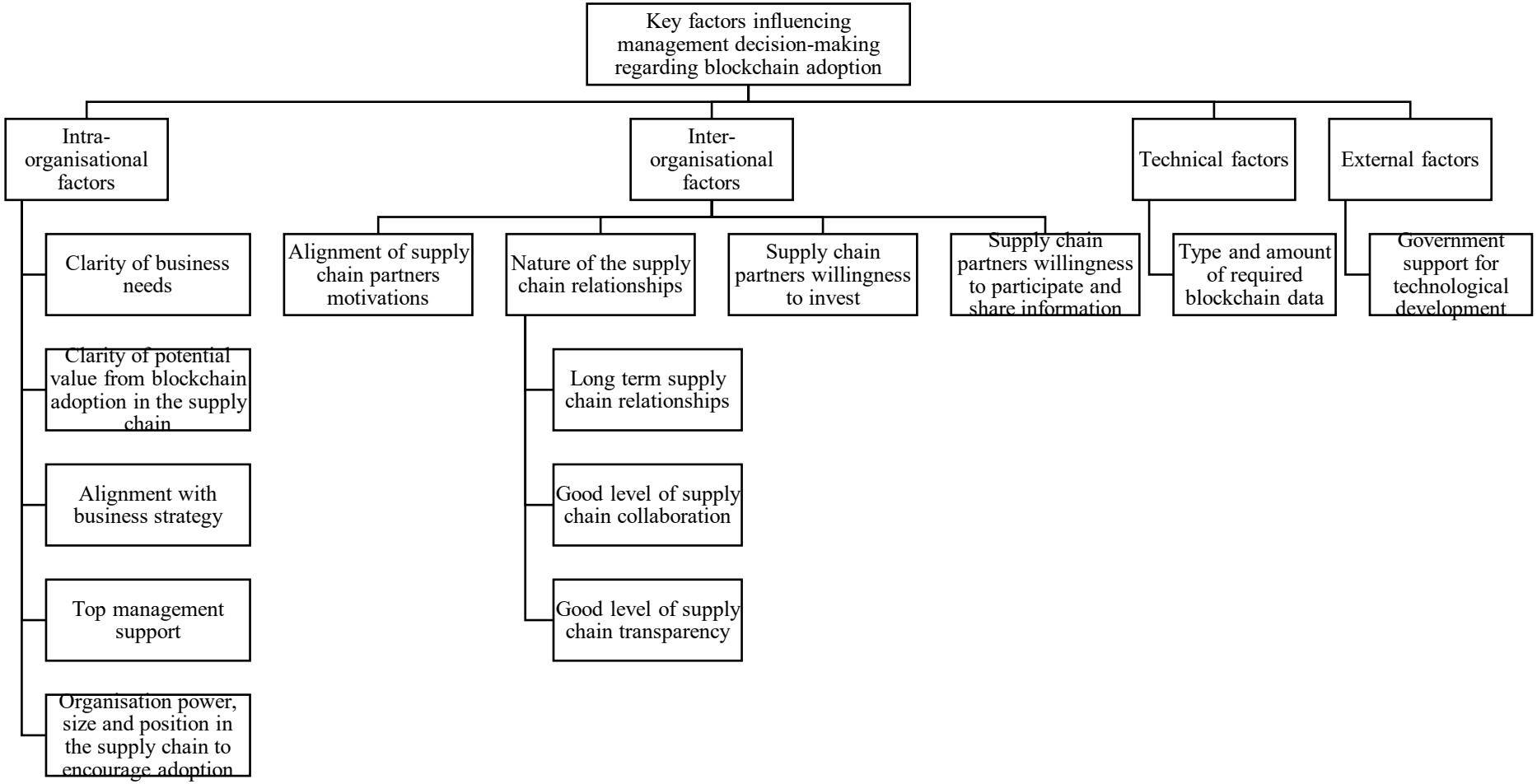


Figure 39. The main factors influencing management decision-making regarding blockchain adoption

a. Intra-organisational factors influencing the decision-making

Five main intra-organisational factors are identified, including clearly defined business needs, clarity of blockchain value proposition, alignment with business strategy, top management support, and degree of the organisation's power and position to encourage blockchain adoption. Having a clearly defined business need is important to identify the blockchain adoption purpose and application area (Wang, 2020). It also prevents the organisation from getting into *"having a solution and looking from a problem"*, as noted by organisaion A. Similarly, identifying the value proposition of blockchain is vital to justify the required investments and anticipate its potential benefits which affect the adoption decision (Clohessy *et al.*, 2019; Crosby *et al.*, 2016; Kamble *et al.*, 2019; Seebacher and Schüritz, 2017; Wang *et al.*, 2016). Both the value proposition of blockchain and business needs must be aligned with the business strategy to support the adoption of the technology. The top management support is also crucial as they are directly involved in the decision-making process and the approval of funds (Caldarelli *et al.*, 2021; Chen *et al.*, 2018; Clohessy *et al.*, 2019; van Hoek, 2019a; Janssen *et al.*, 2020; Mendling *et al.*, 2018). Finally, the organisation's position, size and power influence its ability to lead a SC endeavour. Powerful and large organisations are more likely to encourage other SC partners to collaborate as they would be keen on maintaining their business. In contrast, less powerful and smaller organisations might be reluctant to lead such SC transformation projects and incur the associated costs as they might perceive it as the responsibility of the more powerful and larger players.

b. Inter-organisational factors influencing the decision-making

Four inter-organisational factors were identified, including the alignment in SC partners' motivations behind blockchain adoption, which is particularly important for establishing necessary agreements and partnerships to deploy the technology successfully.

The nature of the SC relationships also plays an essential role in fostering collaboration and information sharing among the SC partners. Long term partnerships can potentially improve the suppliers' willingness to collaborate and share information, especially in highly competitive markets like the automotive battery and shipping industries.

The willingness of the different SC partners to invest is necessary for implementing blockchain-enabled SC solutions. Traditionally, most supply chains are profit-centric and aim at minimising costs across the supply chain, which drove the globalisation of many supply chains to include low-cost countries for low value-adding activities. The importance of SCM

has gained attention due to the increase in sustainability awareness about global supply chains, the need to timely manage changing customers' requirements, and to sustain businesses during SC disruptions. These have stressed the importance of more connected supply chains and encouraged blockchain adoption. However, organisations are concerned with the required investment costs to achieve this connectivity (Sternberg *et al.*, 2021; Wong *et al.*, 2020).

c. Technical factors influencing the decision-making

The type and amount of information shared in the network strongly affect organisations' decision regarding blockchain adoption. There are many concerns about blockchain security and privacy (Babich and Hilary, 2020; Kamble *et al.*, 2020; Saberi *et al.*, 2019; Wang, Singgih, *et al.*, 2019), and organisations are reluctant to include sensitive information on the blockchain. Therefore, the different SC partners have to initially agree on the blockchain data, network type and data governance model.

d. External factors influencing the decision-making

Government support for blockchain adoption is crucial to encourage industry-wide adoption. Organisations must comply with existing legislation and regulations. If regulatory bodies encourage the use of blockchain-enabled systems to ensure data verifiability and immutability, it will accelerate adoption. This can be anticipated mainly in highly regulated industries such as the pharmaceutical industry, where government departments have engaged in blockchain pilots to enforce regulatory compliance e.g., Mediledger (2019). Also, in the automotive sector, governments are providing funds for automotive OEMs to investigate blockchain application in the supply chain e.g., Everledger (2020). These governmental funds facilitated organisation A's leather blockchain pilot project.

10.3.2 The factors influencing blockchain adoption in the supply chain

These factors were identified and compared across only three case studies since the first one has not adopted the technology in Table 27. All these factors can affect both the adoption and scalability of blockchain. However, we distinguish between them to emphasise their importance at the stage of adoption and/or scalability. We present a subset of these factors mainly related to intra-organisational and technical factors in Figure 40 for blockchain adoption in the supply chain, while we discuss the remaining aspects that are more concerned with blockchain scalability in the following section.

a. Intra-organisational factors influencing blockchain adoption

The intra-organisational factors influencing blockchain adoption include the willingness of the SC partners and related stakeholders to adopt the technology and the organisation readiness for technology adoption. Blockchain is a digital technology and to interact with the blockchain network, the different participants must acquire a certain level of digitalisation to access and add information to the blockchain. Therefore, the level of digitalisation and the product and business processes characteristics are key factors influencing blockchain adoption and scalability. The nature of business operations and utilised resources also influence the organisation readiness for technology adoption. Finally, the availability of resources to adopt, manage and maintain the blockchain system is necessary for blockchain adoption (Queiroz *et al.*, 2021; Sternberg *et al.*, 2021; Wong *et al.*, 2020).

b. Technical factors influencing blockchain adoption

The technical factors that affect blockchain adoption include the blockchain system configuration and its ease of adoption. Furthermore, the type and amount of data determine the amount of effort and resources required by the different organisations to adopt the technology. Queiroz *et al.* (2021) also highlighted the ease of adoption and effort expectancy as critical factors positively influencing blockchain adoption. Different organisations across the supply chain also operate with various systems raising the importance of blockchain integration with existing systems for its adoption (Clohessy *et al.*, 2019; Kayikci *et al.*, 2020; Lindman *et al.*, 2017; Lopes *et al.*, 2021; Queiroz *et al.*, 2019).

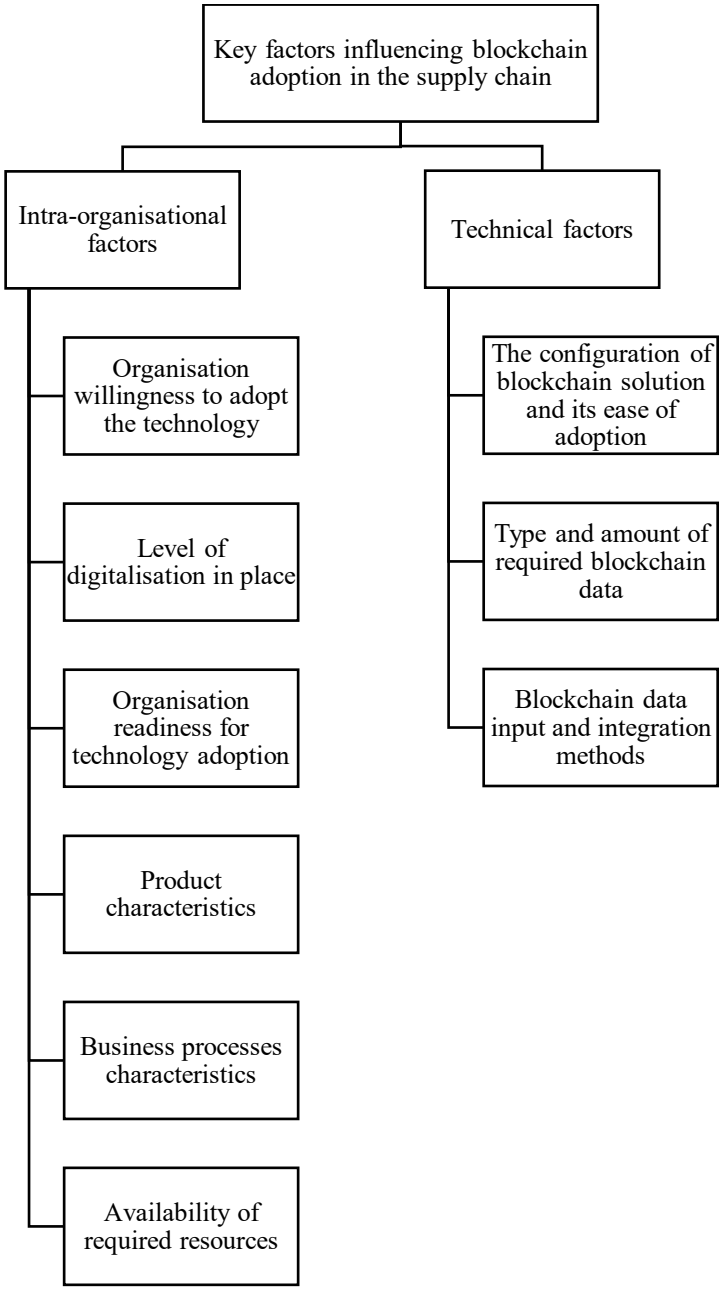


Figure 40. The main factors influencing blockchain adoption in the supply chain

10.3.3 The factors influencing blockchain scalability in the supply chain

There is limited literature investigating blockchain scalability from a SCM perspective. Most research in the academic literature highlighted the technical factors, particularly blockchain technical scalability and interoperability issues (Casino *et al.*, 2019; Crosby *et al.*, 2016; Janssen *et al.*, 2020; Jović *et al.*, 2019; Swan, 2015; Wang *et al.*, 2016; Wong *et al.*, 2020). However, there is a lack of research that consider the supply chain-related factors affecting blockchain scalability in the supply chain. These factors are summarised in Figure 41, considering the inter-organisational, technical and external factors.

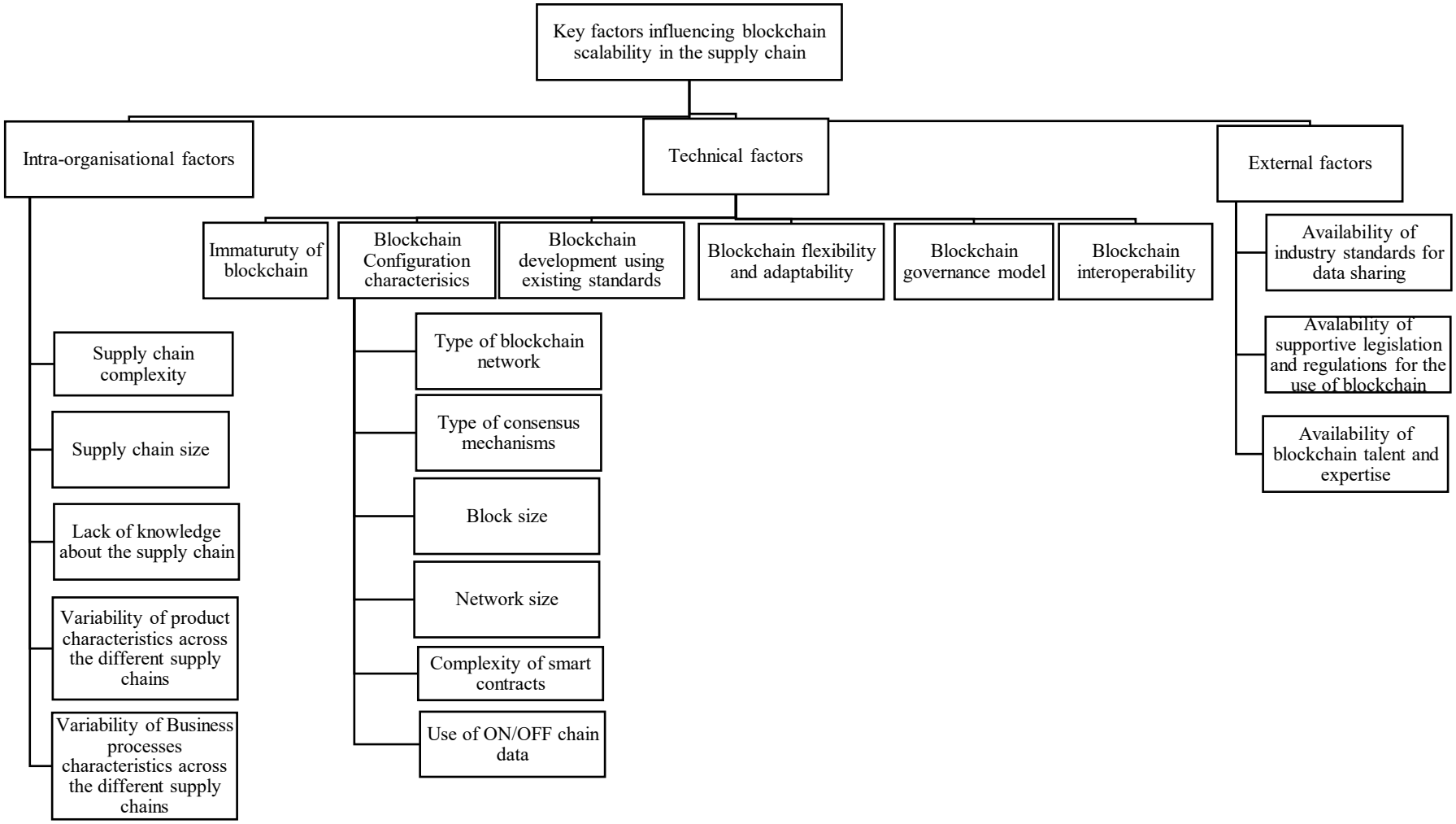


Figure 41. The main factors influencing blockchain scalability in the supply chain

a. Inter-organisational factors affecting blockchain adoption and scalability

These factors are related to the SC configuration characteristics, including its complexity and size. Although blockchain technical capabilities support information sharing within complex SC configurations, the main challenge here is the ability to engage with and onboard these large numbers of parties on the blockchain network. In addition, the lack of SC knowledge is also a key factor influencing blockchain scalability as it would limit the number of network participants. Finally, the variability of the products and business processes characteristics across the different supply chain stages can require different technologies for product identification and data capture that might affect the adoption and scalability of blockchain systems.

b. Technical factors affecting blockchain adoption and scalability

The main technical concerns related to blockchain adoption and scalability are the technology's maturity and scalability issues, which are widely investigated in the literature (Altarawneh *et al.*, 2020; Chauhan *et al.*, 2018; Eklund and Beck, 2019; Mazlan *et al.*, 2020; Sanka and Cheung, 2018; Zhou *et al.*, 2020), and are highlighted in all four case studies. Blockchain scalability varies depending on its configuration characteristics, including type of the network (permissionless vs permissioned), adopted consensus mechanism, use and complexity of smart contracts, block and network size, and use of on-chain/off-chain data (Altarawneh *et al.*, 2020; Eklund and Beck, 2019; Zhou *et al.*, 2020).

Other technical factors that support blockchain's scalability include its development based on existing standards. For example, Solution-B blockchain-based platform was based on GS1 global data standards and Solution-C shipping platform was based on the supply chain reference model from UN/CEFACT in their solution design. As a result, both solutions could incorporate multiple partners across different SC configurations. Furthermore, the developed blockchain platform must be flexible and adaptable to accommodate SC dynamics, including changing SC configurations, product and business processes characteristics, and business needs and requirements.

The blockchain governance model can also support or hinder blockchain adoption and scalability, particularly when aiming for industry-wide adoption, as in the case of the organisation C. Many researchers also discussed blockchain governance mechanisms and their impact on blockchain adoption (Atzori, 2015; Beck *et al.*, 2018; Buchmann *et al.*, 2017;

Crepaldi, 2019; De Filippi and Loveluck, 2016; Janssen *et al.*, 2020; Lacity, 2018a; Lee, 2017; Pedersen *et al.*, 2019).

With the increasing adoption of blockchain across different supply chains, more consideration is given to blockchain interoperability with other blockchain platforms and systems, as it is crucial for the sustainability and scalability of the technology (Casino *et al.*, 2019; Kamble *et al.*, 2020; Kayikci *et al.*, 2020; Lacity, 2018a; Loklindt *et al.*, 2018; Sanka and Cheung, 2018; Thakkar *et al.*, 2018; Tseng and Shang, 2021).

c. External factors affecting blockchain adoption and scalability

These factors include the availability and development of industry-wide standards for data sharing across the supply chain when using blockchain, and having support from regulatory bodies, standards organisations and NGOs regarding blockchain use in the supply chain. Also, the availability of blockchain talent and expertise and raising awareness about the technology and its capabilities are crucial for its wide-scale adoption.

10.4 A Decision Framework for Blockchain Application in the Supply Chain

The literature review identified the lack of research that guides the decision-making processes regarding blockchain adoption and application areas in the supply chain. None of the previously developed frameworks have considered all the core characteristics of blockchain that makes the technology unique and attractive (Table 5). We consider the research findings from the case studies and the academic and practitioner literature analysis to propose a decision framework consisting of five steps, that helps determine when blockchain is the right technology to adopt and where to adopt blockchain in the supply chain (Figure 42). We stress the importance of initially defining the business problem and needs before investigating blockchain adoption and selecting the application area. This need can be influenced by the product or business processes characteristics and/or the external environment in which it operates. Next, it is necessary to determine whether the business problem/needs can be met using technology solutions, and if so to clearly define the data requirements and characteristics that meet business needs. These three steps are crucial to ensure the proper deployment of blockchain and to realise its benefits. The fourth step in the framework help determine whether blockchain is the right technology to use and type of blockchain network needed. Finally, the fifth step informs the decision-making regarding where to apply blockchain in the supply chain. We discuss the latter two steps of the framework next.

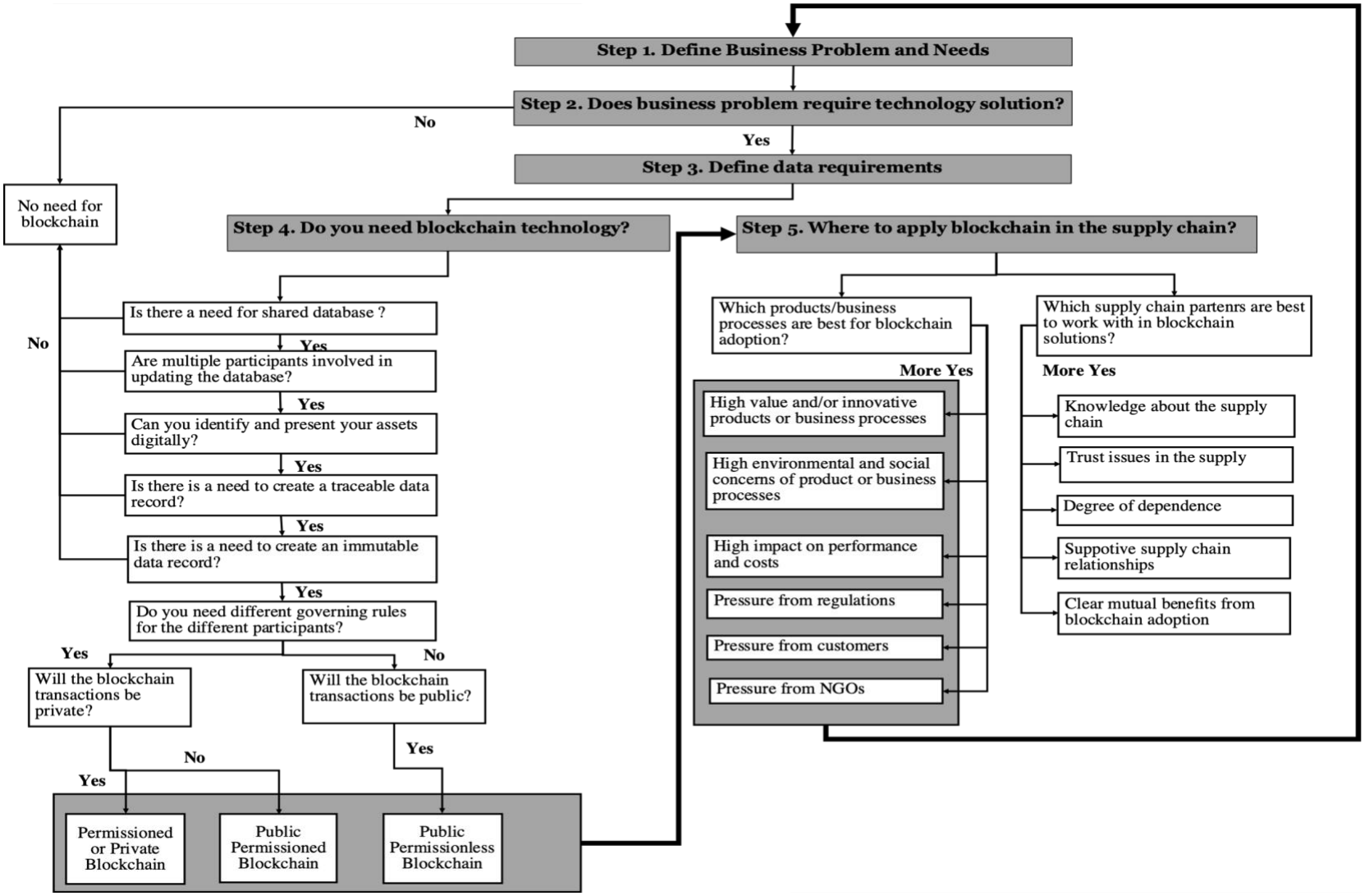


Figure 42. A decision framework: When and where to apply blockchain in the supply chain

10.4.1 When to use and apply blockchain technology

Blockchain is a combination of older technologies that collectively form the capabilities of the technology (Narayanan and Clark, 2017; Treiblmaier, 2020). More information in Section 2.1. Therefore, needing only some of these capabilities can be met using other technologies and not necessarily blockchain. We translate blockchain core characteristics into the main decision-making stages to identify the need for blockchain (Figure 43). The sequence of these stages was developed after comparing and analysing the sequence proposed in the previously developed decision models in the literature (Section 2.2.4), and the researchers' logic and understanding of the requirements for adopting blockchain technology.

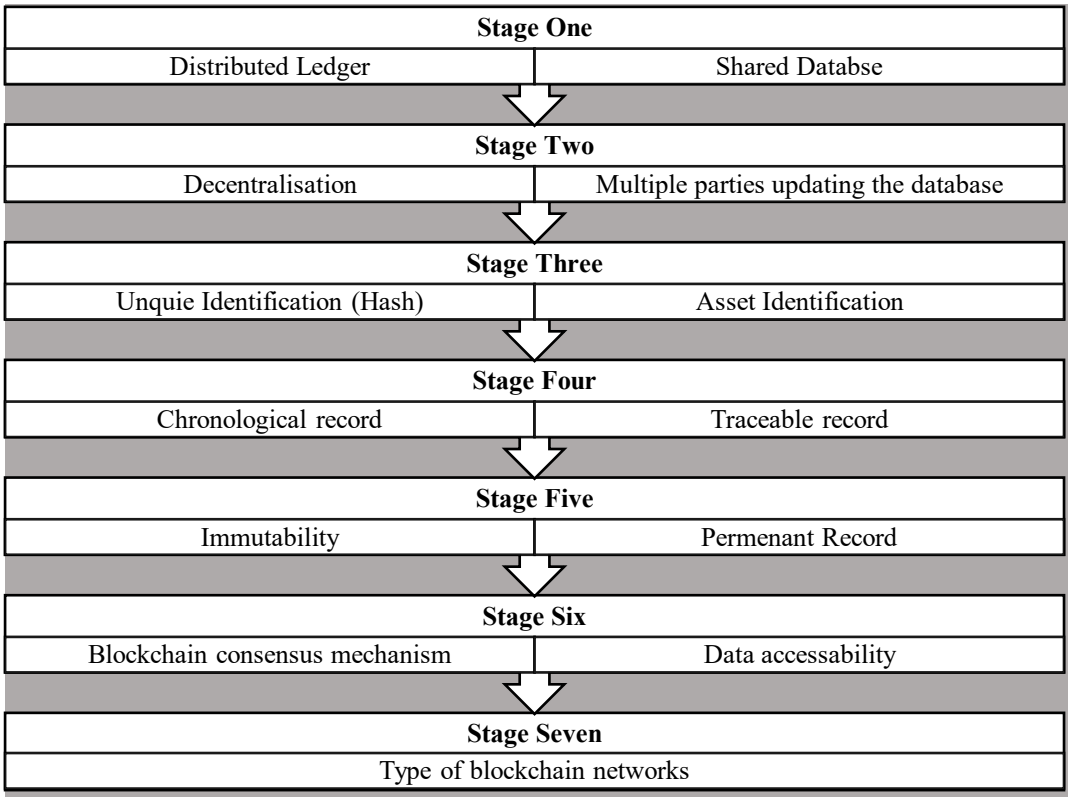


Figure 43. Blockchain decision making stages based on blockchain core capabilities

- **First stage:** The first stage is to decide whether there is a need for a shared database, as having a distributed ledger is inherited characteristics of blockchain. If there is no need to create a shared database, blockchain is not required (Peck, 2017; Pedersen *et al.*, 2019). Hence, there is no need to consider the other core characteristics of blockchain in decision-making.

- **Second stage:** Blockchain is valuable when multiple parties update and access the distributed ledger, supported by its decentralised architecture (Kamble *et al.*, 2019; WEF, 2018;

Wong *et al.*, 2020). If only one participant updates the distributed ledger, there is no need to use blockchain technology.

- **Third stage:** Blockchain is a digital technology storing data in uniquely identified blocks and using cryptography technology to create hashes. For effective use of blockchain, there is a need to identify and represent the stored data in a digital format. This data can represent any physical or digital assets. Assets are defined as anything of value and can be tangible or intangible (IBM, 2022). Assets can consist of products, equipment, documents, cash, investments, etc. If those assets cannot be identified digitally, there is no value in using blockchain, as the stored data would not be representable or meaningful. WEF (2018) also identified the need to work with digital assets as a main decision-making factor regarding the use of blockchain.

- **Fourth stage:** Each blockchain transaction is timestamped and linked to the block that preceded it in the blockchain ledger. The use of blockchain is valuable when history is important. Blockchain provides proof of transaction history through its timestamped and linked transactions. If there is no need to store the history of transactions, blockchain is not necessary. Despite its importance in determining the need for blockchain, none of the previous decision frameworks has highlighted it. However, WEF (2018) has highlighted the need to store large amounts of data as a requirement for blockchain. Having large data storage requirements results from the need to keep the entire history of transactions

- **Fifth stage:** Data immutability is a core characteristic of blockchain and is directly related to the need to have a permanent transaction record. It is one of the main differentiators for blockchain technologies, and it can directly eliminate the need for using blockchain in specific applications. If there is no need to store data permanently, then there is no need to use blockchain as it would have significant unnecessary implications on data storage requirements. The type of data can determine the need for its immutability. For example, schedules and plans are constantly changing data, and there is no need to store such changing data on the blockchain. The case studies show that the respective organisations use other SC platforms for managing planning data. In organisation C's platform, the shipping events were stored in a cloud-based data storage as it is continuously changing while blockchain is only applied to maintain permanent track of the shipping documents. The need for a permanent record was also highlighted in WEF (2018) and Pedersen et al. (2019) decision frameworks.

- **Sixth stage:** At this stage, there is a need to use blockchain due to its inherited core characteristics that meet the business needs. However, we need to consider other blockchain characteristics to determine the optimal type of blockchain network to be used. First, we consider blockchain governing rules enabled by consensus mechanisms. The use of consensus mechanisms supports the security, validity and agreement on the stored blockchain data giving the different participants different rights in posting and updating the blockchain ledger (Christidis and Devetsikiotis, 2016; Farah, 2018). Different consensus mechanisms can be used for different types of blockchain networks. For example, blockchain use in cryptocurrencies such as Bitcoin include the same governing rules for permissionless-blockchain networks. However, for blockchain enterprise applications, different governing rules can be developed for the different participants.

- **Seventh stage:** Different types of blockchain networks can be used (Table 1). One of the main criteria to distinguish these networks is the privacy and accessibility of the data. In public blockchains, anyone can access the distributed ledger data. In public permissioned blockchain data, only permissioned participants can update the ledger but reading from the ledger is open-to-public (indicating having different governing rules for the different participants). In private or permissioned blockchain networks, only permissioned participants can transact and access the network. In all the four case studies, the participants selected permissioned and private blockchain networks to be adopted in their supply chains.

Other factors were highlighted in the previously developed blockchain networks that we argue do not make blockchain adoption entirely distinct. For example, trust was a major factor highlighted in all previously developed decision frameworks (Table 5). We argue that trust must be considered in selecting the users and participants in the blockchain network. However, it does not necessarily determine whether blockchain is the right technology to use or not. Two different views were considered related to the use of blockchain and trust. The first view considers using blockchain when operating in untrusted environments and is strongly highlighted in the literature (Kamble *et al.*, 2019; Saberi *et al.*, 2019; Wamba and Queiroz, 2020; Wong *et al.*, 2020). The second view was highlighted in the case studies is that there must be an existing level of trust in the supply chain to trust the data stored on the blockchain. However, blockchain can be applied in both contexts, given that its core characteristics meet the application needs.

10.4.2 Where to apply blockchain in the supply chain

The second part of the decision framework tackles the issue of deciding where to apply blockchain in the supply chain and the selection of potential solution partners. Supply chains vary in their size, complexity, and materials and information flows. They can include large number of suppliers and diverse materials, making it a tremendous challenge for organisations to decide where to adopt blockchain in their complex supply chain networks. Section 10.1.3 identifies the key industry characteristics influencing blockchain application in the supply chain based on the case studies and reported blockchain used cases analysis. Here, we stress the specific characteristics that can help identify where to apply blockchain in the supply chain and can also influence the business needs prompting blockchain adoption. We also derive key SC relationship characteristics that can directly influence the most suitable SC partners to engage with in blockchain-related applications. This part of the framework is novel in addressing this important gap in the literature.

(1) Selection of blockchain application area

The research findings have strongly identified certain industry characteristics influencing blockchain adoption and application in the supply chain, including product characteristics, business processes characteristics, supply network configuration characteristics, industry standards and regulations and market and customers' demand (Section 10.1.3). We argue that all these characteristics are relevant and important to consider when deciding where to apply blockchain. However, we identified key internal characteristics and external factors that can directly help identify the best application area for blockchain in the supply chain. These areas include products and business processes of high value, high social and environmental impact or high impact on costs and performance. These areas were the most targeted in the case studies and the reported use cases. Other external factors that have pushed organisations to apply blockchain in certain supply chains include pressure from regulations, customers, standard organisations, and NGOs.

(2) Selection of SC partners

Conducting the case studies has helped identify several important factors that would not have been identified without the empirical investigation of practical use cases. It provided opportunities to understand the nature of the SC relationships and the willingness of the SC partners to participate in blockchain solutions. The leather case study provided rich insights into the selection process of blockchain SC partners. The findings from this case study were

confirmatory with other cases where blockchain was already adopted in the supply chain. Five key elements were considered as the most important factors influencing the decision-making process regarding which SC partners to engage with in blockchain projects:

1. Knowledge about the supply chain

Knowledge about the supply chain is essential for blockchain adoption as it helps identify the required participants and their roles and responsibilities in the blockchain solution. It is also essential for designing the blockchain solution and its data governance model. Most developed blockchain pilots included a limited number of known participants. However, to scale the solution in the broader network, organisations in the network would need to know who else is involved in their supply chain. If there is a lack of SC knowledge, the SC partners would need to establish this knowledge before blockchain adoption.

2. Trust issues in the supply chain

Trust is a key factor influencing blockchain adoption (Alazab *et al.*, 2021; Babich and Hilary, 2020; Kamble *et al.*, 2019; Lo *et al.*, 2017; Maull *et al.*, 2017; Pedersen *et al.*, 2019; Queiroz *et al.*, 2021; Wüst and Gervais, 2018). It can be a major factor in determining who to work with and engage with in a blockchain application and was mentioned in previously developed decision models (Table 5). Organisations might seek to apply blockchain in the supply chain to improve trust among the SC partners (Saberi *et al.*, 2019; Seebacher and Schüritz, 2017; Wang, Han, *et al.*, 2019). Therefore, organisations can target supply chains where they have trust issues to tackle with blockchain, considering they can establish agreement on using blockchain. For example, Organisation A was keen on using blockchain in its battery supply chain to enforce information sharing with its tier 1 battery suppliers and improve trust. Organization B was keen on fighting counterfeit and improving trust in its downstream textile supply chain. The organisation partnered with large brands and retailers as they have the majority of their volume and more complex supply chains, raising more concerns regarding product authenticity, and with small high sustainability brands keen on ensuring their fibre's sustainability and trusting their suppliers. Blockchain helps overcome trust issues in sharing faulty documentation in the shipping industry and ensures that valid documents are shared among the shipping partners.

3. Degree of dependence

Organisations must consider partnering with SC partners with whom they have a high degree of dependency to encourage participation and adoption, including suppliers, manufacturers,

investors, banks, NGOs and/or verification and certification entities. This dependency can be in terms of materials, value-adding activities and/or financial support.

4. Supportive SC relationships

The nature of the SC relationship is a strong factor affecting blockchain decision-making. Existing partnership and long-term relationships can facilitate blockchain adoption and the willingness to participate, engage, and make the required investments.

5. Existing mutual benefits in the supply chain from blockchain adoption

Having an alignment in motivations, mutual benefits, or incentives for blockchain adoption and application is a key factor affecting the decision making of the SC partners to participate and engage in the blockchain network.

10.5 Blockchain Adoption for Supply Chain Traceability

Blockchain adoption for supply chain traceability (SCT), is one of the most prominent application areas for the technology, with many pilots conducted across the different industries (Table 29). It is also discussed in the academic literature, where scholars investigated and developed different prototypes and frameworks for blockchain-enabled traceability systems (Agrawal, Sharma, *et al.*, 2018; Baralla *et al.*, 2021; Bechtsis *et al.*, 2019; Bullón Pérez *et al.*, 2020; Casino *et al.*, 2021; da Cruz *et al.*, 2020; Eryilmaz *et al.*, 2020; Haroon *et al.*, 2019; Ho *et al.*, 2021; Tseng *et al.*, 2018; Xu *et al.*, 2019). However, literature discussions tend to be broad and general. There is a lack of research that investigates empirically the requirements and factors influencing the effective deployment of blockchain for SCT in detail. Hastig and Sodhi (2020) is one of the limited papers that investigated this topic in the context of cobalt mining and pharmaceutical industries. However, their work was based on secondary data analysis of the academic and practice literature and required further validation through empirical research. Specifically, there is limited research investigating granularity levels that can be targeted for SCT (Aiello *et al.*, 2015; Dasaklis *et al.*, 2019; Karlsen *et al.*, 2012).

In our research, we focused on this important issue of supply chain traceability and investigated in detail the motivations and factors influencing the level of traceability targeted by the different organisations. Our research provides empirical evidence on the main motivations, requirements and factors that influence blockchain deployment for SCT. The case studies and the executive workshop provided extensive insights into blockchain adoption for SCT. Different levels of traceability have been targeted by the lead companies in the case studies.

Additionally, the executive workshop included participants with high levels of expertise on implementing SCT solutions and standards. We briefly discuss the main motivations for SCT and distinguish between two dimensions for SCT evident from the analysis to define the scope of traceability and key requirements. We then identify and discuss the main factors influencing the SCT scope and its costs and benefits in the supply chain.

10.5.1 The main motivations for supply chain traceability

Figure 44 summarises the main motivations for SCT identified in the research, providing empirical validation to some of the motivations highlighted in purely literature-based studies (Hastig and Sodhi, 2020). Identifying product provenance is one of the main motivations behind SCT. It can be a regulatory requirement as in the food, pharmaceutical and aerospace industries (Eryilmaz *et al.*, 2020; Mann *et al.*, 2018). It can help ensure product quality and sustainability (main motivations for traceability in organisation A's battery and leather supply chains). It is also necessary to manage product recall processes effectively (Kshetri, 2018).

Many financial drivers were identified for SCT in the workshop. SCT can increase sales and provide a marketing boost by influencing the buyer's decision regarding the products they purchase. It can also demonstrate SC integrity to external stakeholders, which can facilitate SC finance and encourage ethical investment. Indirect positive financial implications include strengthening brand value, gaining competitive advantage, and reducing SC costs due to improved efficiency and increased visibility.

Organisations are increasingly expected to ensure the sustainability of their products and extended supply chains, requiring investments in SCT systems to tackle the SC social and environmental issues and promote sustainable practices (Hastig and Sodhi, 2020). Organisation A sought to ensure the sustainability of leather supply. Its blockchain-enabled traceability solution supports the tracking of carbon across the supply chain. SCT also enables organisations to verify that only certified suppliers participate in their networks. A key feature of organisation B's traceability solution is that it provides access to suppliers' certifications and auditing reports across the SC.

Organisations also need SCT to ensure authenticity and fight counterfeit products, which can have detrimental societal, environmental, and economic implications. Organisations in different industries suffer from fraud to different degrees. Organisation B aimed for traceability in its downstream supply chain to ensure authentic use of its sustainable fibres in final

garments. Illegal practices and corruption are significant concerns for organisations in the mineral extraction (Chohan, 2021), and additive manufacturing (Lacity, 2018a), stressing the need for SCT.

Organisations can aim for SCT to promote information sharing and improve transparency among the SC partners, which is important for other stakeholders such as investors, standards organisations and regulatory bodies. SCT also improves different partners' knowledge about their supply chain, which can inform their decision-making processes and help them better manage and prevent SC risks and disruptions. SCT for risk management is getting much more attention with the covid-19 pandemic. Responding to customers' demand is another main motivation behind SCT as customers are increasingly demanding product's authenticity (e.g., textile case study), sustainability (e.g., battery case study), and provenance (e.g., leather case study), which all required SCT.

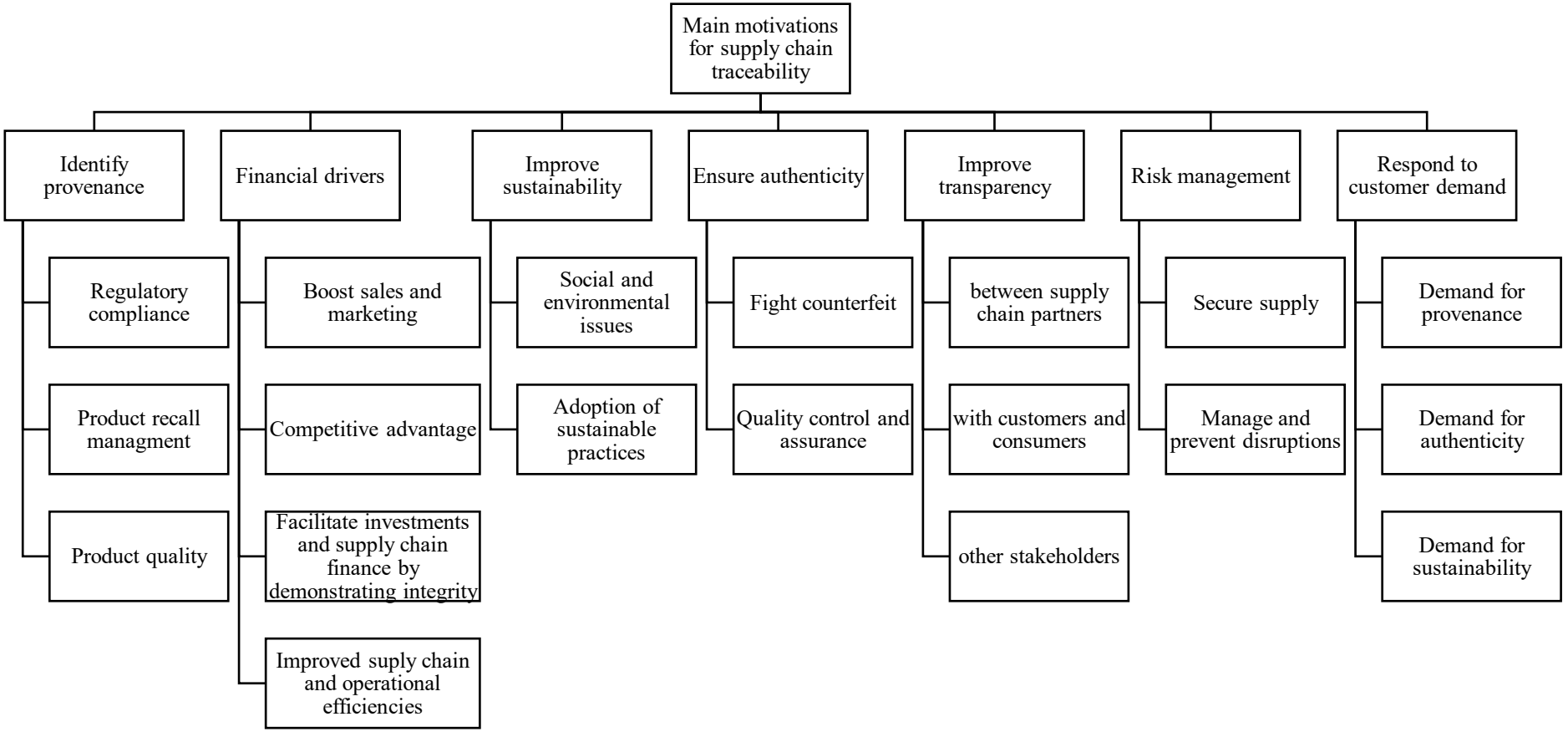


Figure 44. The main motivations for supply chain traceability

10.5.2 Scope of supply chain traceability

The analysis and research findings show clearly that defining scope is crucial when aiming to develop effective traceability solutions. Organisations need to clearly define the purpose of traceability and translate this need into a set of specific traceability requirements at every stage of their supply chain. The precise motivations affect the scope of SCT targeted by organisations in the different industries. We identify two major dimensions of SCT that define its scope and help assess its feasibility, requirements, and scalability:

A. SCT Horizontal Dimension (Start and endpoints of traceability)

The horizontal dimension captures the start and endpoints of traceability in the supply chain. Full horizontal traceability starts from the raw materials origin to end customers and can further include end-product reuse or recyclability in closed loop supply chains. However, not every traceability attempt needs to, or can provide end-to-end SCT. The end and start points vary depending on the traceability purpose and SC characteristics. Organisations can track products in a manufacturing environment using Kanban processes or during transportation between two SC entities using shipping data and documents. SCT can start from manufacturer to the downstream supply chain and/or from raw materials suppliers to manufacturers.

B. SCT Vertical Dimension (Level of granularity)

The vertical dimension of SCT investigates the targeted level of granularity. Granularity can be defined as *"different levels of traceable units ... determined by the size of a traceable unit and the number of the smallest traceable units necessary to make up the traceable unit at a specific granularity level."* (Karlsen *et al.*, 2012). The unit for traceability can be assets, processes, or organisations. Physical materials traceability can start from their origin and carry on along the supply chain as they are transformed, assembled, or manufactured at each stage. Traceability data gathered alongside the product can include suppliers' contracts, financial invoices, purchasing orders, maintenance and quality certifications or shipment documents. In addition, traceability data can include location information for traceable assets, such as raw material origin or location of the SC actors involved in the production and/or delivery of products/services across the supply chain.

Depending on the purpose of traceability, different levels of granularity can be required at different SC stages. Hence, different information can be required from the different SC parties. Products can congregate in batches at some SC stages and/or be disaggregated at other stages. Determining the level of granularity is crucial when developing any traceability system

(Dasaklis *et al.*, 2019), as it influences the feasibility of the SCT system (Aiello *et al.*, 2015; Karlsen *et al.*, 2012). In addition, it determines the resources requirements to enable traceability. A high level of granularity requires more resources to identify and collect data on products (Karlsen *et al.*, 2012). The required level of granularity varies across sectors and SC characteristics (Aiello *et al.*, 2015). Similarly, the value perceived from higher levels of granularity differs across sectors, supply network configurations and characteristics. In the food industry, for example, the level of granularity significantly impacts the effectiveness and cost of product recalls (Aiello *et al.*, 2015). Automotive vehicles can have a high level of customisation per vehicle per customer, raising the need for vehicle parts traceability at high granularity of batch or unique parts (Kuhn *et al.*, 2021). Finally, for textile and apparel products, traceability can be achieved at low granularity, indicating the location of the parties involved in the sourcing and manufacturing processes e.g., in organisation B.

Figure 45 presents the SCT scope targeted in the four case studies, indicating that organisations can aim for different levels depending on the traceability purpose. Organisation A was interested in investigating the potential to enable traceability in its complex upstream cobalt supply chain. It also considered scaling its leather blockchain-enabled traceability solution in its downstream supply chain. However, the company was concerned about the level of granularity required for downstream leather traceability considering the complexity and inevitable product mixing in the downstream supply chain. Organisation B was more concerned about the counterfeiting issues in its downstream supply chain. Hence, SCT was targeted at a low level of granularity - only linking the fibres back to the organisation. Traceability in the shipping industry is concerned with the movement of products from point A to B. Shipping documentation must be prepared and exchanged between multiple parties to facilitate this movement. These parties include beneficiary cargo owners, third-party and fourth-party logistics, freight forwarders, customers authorities, transport operators and ports and terminals. Therefore, in the shipping case study, the scope of traceability includes traceability of logistical units and related documentation.

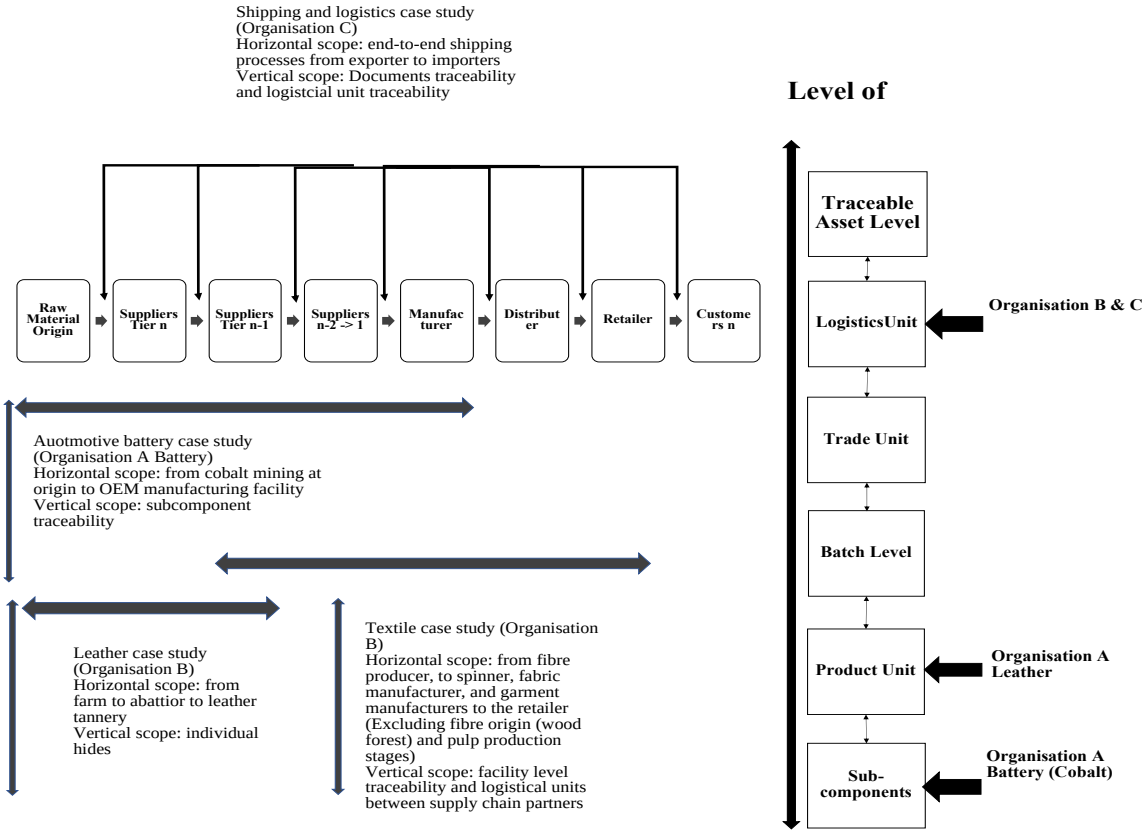


Figure 45. Different supply chain traceability targeted in the four case studies

We consider previous work and the insights driven from the case studies to identify five overlapping elements of traceability and derive five granularity levels for each one of them. These elements are stakeholder, process, traceable asset, transport, and location (Figure 46). Stakeholders represent the entities engaged in the traceability system. Process refers to the activities undertaken by stakeholders in the supply chain. Traceable assets represent the unit of traceability that can be an outcome of stakeholders' use of certain processes. Finally, transport connects the traceable assets between stakeholders, processes, and locations. Locations can be identified for stakeholders, processes, traceable assets, and transport elements.

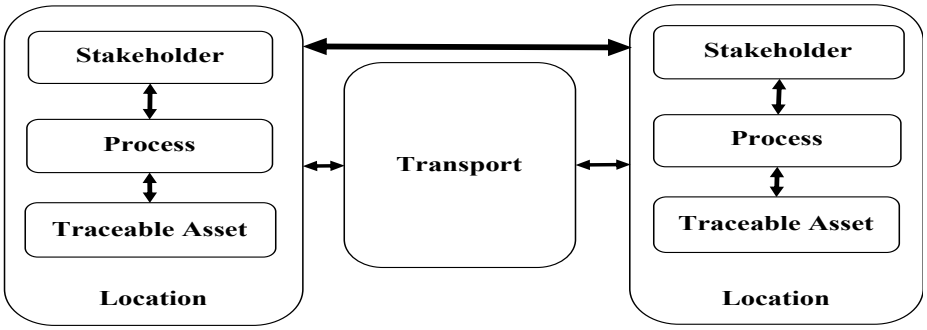


Figure 46. Supply chain traceability identification levels

Figure 47 presents a SCT framework, indicating the two dimensions for SCT and the five identification elements and their respective levels of granularity. Depending on the traceability purpose and the data sharing and disclosure requirements, different levels of identification can be achieved. For example, stakeholders can be identified based on their role in the value chain, specific position and activity in the value chain, or their organisation, facility or department identification details. At the process level, the SC process identification can start at the facility activity, operations activity, specific processes, sub-processes, and equipment used. The traceable asset can be a logistic unit, trade unit, batch, individual products or subcomponents. The transport level can be identified as modes of transport, means of transport, transport operator, transport unit, and logistics unit. Finally, locations can be identified at the continental, regional, country, city, or physical address levels.

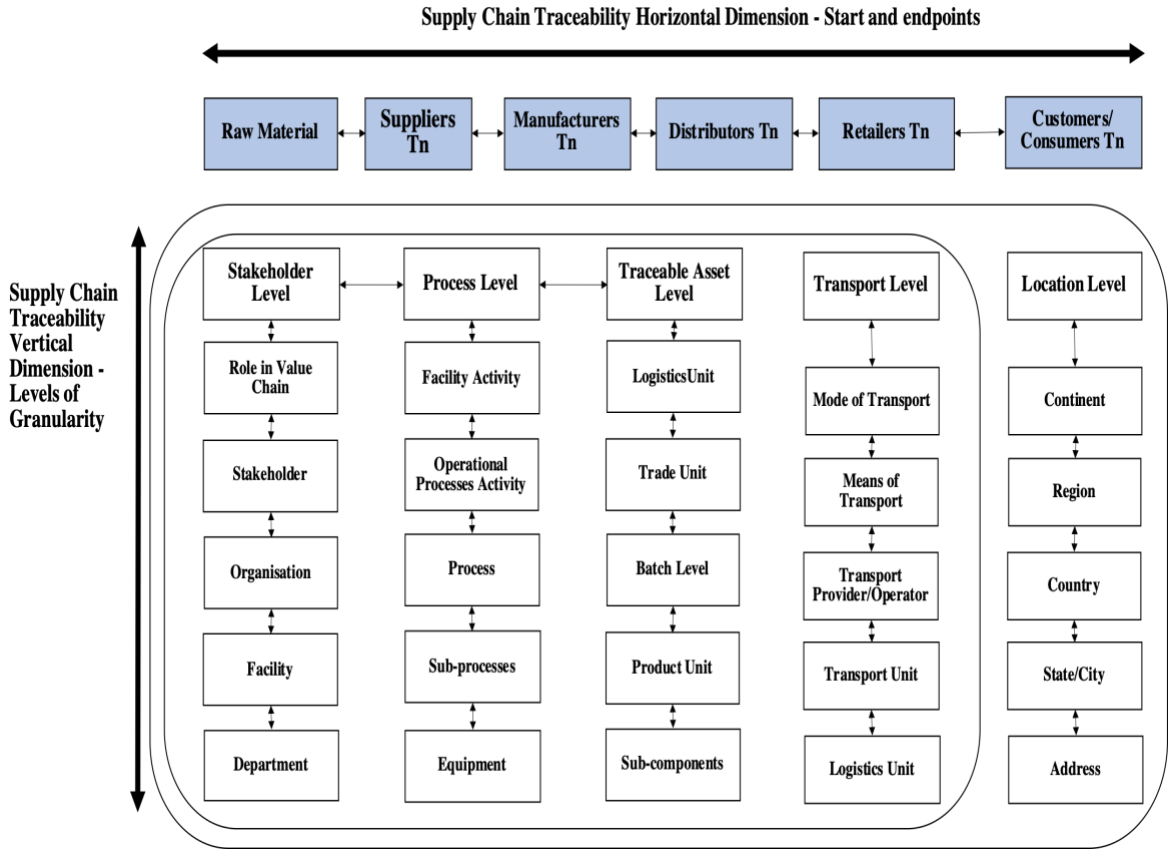


Figure 47. Supply chain traceability scope framework

Different traceability information can be collected at each of these identification levels. We further analysed the traceability information identified by UNECE (2021) in the case studies to map this information to the proposed identification levels in Table 33 along with some general examples from the automotive battery industry.

Table 33. Traceability information for different supply chain traceability scope and identification levels

Levels of granularity/ Identification levels	Related Traceability Information
Stakeholder Level ↓ Role in Value Chain (e.g., supplier) ↓ Stakeholder (e.g., battery cell manufacturer) ↓ Organisation (e.g., CATL) ↓ Facility (e.g., CATL Erfurt, Germany) ↓ Department (e.g., Factory)	▪ Stakeholder Activity Information ▪ Audits and Certifications ▪ Contracts Information ▪ Sustainability Information ▪ Other Management Information
Process Level ↓ Facility Activity (e.g., cell manufacturing) ↓ Operational Processes Activity (e.g., cell assembly) ↓ Process (e.g., cell conditioning) ↓ Subprocess (e.g., cells charging and discharging) ↓ Process Equipment (e.g., cell charger)	▪ Facility/process information and Specifications ▪ Inputs and outputs characteristics, date and time ▪ Quality (characteristics, inspections, audits, and certifications) ▪ Equipment capabilities and quality information ▪ Sustainability information ▪ Other management information
Traceable Asset Level ↓ Logistics Unit (e.g., Container) ↓ Trade Units (e.g., Commercial batch – 100 battery pack) ↓ Batch (e.g., production batch size- 60 battery pack) ↓ Product Unit (e.g., one battery pack) ↓ Subcomponents (e.g., battery cell)	▪ Origin Information ▪ Composition (ingredients) ▪ Technical Specifications (Materials/product specifications) ▪ Quality (characteristics, inspections, audits, and certifications) ▪ Sustainability Information ▪ Other management Information
Transport Level ↓ Mode of Transport (e.g., air, water, land) ↓ Mean of Transport (e.g., aeroplane, rail) ↓ Transport Provider/Operator (e.g., CMA) ↓ Transport Unit (e.g., container ID) ↓ Logistics Unit (e.g., Containers, Pallet)	▪ Pickup and Delivery Location ▪ Pickup and Delivery Schedules (date and time) ▪ Transport method Information ▪ Logistics Units Information ▪ Sustainability Information ▪ Other Management Information
Location Level ↓ Continent (e.g., Europe) ↓ Region (e.g., North-western Europe) ↓ Country (e.g., United Kingdom) ↓ State/City (e.g., Nottingham) ↓ Address (e.g., NGX 3ZX)	▪ Can be related to stakeholder, process, traceable asset and transport. ▪ Sustainability Information ▪ Other Management Information

10.5.3 The main factors influencing the scope of supply chain traceability

Despite the importance of traceability for SCM, there are many challenges associated with implementing traceability systems (Dasaklis *et al.*, 2019). A significant issue is related to

traceable assets identification throughout the supply chain (Aiello *et al.*, 2015). Three general requirements for product identification and traceability are indicated in the ISO 9001checklist: *"(1) establish the identity and status of products, (2) maintain the identify and status for products, and (3) maintain a record of serials or batch numbers."* (ISO 9001 Checklist, 2021). Hence, product identification and record maintenance are key pre-requisites for SCT. We briefly discuss them below.

a**. Product Identification:** Product identification is not a straightforward process, and varies depending on the desired level of granularity, the nature of the product and its manufacturing processes. Several technologies have emerged that enable the identification of products at the different SC stages, such as IoTs, barcodes, RFIDs, QR codes and labels (Kshetri, 2018). Ravasio (2019) classified the existing technologies for product identification into three categories: (1) Off-product techniques where the identifier is supplied with the product, such as product certificates, (2) On-product techniques where the identifier is attached to the product, such as RFIDs and labels, and (3) In-product techniques where the identifier is embedded in the product, including the use of dyes, tags or particles where physical particles are embedded to the product. Laser engraved marking techniques are another type of in-product technique (Thakur *et al.*, 2020). Different identification methods can be used at the different SC stages. Various product identification techniques were used in the research case studies. For example, in the leather pilot project, on-product techniques using labels and ear tags were used to identify the hide through the tanning processes. In the textile case study, the in-product identification technique, specifically by embedding specific chemical material, is used to identify the fibres in the end garment. The identification of shipping documents can be considered an embedded product identification technique where each electronic document is identified using a generated hash value and digital signature.

b. **Product record maintenance:** Product records can be kept in various formats, including paper-based records, spreadsheets, or centralised or decentralised databases. These records will need to be shared among and transferred between the different SC partners for SCT, raising issues on data tampering, security and privacy (Fu *et al.*, 2020). The use of digital technologies such as blockchain, has facilitated information sharing between multiple parties. It enables the creation of a SC digital twin (Srai et al.,2019), which is critical to ensure the credibility of the traceability system and the validity of its data. Blockchain has emerged as a potential technology that facilitates SCT (Agrawal, Sharma, *et al.*, 2018; Hastig and Sodhi, 2020).

Our findings provide empirical insights into the main factors influencing the SCT scope that can be targeted by different organisations (Figure 48). We identify and discuss these factors below.

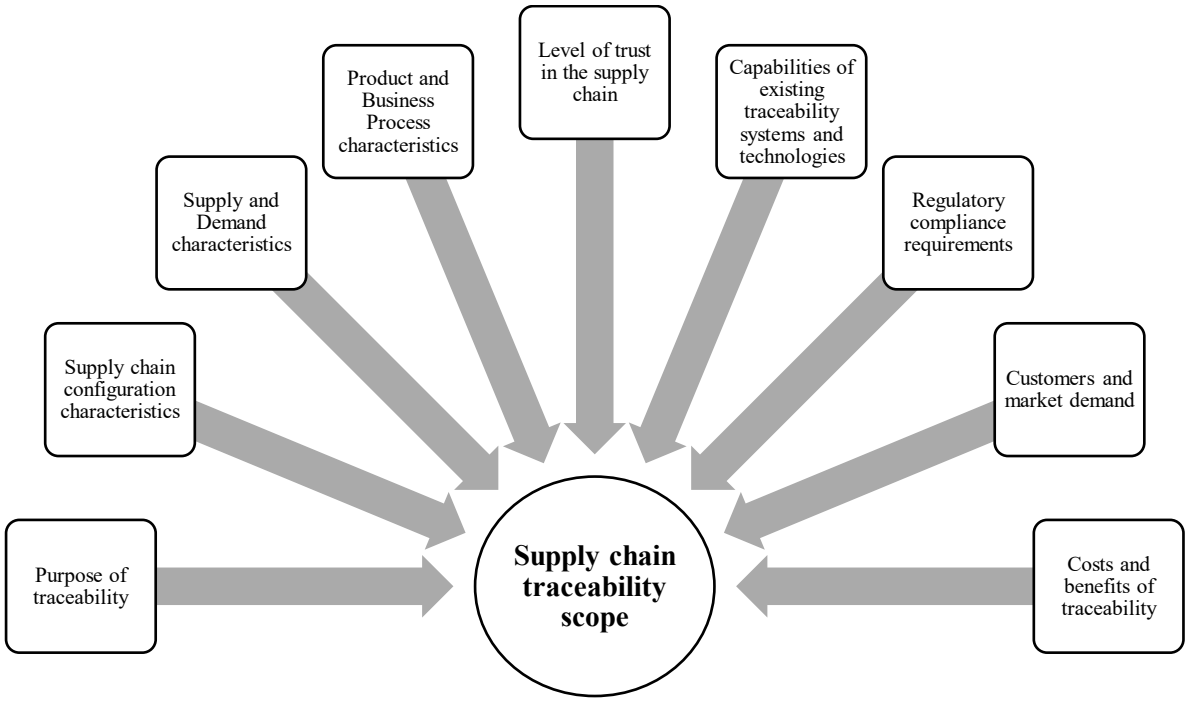


Figure 48. The different factors influencing the supply chain traceability scope

- **Purpose of traceability:** SCT is needed for different purposes, including regulatory requirements, sustainability compliance, authenticity of products, quality assurance, operational performance, response to disruptions, strategic sourcing, and SC restructuring endeavours. The purpose of traceability determines the SCT scope and the type of information to be collected in the supply chain. For example, location information must be captured and transmitted across the supply chain to identify product provenance. Information related to Co2 emission from the product and its manufacturing processes and transportation has to be captured to conduct product LCA. The purpose of traceability can differ across sectors and product characteristics, and it can be influenced by market and regulatory requirements.

- **SC configuration characteristics:** the structure, size and complexity of the supply chain are important aspects to consider when defining the SCT scope and designing and implementing SC traceability systems. It helps identify the number of parties involved and

the investment requirements. Complex supply networks are harder to trace. However, traceability might be more needed in these types of supply network configurations.

- **Supply and Demand characteristics:** The diversity, volume and fluctuation of supply and demand provide information about the requirements of the traceability system, including its adaptability and flexibility to accommodate changes in supply and demand.

- **Product and Business Processes characteristics:** The nature of the product and its manufacturing processes can influence the SCT scope and the optimal level of SCT. Food and pharmaceutical products will benefit from implementing traceability at a high level of granularity, while it might be appropriate to track commodity products at aggregated volumes. The nature of the manufacturing process can impact the feasibility and practicality of products' traceability across the supply chain and the possible level of granularity. This was evident in the leather case study where it was difficult and infeasible to maintain hide level traceability during the tanning processes.

- **Level of trust in the supply chain:** The level of trust in the network affects information sharing, security and control requirements targeted by the traceability system. It can also influence the type of information systems used and data governance.

- **Capabilities of existing traceability systems and technologies:** the capabilities of existing technologies in enabling traceability are important to consider especially, product identification technologies and information systems. It helps identify data availability, which is important to identify data collection and capture requirements.

- **Regulatory compliance requirements:** Having clear regulatory requirements indicating what level of traceability should be achieved and what information should be gathered would facilitate the identification of traceability requirements and the development of traceability systems.

- **Customers and market demand:** Customers and market demand can drive and guide the design and implementation of traceability systems. For example, customer demand for product provenance would require the collection of location information and the implementation of the traceability system from the sourcing of raw materials to identify its

provenance, while customers demand for reduced carbon footprint would require the collection of CO_2 emissions data across the entire supply chain.

- **Costs and benefits of traceability:** One of the important factors influencing targeted level of traceability is its costs and benefits. Different traceability costs and benefits were identified in Table 31. The benefits of traceability must exceed the investment costs to become feasible. The higher granularity required for the SCT solution, the higher the costs and the more complex it becomes, which affect the implementation and practicability of the traceability system (Karlsen *et al.*, 2012). However, high granularity provides more accurate information about the product and can reduce product recall costs (Karlsen et al.,2012, Aiello et al.,2015). Hence, it is crucial to find the optimal level of granularity for the traceability system where the benefits exceed the costs (Aiello *et al.*, 2015; Karlsen *et al.*, 2012). Identifying the costs and benefits of traceability can impact the incentive level of the different participants to participate in the traceability system. The costs and benefits of traceability can be affected by all the above factors and the desired scope of traceability. The desired level of granularity affects the requirements and outcomes of the traceability system and hence, its costs and benefits. Similarly, the regulatory requirements, SC configuration complexity and adopted technology can all affect the costs and benefits of traceability.

  Other factors that influence the costs and benefits of traceability include the amount of data collected and the data collection method as they both affect the number of resources required. Manual data records will require more resources, and the implementation costs for automated data recording technologies can be high (Aiello *et al.*, 2015). It will also affect the storage data requirement for the traceability system. Notwithstanding, rich and high-quality data availability can lead to better SC planning and management. Finally, enterprise size can affect the costs and benefits of traceability. In general, large enterprises have a higher level of digitalisation than SMEs. With already advanced ICT and information systems, enabling traceability for large enterprises may have less cost implication compared to SMEs who might be using manual systems and find the required investment to be costs prohibitive (Nishantha *et al.*, 2010). SCT can provide different benefits for different SC partners. Large enterprises can reduce product recall costs when non-conformance by precisely identifying the sources of contamination. This is more significant for large enterprises since product volumes are relatively higher than SMEs.

SCT can also enable large enterprises to comply with regulatory requirements and meet customer demand. For SMEs, SCT can provide them with a competitive advantage against their rivals. All these issues are strongly relevant in considering blockchain–enabled SCT solutions.

Determining the optimal level of SCT is a prominent area that has attracted only limited research. Taking the SCT for leather as an example in the workshop, the different participants were asked to propose an optimal level of traceability. Different groups had different opinions, including enabling traceability at the organisation level (business to business), starting traceability from the indirect leather supply chain, having 100% end-to-end traceability across the supply chain at a high level of granularity, and having different levels of traceability across the supply chain where high granularity is targeted at the most variable areas and low level of granularity at less variable areas in the supply chain. The variety of opinions provided in the workshop highlighted the lack of common understanding and guidance regarding the level of SCT that organisations should aim for, and the need for research that investigate this important issue.

10.6 Theoretical Perspectives for Blockchain-SCM Research

Some previous research has illustrated how existing theories may be applied and modified to describe, explore, and predict the changes that may accompany blockchain application (Kummer *et al.*, 2020; Saberi *et al.*, 2019; Sternberg *et al.*, 2021; Treiblmaier, 2018). The nature of blockchain applications and their potential impacts calls for multidisciplinary theoretical perspectives to better understand the technology, its capabilities, and its implications at this early stage in its development (Saberi *et al.*, 2019). This research adopted grounded theory to gather comprehensive insights about blockchain adoption in the supply chain.

Considering the multidisciplinary nature of blockchain research, no single theory can holistically address or explain blockchain adoption in the supply chain. However, the research findings helped identify various theoretical perspectives relevant to the blockchain-SCM research that can be used in future research to fully capture and explain the disruptive potential of blockchain. Figure 49 presents the combinations of theories that can be used to further study certain aspects related to blockchain adoption in the supply chain. These multidisciplinary theoretical perspectives can be applied, tested, and modified to further develop blockchain-SCM research. We discuss relevant theories that can potentially advance research on blockchain-SCM considering the intra-organisational, inter-organisational, system and external dimensions:

- **Resource-based view (RBV):** The research findings illustrate that not all products and processes benefit equally from the introduction of blockchain. They indicate the criteria that ultimately determine the feasibility of a blockchain application and whether it is likely to add value. In a nutshell, products and processes of high value, safety-critical, or that have high social, environmental or economic impact benefit most from blockchain. From a theoretical perspective, these characteristics can further be investigated considering the resource-based view (Wernerfelt, 1984). The RBV enables organisations to assess their internal resources to prioritise the most valuable products and processes for blockchain adoption and deployment that can enable the organisation to gain a competitive advantage. This is particularly important in the pre-adoption stage. After blockchain adoption, the blockchain solution is one of the organisation's resources that can be evaluated and further enhanced and scaled through the RVB lens to sustain a competitive advantage.

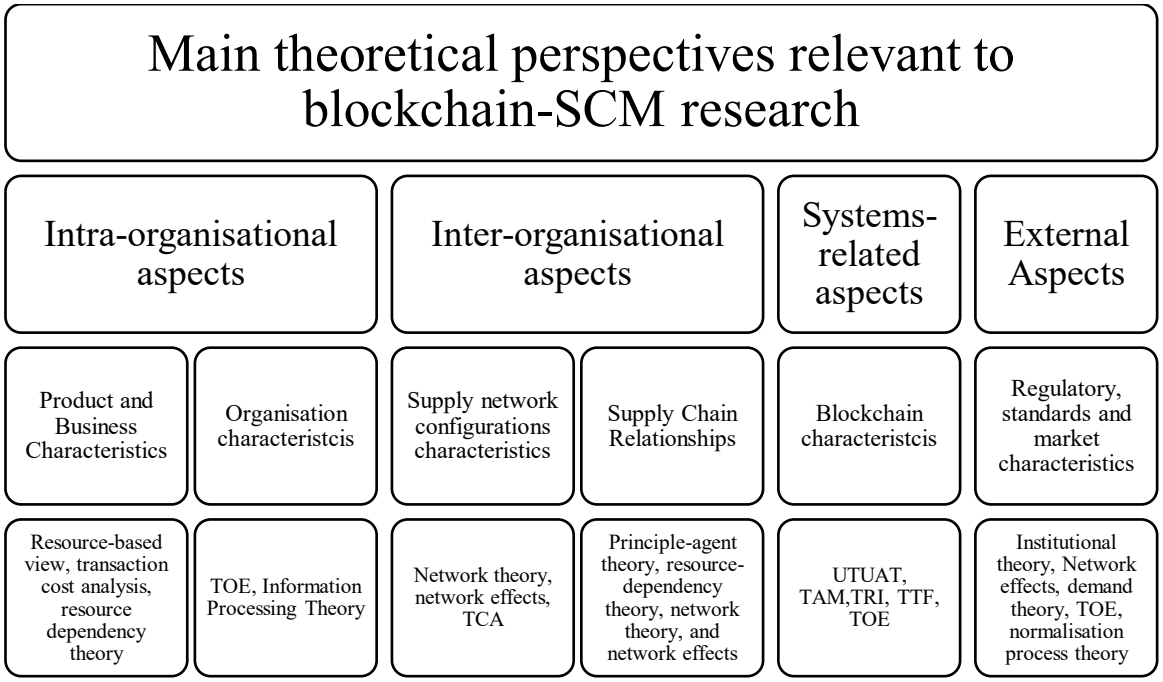


Figure 49. Framework for theory relevant to blockchain-SCM research

- **Transaction cost analysis theory (TCA):** Cost reduction has been one of the main motivations for blockchain adoption in the supply chain. The different organisations were also concerned about the perceived value of blockchain and the investment costs required to adopt and maintain the technology. TCA (Coase, 1937; Williamson, 1981), is particularly important when evaluating the value proposition of blockchain in SC applications. It is relevant for intra- and inter-organisation evaluation as organisations can assess the internal costs associated with their SC transactions with and without blockchain. Similarly, the different SC partners can collectively evaluate the overall impact of blockchain on SC transaction costs since they are directly or indirectly impacted by changing costs across the supply chain. The SC transaction costs can also be influenced by the supply network configuration characteristics and the number of parties involved in exchanging products across the supply chain.

- **The Technology-Organisational-Environmental (TOE) framework:** The different elements of the TOE framework are relevant to blockchain adoption and scalability in the supply chain. The technical factors, including availability and characteristics, were evident in the systems-related factors identified in this research. They are directly related to blockchain immaturity, ongoing development, and the characteristics and configuration of the blockchain solution. The organisational factors, particularly organisation structure, size and communication processes, are highlighted as key factors influencing the decision-making

regarding blockchain adoption in the supply chain, particularly organisation internal capabilities and level of digitalisation. Finally, the environmental factors include the industry characteristics, market structure, government regulations and technology infrastructure are all related to blockchain adoption. One of the main limitations of solely using the TOE framework is that it does not consider the specific intra-organisational aspects that play a crucial role in the decision-making regarding blockchain adoption and scalability based on our research.

- **Information processing theory:** The organisation's capabilities to process and utilise the information gathered by blockchain systems can affect their perceived value of blockchain. Organisations ought to be able to process and utilise the data accessed by blockchain to gain valuable insights to improve their performance. This was one of the concerns highlighted in the case study where different participants raised concerns about how to analyse collected data and the potential value. The use of information processing theory can help identify the organisation's existing or required information processing capabilities for blockchain data analysis.

- **Network theory:** The research findings illustrate how the characteristics of the supply network configuration influence the pre-requisites for and factors influencing blockchain adoption and scalability in the supply chain. Characteristics such as the geographical expanse, SC complexity and network size should be considered. Thus, network theory (Latour, 2005), can help refine and sharpen the key requirements for effective blockchain deployment. It can also help in investigating how the supply networks evolve and the nature of SC relationships that significantly influence the willingness of the different organisations to adopt blockchain.

- **Network effects:** Blockchain is an inter-organisational technology. The potential value and benefits of blockchain increase with the increase of participating nodes as it directly enhances the amount of information shared and accessed among the network participants. Hence, blockchain adoption is strongly influenced by the Network effects (Katz and Shapiro, 1985). Network effects have long been identified as an important technology adoption motivation and, in many cases, as the decisive factor for network survival and growth. This study has identified certain characteristics and factors that have strong repercussions on network effects, including the development of supportive standards and regulations for blockchain adoption, the need for compliance to existing standards and regulations, and the development of industry-wide standards. These observations from industry-wide blockchain

consortia provide valuable extensions for the refinement and adaptation of network effects theory for SC applications. By considering the network effect on blockchain adoption, interested organisations and researchers can focus on investigating the key aspects of blockchain that can be desirable by the majority of users to incorporate in the blockchain solution design. For example, these aspects can be considered in developing the blockchain data governance model to encourage wide-scale adoption.

- **Principal-agent theory:** The research findings stressed the importance of having mutual interests and motivations to encourage blockchain adoption in the supply chain. This can strongly be influenced by the nature of the SC relationships and the willingness of the SC partners to share information. Principal-agent theory (Eisenhardt, 1989a), is particularly important to investigate the various interests of the different SC partners to ensure alignment in motivations. This is one of the main identified decisive factors for blockchain adoption. It is also important theory to investigate the potential changes in roles, power, and control of the SC partners considering blockchain transparency and decentralisation that might potentially transform traditional principle-agent relationships

- **Resource dependency theory (RDT):** The research findings suggested the consideration of partnering with SC partners with whom organisations have level of dependency. Resource dependency theory (Casciaro and Piskorski, 2005), can help organisations identify and manage inter-dependencies across the supply chain. RDT is also relevant to investigate the product and processes characteristics as raw materials scarcity and innovative processes can impact the degree of dependency among the SC partners. Furthermore, by taking the RDT lens, researchers can further investigate the changing power structures and authorities resulting from blockchain adoption and increased transparency and decentralisation across the supply chain.

- **Demand theory:** The research findings reveal that engagement in blockchain-based solutions can be strongly driven by market and customer demands, including demand for authenticity, performance, provenance, security, and sustainability. From a theory perspective, all these demands are pull factors for blockchain adoption and warrant rigorous academic studies to better understand their role in the technology adoption. This is especially interesting since most research so far has looked into the driving factors of blockchain adoption in those organisations that are actually deploying it, but the driving force that is exerted by the outside

world (which might be SC partners, consumers or regulators) has gained very little attention. Thus, demand theory (Mark *et al.*, 1981; Morgenstern, 1948) calls for a thorough investigation of consumer behaviour and needs and their implications on organisations' decision-making regarding blockchain.

- **Normalisation process theory (NPT):** The research identified the need for regulatory and standard organisations support to promote blockchain adoption in the supply chain. This is crucial for the scalability and the maturity of the technology. Furthermore, the use of blockchain to share SC data will require in-depth investigation into blockchain's short- and long-term implications on related business activities. Furthermore, concerns related to blockchain integration with existing platform was strongly evident in the research. All these indicate the relevance of normalization process theory (Murray *et al.*, 2010), which addresses the complex intervention of technologies and the required factors for its successful deployment and integration. NPT can help better understand how blockchain can be incorporated into the complex landscape of supply chain and organisational systems.

- **Institutional theory:** The institutional theory (Hirsch, 1975), is directly related to one of the frequently highlighted external factors in our research which is the regulatory and standards pressures and support that can direct, guide and encourage blockchain adoption in the supply chain. Blockchain platforms can be shared across the globally dispersed supply networks expanding across multiple countries if not continents. The use of institutional theory can help address the importance of considering the institutional practices of involved countries and their impact on blockchain use and development.

- **The unified theory of acceptance and use of technology (UTAUT) and Technology Acceptance Model (TAM):** The UTAUT and TAM have been commonly adopted in the blockchain-SCM research to assess the adoption behaviour of the technology. The research findings indicate the perceived value from blockchain adoption, and ease of adoption as key factors affecting blockchain adoption and scalability which are directly related to TAM. Furthermore, it identified the type and amount of data required, and availability of resources as main factors influencing blockchain adoption. These factors can also directly relate to effort expectancy, and facilitating conditions constructs of UTAUT. However, we argue that more contextual factors can significantly mediate or moderate the UTAUT and TAM constructs to

provide more comprehensive insights and better understanding about blockchain adoption in the supply chain.

- **Technology readiness index (TRI):** Many researchers and practitioner claimed that blockchain is a disruptive technology, resulting in a hype surrounding its potential that was investigated by Gartner (Litan, 2021). Blockchain is a combination of different technologies, and it is not easy to grasp terms like decentralisation, cryptography, consensus mechanism, and autonomous contracting. All these affect people's perception and limit their understanding of blockchain, significantly affecting the technology adoption. The lack of awareness about blockchain is a major inhibitor identified in our studies. TRI theory can help better understand people's tendency to adopt blockchain considering the amount of knowledge they have about it. This might have a wider implication on organisational training requirements to facilitate blockchain use.

- **Task-Technology Fit (TTF):** The research findings highlighted the organisations concerned about the amount and type of information required on the blockchain platform. Besides worrying about information disclosure and security, it is important for identifying the resources requirements for the management and maintenance of the blockchain system. Resources availability and investment requirements are key considerations identified influencing blockchain adoption. Furthermore, blockchain adoption in the supply chain brings new product identification requirements to enable traceability. Introducing new identification methods for products can result in new tasks required by involved participants and other technology not used before. The task-technology fit theory (Zigurs and Buckland, 1998), supports the investigation of the technology adoption and the associated tasks. TTF can help evaluate and identify the requirements of the blockchain solution and its impact on the processes it aims to support.

Chapter 11: Research Contribution, Conclusion and Future Research Directions

Blockchain technology has captured the interest of many in the SCM communities in academia and industry. The rapid pace at which blockchain is developing and being increasingly tested in various applications presents a challenge for researchers to actively investigate this technological phenomenon. The literature review identified the lack of empirical research on blockchain-SCM, and the repetition of the same conceptual themes identified in multiple literature reviews. It also identified the need to take an SCM lens when investigating blockchain adoption and application rather than focus entirely on the technical aspects of the technology. An increasing number of scholars have adopted several empirical research methods to address the identified gaps. However, most research has focused on specific SC elements, specific industries, or even specific theoretical constructs. Limited literature takes a holistic and grounded empirical approach to fully understand this complex and emerging phenomenon across industrial sectors.

This research investigated and critically analysed the potentials of blockchain technology in the SCM field using mixed methods research, including multiple case studies, an analysis of reported blockchain use cases and an executive workshop. The variety of methods used in this research enabled the collection of comprehensive data that provided tremendous insights into the main motivations, pre-requisites, inhibitors and factors influencing the decision-making, adoption and scalability of blockchain in the supply chain.

The multiple case studies included leading organisations in different industries and at different positions in the supply chain, which enabled generalisation of the research findings. Furthermore, studying organisations at different stages of blockchain adoption, ranging from pre-adoption, development of a use case, one pilot, many pilots, and an operational platform, provided in-depth empirical insights at different adoption stages, which enriched the research findings significantly. The analysis of blockchain use cases reported over the past five years and across different sectors provided strong complementary evidence for the triangulation of the multiple case studies findings. It also provided additional insights into other sectors not included in the case studies to further support the generalisation of the research findings. The executive workshop enabled the inclusion of additional participants from more organisations to investigate one of the prominent areas for blockchain application - supply chain traceability.

It provided further complementary findings to the multiple case study considering experts' perspectives with different backgrounds and expertise in implementing traceability solutions.

The research findings provided empirical analysis to underpin the largely conceptual research on the topic. It has provided new empirical evidence on the motivation, pre-requisites, inhibitors, and factors influencing the decision-making, adoption and scalability of blockchain in the supply chain. We re-visit the research questions and summarise the main research contributions related to each research question below:

RQ1: How do industry characteristics influence blockchain applications in the supply chain?

This research is the first to investigate the different sectoral characteristics and their influence on the motivations of blockchain adoption and application areas in the supply chain. The research identifies five clusters of industry characteristics and their sub-categories influencing blockchain motivations and application areas, relating to the products, business processes, supply network configuration, standards and regulations, market and customer demand characteristics (more on Section 10.1.3).

RQ2: What are the main motivations for blockchain adoption and application in the supply chain?

This research identified the main motivations for blockchain adoption in the supply chain across different industries based on empirical evidence. Our findings add to the academic literature by confirming and describing in more detail motivations such as traceability, transparency and efficiency, but also identifying new dimensions not previously highlighted, including customer service, risk management, and quality assurance. Specific motivations related to blockchain application for supply chain traceability are also identified (Section 10.5.1).

The research also provided a detailed cross-industry analysis of the specific blockchain application areas in the supply chain targeted by the different organisations. Specifically, the study identified (1) the traceability of products across the supply chain and in aftermarkets, (2) the automation, digitalisation, and optimisation of business processes, and (3) the enhancement of customer experience by sharing valuable information such as product provenance information.

The research findings related to the above two research questions led to the development of an evidence-based conceptual framework that captures the principal industry motivations, the main application areas, and the key industry characteristics influencing blockchain adoption and application in the supply chain. The framework is the first to take a cross-industry perspective on blockchain applications in the supply chain. The framework provides a strong foundation that can be further investigated and tested using appropriate theoretical perspectives and, by matching industry findings with theoretical propositions, help to further develop and refine existing theory as the rate of adoption of blockchain increases and the application domain matures.

RQ3: What are the key pre-requisites and inhibitors for blockchain adoption and deployment in the supply chain?

The research identifies six main pre-requisites for blockchain adoption in the supply chain. The research provided empirical confirmation to requirements suggested in the literature, such as having a clearly defined purpose for blockchain application (Wang, 2020), establishing an agreement among the participants (Babich and Hilary, 2020), the inclusion of all necessary parties (Jović *et al.*, 2019; Sternberg *et al.*, 2021), and development of data governance model (Wang, 2020). However, it identifies two additional prerequisites that are ignored in the literature, namely, knowledge of the supply chain and the ability to create a supply chain digital twin.

The research findings also provide a structured framework including an exhaustive list of potential inhibitors for blockchain adoption in the supply chain based on empirical evidence. Challenges related to the SC configuration and complexity, creation of a supply chain digital twin, and having incompatible business processes, are new inhibitors identified by this research.

RQ4: What factors influence the decision-making and scalability of blockchain-enabled solutions in supply chain applications?

The research is the first to identify in detail the factors influencing the decision-making, adoption, and scalability of blockchain in the supply chain based on empirical cross-sectoral evidence of real blockchain application at different stages of adoption. Most blockchain implementations do not expand beyond the pilot stage due to the immature understanding of blockchain and its implications on business practice. The research makes several contributions

in response to this research question. First, the research findings enabled the development of an empirical-based decision framework that guides the decision-making regarding blockchain adoption and the selection of potential application areas (Section 10.4). The first part of the framework addresses the limitations of existing decision frameworks developed in the literature by considering all the core characteristics of blockchain. The second part of the framework provides new guidance to select blockchain application areas in the supply chain by identifying which products and business processes can benefit the most from blockchain and which SC partners are best to collaborate with in developing a blockchain SC solution. Second, the research provides new insights into the factors influencing the scalability of blockchain-enabled supply chain solutions considering the characteristics of the blockchain solution and the supply chain. These factors are distinguished from blockchain adoption factors in that it takes a supply chain perspective rather than an organizational perspective. Third, the research provides new empirical insights into one of the prominent issues of blockchain implementation for supply chain traceability, defining the level of traceability that organisations across the different sectors should aim for. The research findings provided focused empirical insights into the potential scope of supply chain traceability and the main factors influencing the level of traceability targeted by the different organisations. The research proposes a comprehensive new framework that defines the scope of supply chain traceability solutions that different organisations can target. This framework identifies two dimensions of supply chain traceability scope - the start and end points of traceability and the level of granularity - which can inform the design of the traceability system and help identify traceability requirements.

Finally, the research findings have helped in the development of a framework for theory that provides guidance to the use of theory in blockchain-SCM research and proposes different combinations of relevant theoretical perspectives that can be used in future research to investigate particular aspects of blockchain adoption in the supply chain.

11.1 Contributions to Practice

The research contribution provides in-depth insights into how blockchain can be applied in practice and has identified tremendous opportunities for future research. The research findings and developed frameworks provide comprehensive guidance to SCM practitioners interested in implementing blockchain or considering the scalability of adopted blockchain solutions in their broader supply networks. Besides the overall research contribution, the case studies

provided a unique set of contributions that has significant practical implications. We summarised the main practical implications of the research below:

- The research stressed the importance of considering both the inter-organisational and intra-organisational characteristics in the decision-making regarding blockchain technology adoption in the supply chain. For example, in the battery case study, although blockchain has been successfully implemented in the cobalt supply chain of other automotive OEMs, organisation A decided not to adopt it due to specific SC characteristics.
- The research stressed the importance of supply chain mapping as a necessary tool that informs the decision-making, design and development of blockchain supply chain solutions.
- Several important considerations were raised regarding establishing an agreement among the SC partners, having mutual interests, and incentives that can be valuable for practitioners interested in adopting the technology.
- The research also investigated vital issues related to product identification, levels of traceability, and scalability considerations that other SCM researchers and practitioners can strongly relate to and benefit from in their blockchain adoption journeys.
- The research provided detailed insights into the stages of developing blockchain SC solutions, which is relevant to a wide range of blockchain applications.
- The research identified opportunities and major challenges for extending SC traceability solutions across the entire supply chain from raw material to end consumer in the textile and apparel sector. These insights have relevance to blockchain applications in many other sectors with different supply chain configurations.
- The use of SWOT analysis in the shipping case study has revealed important considerations regarding the development of industry-wide solutions and the implications of shipping processes digitalisation on the shipping ecosystem members, a major identified literature gap in the industry.

11.2 Research Limitations and Future Research

The research is limited in the number of case studies used. However, considering the recent emergence of blockchain technology and the immature adoption of blockchain in practice, the research was able to investigate in detail pioneer organisations that have taken the lead in their respective sectors on blockchain adoption. Organisation A is the first to trial and implement

blockchain in the leather supply chain. Organisation B, a world-leading fibre producer, is a pioneer in adopting blockchain in several supply chains in the textile and apparel industry, and that has partnered with leading brands and retailers. Organisation C is very much a pioneer in providing an operational blockchain-enabled digital solution in terms of its scope (it extends beyond the ocean carriers), size (there is an increasing number of participants), and operations (there is an increasing number of shipments processed through the platform). All of these make the selection of case studies valuable, notwithstanding their limited number. Furthermore, the case study findings and analysis are supported by the existing literature, two complementary studies of reported blockchain use cases in practice and an executive workshop that have enabled triangulation and generalisation. Nonetheless, including more case studies will provide additional insights into this emerging and interesting area of research, which is vital for its wide-scale adoption and further development.

Considering the rapid development of blockchain applications in the supply chain, further research is needed to investigate empirically the increasing number of blockchain implementations in the supply chain in the different industries. In addition, future research can consider other important industries not covered in this research, such as the construction and energy sectors where blockchain applications are of high prominence.

Finally, the research findings strongly contributed to the development of blockchain-SCM in terms of theory development. By using grounded theory, the research findings enabled the development of a theoretical framework that guides the use of existing theory in investigating the different aspects of the broad blockchain-SCM field. More research can empirically adopt the proposed combination of theoretical perspectives to further investigate blockchain applications in the supply chain and contribute to theory development.

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Appendix A

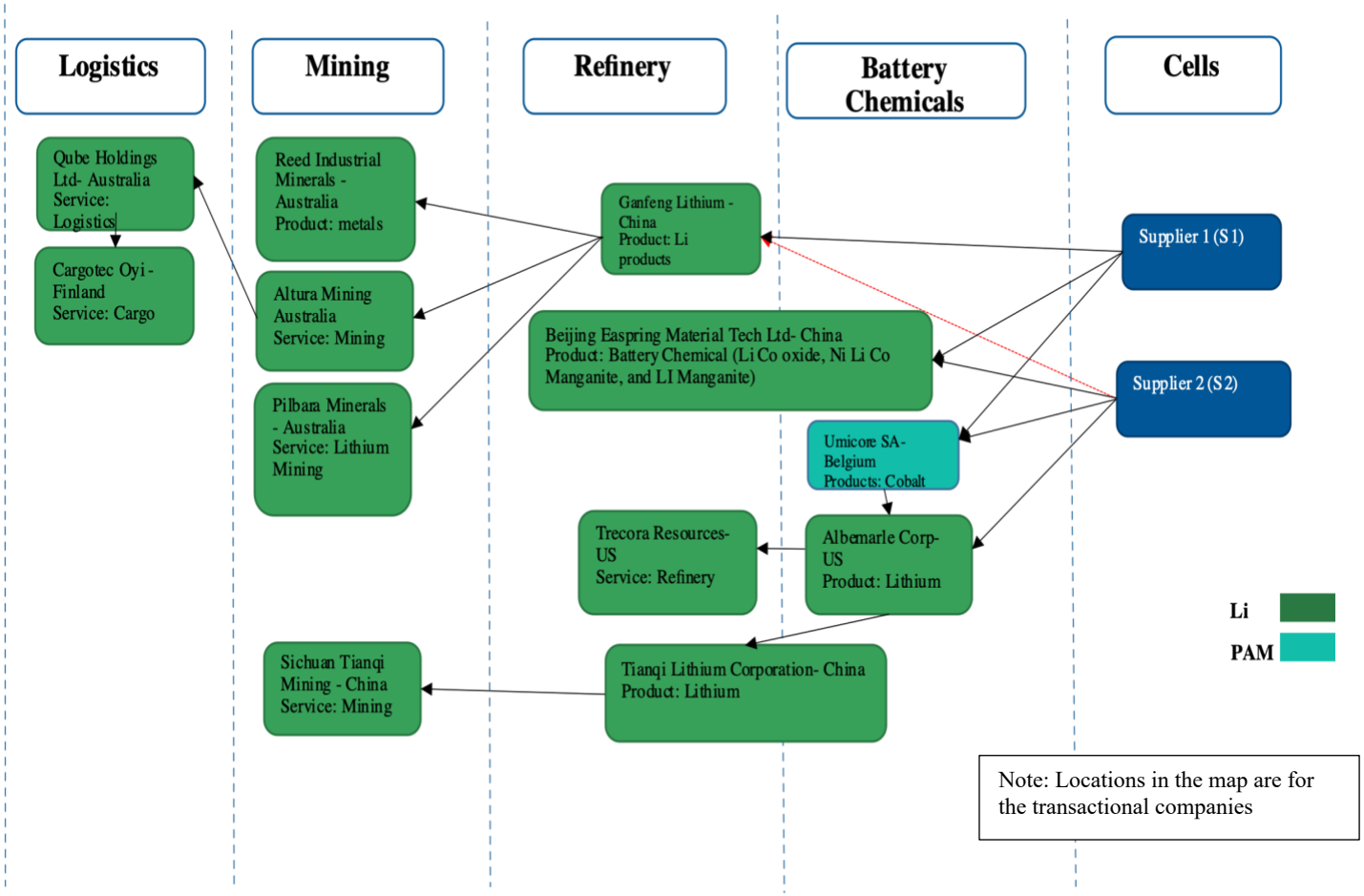


Figure 50. Organisation A lithium supply chain map

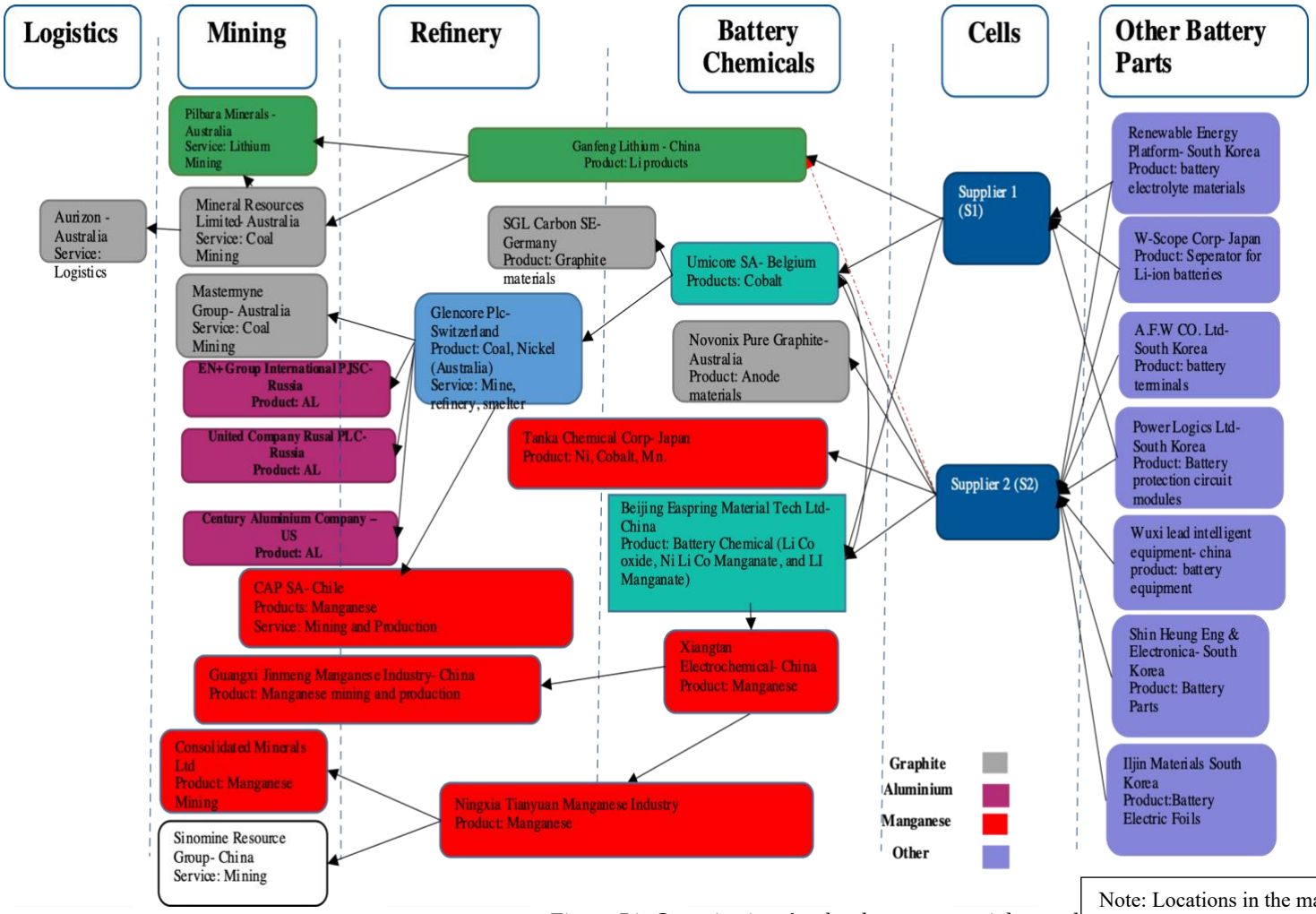


Figure 51. Organisation A other battery materials suppl

Note: Locations in the map are for the transactional companies