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Dynamic Analysis of the Implementation of the Blockchain Technology in the Supply Chain

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DYNAMIC ANALYSIS OF THE IMPLEMENTATION OF THE BLOCKCHAIN TECHNOLOGY ON THE SUPPLY CHAIN

by

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ABSTRACT

Blockchain technology is a new digital technology that has been disrupting the way businesses are performing. It is a decentralized and distributed ledger that enables transactions of any form of value. As blockchain technology provides visibility, transparency, and security through the multi-agent system, the supply chain sector is one of its critical and promising applications. In a highly dynamic environment, the supply chain's efficiency needs to be measured from a blockchain perspective. As the main benefit of blockchain technology is the visibility and real-time access to data, blockchain technology's preeminent affected areas within the supply chain are the responsiveness to the customer and the inventory efficiency among the supply chain partners. This research developed a dynamic model to measure supply chain efficiency from the blockchain perspective. The developed model is based on system dynamics methodology to model a typical three-tier supply chain; manufacturer, distributor, and retailer. It consists of three components; chain system, backlog system, and supply chain efficiency evaluation system.

First, an introduction to the supply chain and blockchain technology is provided. Second, a literature review of supply chain and blockchain technology is presented. From the literature analysis, a research gap is identified with the research questions and objectives. Third, the methodology proposed in this research to answer the research problems is discussed with a literature review about applying system dynamics methodology within the supply chain, and technology adoption is provided. Forth, an illustration of the proposed model is given. Fifth, the dynamic analysis of the supply chain's performance according to various scenarios is evaluated. Finally, a conclusion with the future work is provided.

I dedicate this work to:

My great father, **Mohamed**, for his support, love, and belief in me

My beloved mother, **Kamilia**, for her ongoing love, sacrifices, and support

My lovely husband, **Mahmoud**, for her love, patience, and sacrifices

My beautiful kids, **Hamza** and **Omar**, for the happiness and joy they bring to my life

My brothers, **Ahmed** and **Mahmoud**, for their encouragements

My mentor **Ahmed Deif** for his unstoppable support and inspirit

And my friends for their care and help, especially **Hajar Naguib** & **Noor Mohamed**

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CHAPTER 1: INTRODUCTION

1.1. Background

Industries worldwide are continually seeking to increase their network of suppliers, distributors, retailers, and partners to satisfy the tremendously changing customer' needs. In order to achieve this goal, supply chains become much more complicated than ever. The management of material, money, and information flow in the supply chain needs more reliable technology to achieve transparency and visibility to all supply chain partners. Blockchain technology is a highly growing technology that can provide trust, decentralization, visibility, and transparency to the supply chain network from the early start of the origin of material to the end customer. In this chapter, an introduction to the supply chain and its components is provided. Then the blockchain technology and how it works is elaborated. Furthermore, the problem statement, research objectives, and research questions are presented.

1.1.1. Supply Chain

A supply chain (SC) is a network of entities needed to design, make and use a service or product (Michael Hugos, 2003). Supply chain activities include the procurement (or creation as farmers) of raw material, transforming these materials through one or various facilities into intermediate or finished products, and distributing these products or services to customers (Campuzano & Mula, 2011). The strategy to manage these activities to achieve a specific goal is defined as supply chain management (SCM). Any supply chain's goal is to deliver the right product/service to the right customer in the right quantity with the right conditions at the right time within the right place at the right cost (Safiye Esmanur ACUNGIL, 2019).

Supply chain management is defined as "the systemic, strategic coordination of traditional business functions and the tactics across these functions within a particular company and across businesses within the supply chain, to improve the long-term performance of the individual companies and the supply chain as a whole" (Hald & Kinra, 2019). The supply chain's management focus has been shifted from increasing the operational efficiency to agility, e-business, and SCM synchronization, as shown in Figure 1.

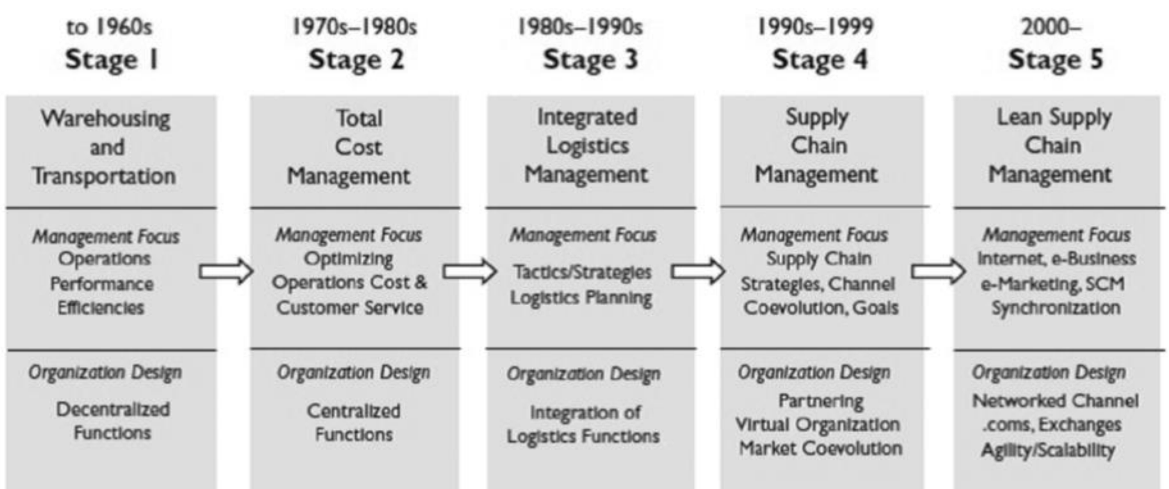


Figure 1: Evolution of supply chain management (Kumar et al., 2020)

A typical supply chain consists of a supplier, manufacturer, distributor, retailer, and end customer. Three types of flows run in a typical supply chain; the material flow, the financial flow, and the information flow (Petersen, Hackius, & von See, 2018), as seen in Figure 2. The material flow usually goes upstream while the money flow goes downstream. The information flow is the most complicated part as it is meant to be across the whole supply chain partners.

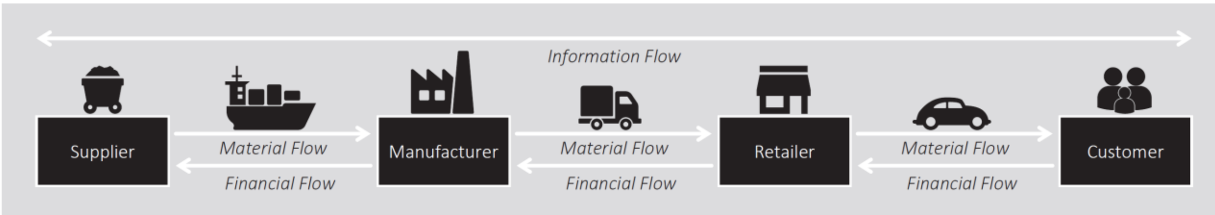


Figure 2: The material, financial, and information flow in a typical supply chain (Petersen et al., 2018)

The traditional nature of a static linear supply chain has been dramatically changed to a circular, dynamic, and interconnected system or digital supply network (DSN), according to (Deloitte Insights, 2018). In the traditional supply chain, each step depends on the previous step, so any early steps' inefficiencies will amplify throughout the chain. The digital supply network can overcome this problem by providing real-time data, transparency, and collaboration throughout the whole supply network (see Figure 3). This digital transformation can be done via industry 4.0 or the fourth industrial revolution (as blockchain, IoT, AI, robotics, etc.) to provide real-time access to exciting and new data (Deloitte Insights, 2018).

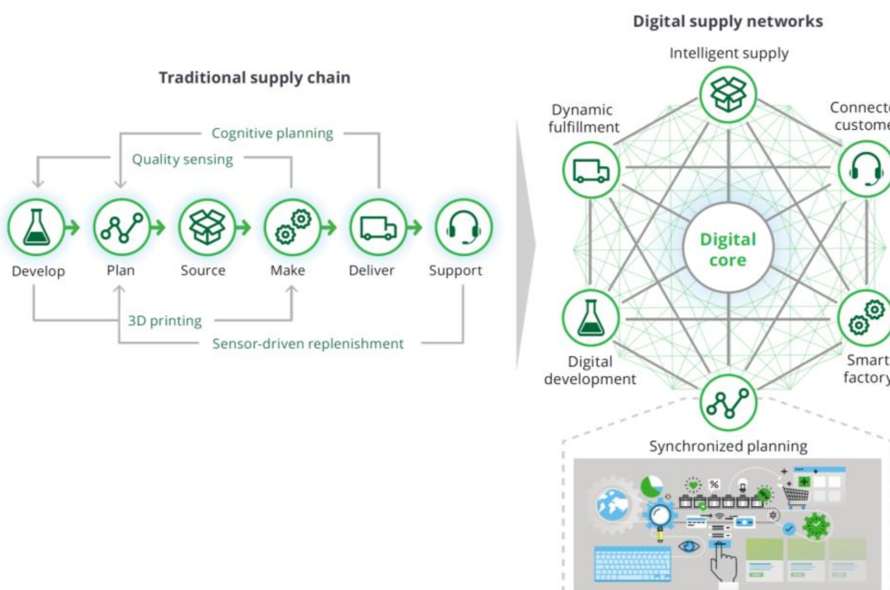


Figure 3: Shift from traditional supply chain to digital supply network (Deloitte Insights, 2018)

1.1.2. Blockchain

Digital technologies today as 3D Printing, the Internet of Things (IoT), blockchain, etc., are disrupting almost every industry and sector, either public or private. According to (Startup Genome LLC, 2019), blockchain technology has grown from being the third of the top four growing subsectors in 2018 to the second rising subsector in 2019 after advanced manufacturing and robotics. It is also the first sector in the startup creation growth with 23.9% in 2019 (see Figure 4), increasing from 17.9% in 2018, attracting many researchers' interests in academia and industry.

Sub-Sector	Early Stage Deals 5-Year Growth	Exits 5-Year Growth, Count	Share of Global Startups	Startup Creation Growth
Advanced Manufacturing & Robotics	107.9%	143.8%	1.8%	6.6%
Blockchain	101.5%	93.9%	2.7%	23.9%
Agtech & New Food	88.8%	74.1%	0.8%	8.3%
AI, Big Data, & Analytics	64.5%	130.3%	7.1%	9.7%

Figure 4: Startups Subsectors Statistics (Startup Genome LLC, 2019)

The blockchain is "an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value." (Tapscott, 2018). This ledger is decentralized, so no central system is needed to verify the transaction, eliminating the role of a middleman. The mechanism of how blockchain is working is shown in Figure 5. It starts with someone/entity requests a transaction of any kind. A transaction is any event in which data are written to the ledger for which there are at least two stakeholders that care about the validity of that data (Benton, Radziwill, Purritano, & Gerhart, 2018). This transaction is sent to a group of computers (nodes) to be verified. Once the transaction is verified, it is combined with other transactions to form a block, and now this transaction is complete. Any change in any transaction in this block cannot be done without all entities' approval within this block, making it trustworthy.

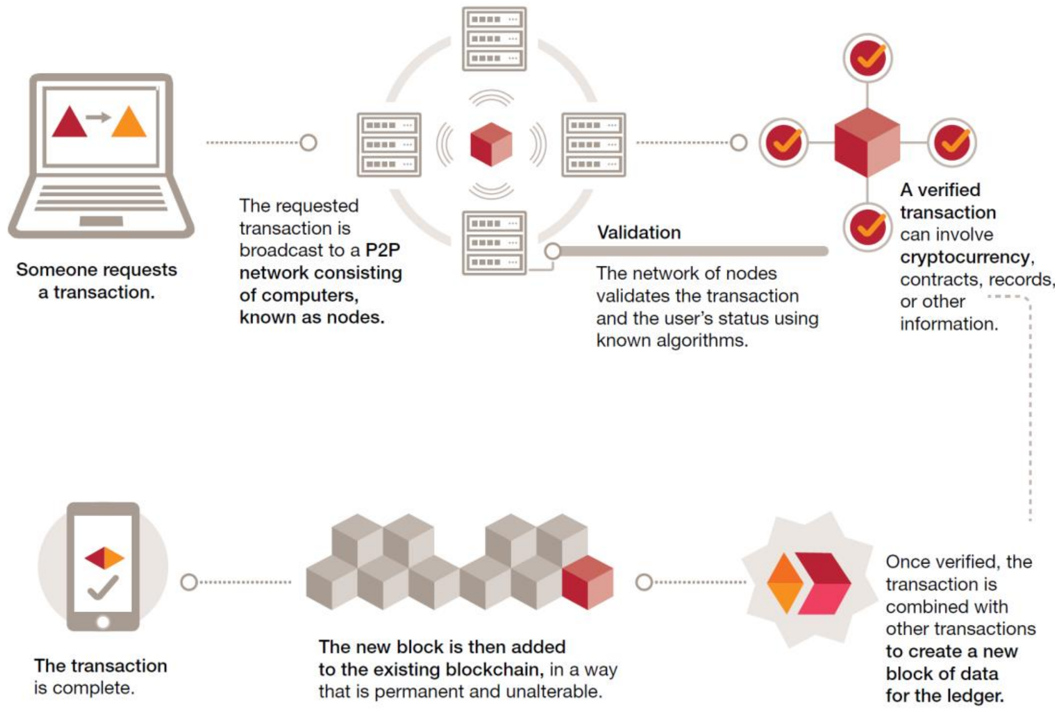


Figure 5:How blockchain works (Baru, 2018)

Blockchain has three different types: public, private, and consortium (Chandra, Liaqat, & Sharma, 2019), as shown in Figure 6. The public blockchain is fully decentralized, and everyone can write, read, and share transactions on it. In a private blockchain, written permissions are needed and generally used between organizations to maintain privacy. The consortium type is usually done between several organizations, and the public can read. The last type is the most suitable one to be used across the supply chain (Galvez, Mejuto, & Simal-Gandara, 2018).

Types of Blockchain		
Public	**Private**	**Consortium**
Fully decentralized	Writing permissions are centralized and confined to one organization	Consensus is done by a set of known nodes (usually among several parties/organizations.
Everyone can read, write and share transactions.	Usually used within organizations where some privacy needs to be maintained	Public can read, hence carry a partially decentralized character.

Figure 6: Types of Blockchain (Chandra et al., Feb 2019)

1.2. Problem Statement

The applications of blockchain technology are tremendously increasing, not only in the finance sector (bitcoin and initial coin offering ICO) but extends to supply chain, healthcare, education, marketing, advertising, human resources, management, and still expecting more! This sharp adoption of the technology with high uncertainties, undefined structure, and measures shows enormous research and investigation opportunities.

It is becoming clear that companies need to understand better how blockchain's adoption can be achieved in today's complex, dynamic business environment. Companies plan and adjust their activities, usually assuming that they will operate in a mostly stable environment. By taking action without first understanding their dynamic conditions — the uncertainty and sudden change, companies risk falling far short of their goals. This research measures the supply chain efficiency in a multi-tier system from a blockchain perspective. The research is based on a system dynamics approach to model the supply chain's three partners: manufacturer, distributor, and retailer. It explores the impact of implementing various scenarios on the supply chain efficiency metric.

1.3. Research Objective

The objective of this research is to enhance the understanding of blockchain supply chain integration. This research uses the system dynamics (SD) methodology to model blockchain technology's impact on a particular supply chain. It aims to develop a supply chain efficiency metric to measure supply chain efficiency under different conditions. SD methodology is a beneficial methodology to model the dynamics of complex systems. The model will give decision-makers a clear and profound picture of supply chain dynamics from blockchain technology perception. It also aims to enhance the decision-making process in enabling this technology and enhance firms' competitive advantage.

1.4. Research Questions

This research addresses the following questions:

- What is the potential impact of blockchain technology on the supply chain sector?
- How can we describe the dynamics of the blockchain supply chain integration?

1.5. Outline

The rest of this dissertation is organized as follows:

Chapter 2 examines the state-of-the-art literature about implementing blockchain technology within the supply chain using the systematic literature review methodology driving bibliometric analysis of the literature. It also discusses the literature's research gaps and how this research will fill some of these gaps.

Chapter 3 elaborates the research methodology to achieve this research objective. Also, it introduces the system dynamics methodology used in this research. Furthermore, it presents the usage of system dynamics methodology in the technology adoption and supply chain literature.

Chapter 4 introduces the model structure, nomenclature, subsystems, and equations.

Chapter 5 includes the analysis of the proposed model. This analysis will examine different policies, scenarios, and their effect on supply chain efficiency metric. It also contains the model's design of experiment analysis.

Chapter 6 provides the conclusion, recommendations, and suggested future work.

CHAPTER 2: LITERATURE REVIEW

This chapter covers the research efforts in the area of adopting blockchain technology in the supply chain to identify the research gap(s). It starts with introducing the systematic literature review methodology and how it is conducted to review the literature. A review of the literature on the application of blockchain technology in the supply chain area is then conducted. Furthermore, the bibliometric analysis of the reviewed literature is presented. Finally, the research gaps are discussed to illustrate how this research could fulfill some of these gaps.

2.1. Systematic Literature Review

In order to define the research gap, a systematic literature review methodology is used. The systematic literature review (SLR) is a methodology that collects current studies, selects the appropriate ones according to the selected criteria, evaluates, analyzes, synthesizes the data, and reports the output and results (Denyer & Tranfield, 2009). The five SLR steps are applied as shown in Figure 7 to ensure a clear and unbiased literature examination.

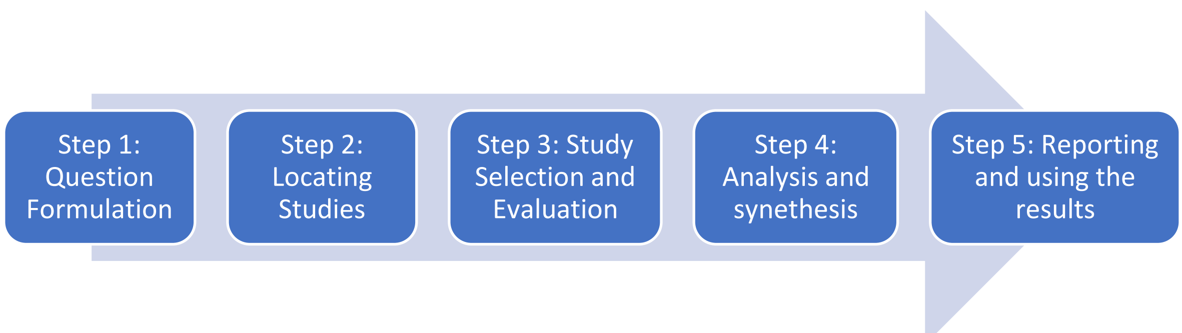


Figure 7: Systematic literature review process (Denyer & Tranfield, 2009)

The first step is to articulate a clear research question(s) to prevent distraction from the study scope. So, this SLR is intended to address the following questions:

SLR Q1: What are the key blockchain application areas in the supply chain context?

SLR Q2: What are the key benefits of the implementation of blockchain in the supply chain?

SLR Q3: What are the key barriers or challenges facing blockchain adoption in the supply chain?

The second step is to locate studies among various search engines and databases. In this step, the databases, keywords, time, language, publication type, search fields, and inclusion criteria are defined as shown in Table 1.

Table 1: Applied research protocol

Research Protocol	Description
Research databases	ScienceDirect, Google Scholar, Emerald, and Web of Science databases have been used in this research.
Type of Publication	Only peer-reviewed journals have been considered
Language	Only English publications are considered
Date Range	From 2017 through 2020
Search Terms	Blockchain in supply chain; blockchain and traceability in supply chain; blockchain in logistics.
Search Fields	Titles, Keywords, Abstracts
Inclusion Criteria	• For blockchain: must have blockchain as the primary technology in the research, can be combined with other technologies like IoT, RFID, etc. • For Supply Chain: can have the supply chain as the main subject or traceability, supply chain management, and logistics.

Thirdly, the study selection and evaluation are conducted based on the inclusion criteria. At the first screening step, 1763 papers are collected from four different databases: ScienceDirect, Google Scholar, Emerald, and Web of Science. Only the peer-reviewed journal papers are selected, with a total of 1001 papers. The second screening was based on the inclusion criteria, the relevance to the main topic, and removing the duplicates to end up with 114 papers that can help answer the main research questions. The SLR selection process is shown in Figure 8.

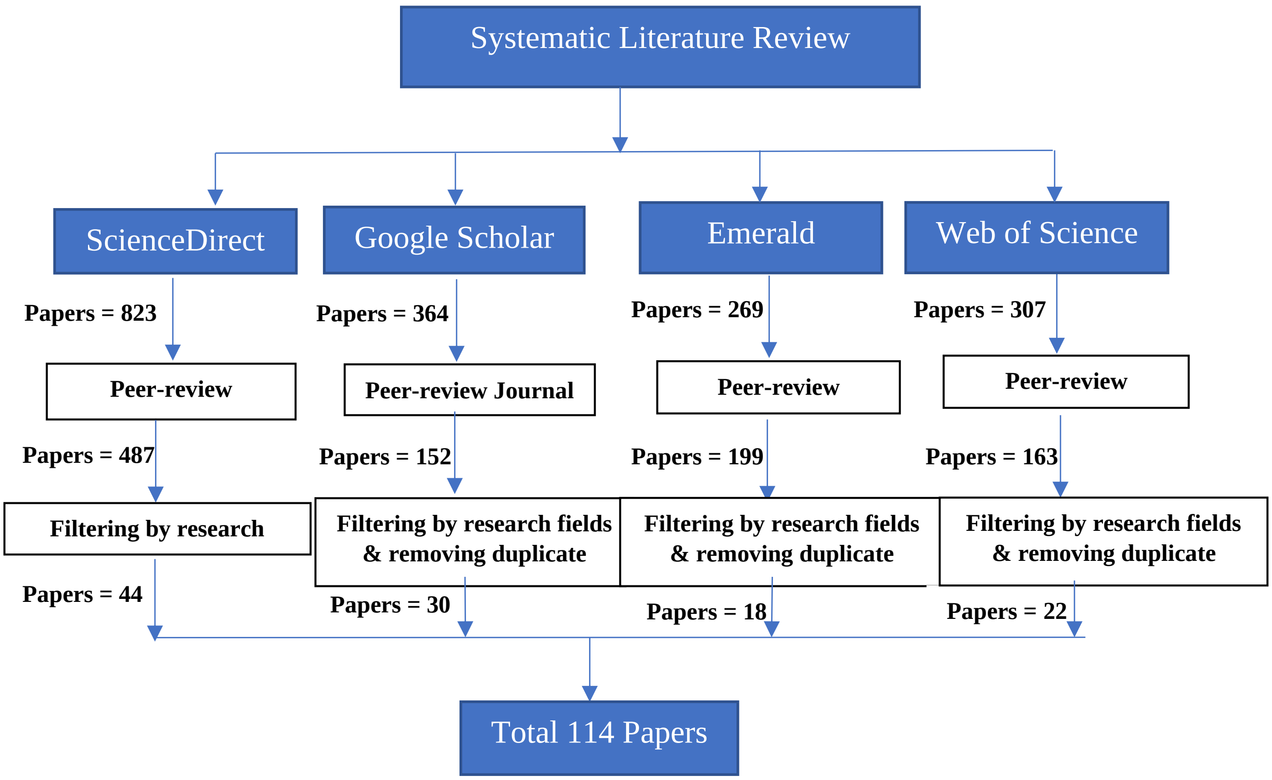


Figure 8: Systematic literature review selection and evaluation process

Fourthly, the analysis and synthesis of the selected publications are conducted. In this step, each paper I analyzed separately then connected with literature to drive insights about the current status of BCT adoption in SC. This analysis also helps in answering the research questions.

In the last step, "reporting and using the results," the objective is to present the analysis in an effective and integrated way to help better understand the topic under investigation. The main goal of this step is to try to answer the research questions. A summary of the literature about adopting blockchain technology in the supply chain and the benefits and obstacles facing this adoption is presented. Also, the main insights in each publication used methodologies and application areas are presented. All information gathered about the publications is shown in APPENDIX A: LITERATURE REVIEW SUMMARY.

2.1.1. Bibliometric Analysis

The content-analysis approach has been used in analyzing the literature based on the number of publications per year, country of publication, publication journals, and databases (Queiroz, Telles, & Bonilla, 2019).

2.1.1.1. Publication by Country

The country of publication was collected and analyzed, as shown in Table 2. The most contributing country in the context of the implementation of BCT in SC is the USA, with 17.7% of the whole publications, followed by China with 12.8%. This is attributed to both the USA and China having major institutions and ecosystems driving this contribution. According to (Startup Genome LLC, 2019), the USA has the top 30 startup ecosystems globally, with Silicon Valley and New York City as significant hubs. Similarly, China has Beijing and Shanghai as significant hubs. These ecosystems and technology hubs drive investment and research related to Industry 4.0 and provide more opportunities to apply BCT beyond the bitcoin concept (Queiroz et al., 2019). The USA and China are also considered the biggest and the most important markets to support SC globally (Sherrington, 2019). This also applies to most countries in the top ten, such as India, UK, and Hong Kong.

Table 2: Publications by country

Country	Count	Percentage
USA	29	17.7%
China	21	12.8%
India	13	7.9%
UK	13	7.9%
Hong Kong	9	5.5%
Germany	7	4.3%
France	6	3.7%
Australia	5	3.0%
Brazil	4	2.4%
Denmark	4	2.4%
Italy	4	2.4%
Malaysia	4	2.4%
Taiwan	4	2.4%
UAE	4	2.4%
Finland	3	1.8%
Russia	3	1.8%
Switzerland	3	1.8%
Canada	2	1.2%
Greece	2	1.2%
Japan	2	1.2%
The Netherlands	2	1.2%
Pakistan	2	1.2%
Spain	2	1.2%
Sweden	2	1.2%
Turkey	2	1.2%
Austria	1	0.6%
Belgium	1	0.6%
Cyprus	1	0.6%
Egypt	1	0.6%
Estonia	1	0.6%
Iran	1	0.6%
Ireland	1	0.6%
Lebanon	1	0.6%
Martinique	1	0.6%
Norway	1	0.6%
Romania	1	0.6%
Saudi Arabia	1	0.6%

2.1.1.2. Publications by Journal

Blockchain research is cross-disciplinary, allowing publications from various types of journals, with 31.6% of journals participating with only one article. The remaining contributing journals (about 68.4%) of the literature and their impact factors (Analytics, 2021) are shown in Table 3. The IEEE Access is responsible for 14.04% of the total publications, followed by the International Journal of Production Research with 11.4%. Among top contributors, the highest impact factor is 8.21 for the International Journal of Information Management, responsible for 9.65% of the literature, followed by the Resources, Conservation & Recycling with 8.086 impact factor 2.63% participation. The total journals and their statistics can be found in APPENDIX B: JOURNALS' STATISTICS.

Table 3: Publications by journal

Journal	Count	Percentage	Impact factor
IEEE Access	16	14.04%	3.745
International Journal of Production Research	13	11.40%	4.577
International Journal of Information Management	11	9.65%	8.210
Supply Chain Management: An International Journal	8	7.02%	4.725
International Journal of Production Economics	5	4.39%	5.134
Transportation Research Part E	5	4.39%	4.690
Computers & Industrial Engineering	3	2.63%	4.135
Resources, Conservation & Recycling	3	2.63%	8.086
Annals of Operations Research	2	1.75%	2.583
Business Horizons	2	1.75%	3.444
Future Generation Computer Systems	2	1.75%	6.125
International Journal of Operations & Production Management	2	1.75%	4.619
International Journal of Physical Distribution & Logistics Management	2	1.75%	4.744
Journal of Cleaner Production	2	1.75%	7.246
Journal of Manufacturing Technology Management	2	1.75%	3.385

2.1.1.3. Databases Distribution

ScienceDirect has the majority contribution from the four databases selected, with 38.6% of papers contributing to blockchain adoption in the SC context. While Google Scholar comes second with 26.3%, followed by Web of Science with 19.3%, and finally, Emerald with 15.8%, as shown in Table 4.

Table 4: Database' statistics

Database	Count	Percentage
ScienceDirect	44	38.6%
GoogleScholar	30	26.3%
Web of Science	22	19.3%
Emerald	18	15.8%

2.1.1.4. Literature Timeline

The interest in the topic of blockchain generally and its application in the SC specifically has been rapidly increasing significantly in recent years. The published papers increased from 1 in 2017 to 10 in 2018 to 47 in 2019 to 56 in 2020, as shown in Figure 9.

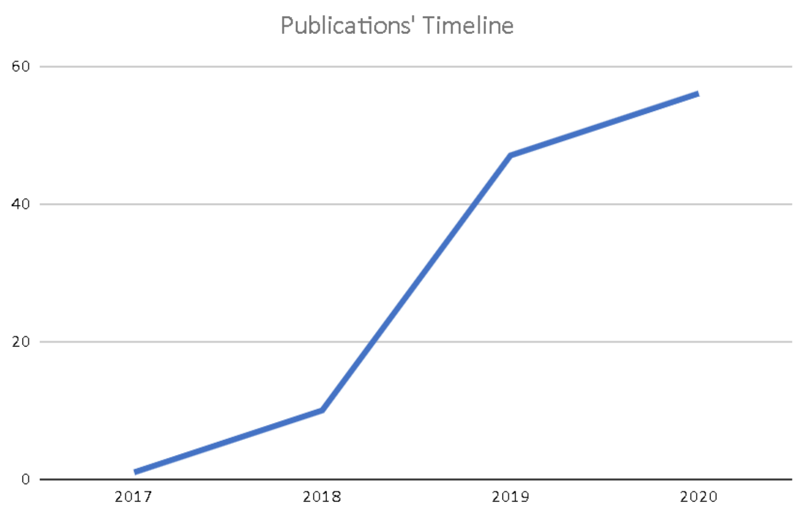


Figure 9: Publications' timeline

2.1.2. Blockchain in Supply Chain Literature

The implementation of blockchain in the supply chain has gained high momentum in both academia and industry. BCT can enhance the visibility, security, transparency, and accuracy of the supply chain. It can record date, price, location, certification, quality, or other information to manage better the supply chain (Benton et al., 2018).

The current traditional SC suffers from multiple data management problems, including cost problems, trustworthiness problems, efficiency problems, and safety problems, as shown in Figure 10 (Liang, Huang, Cao, Liu, & Wang, 2019). These problems can be eliminated or minimized by applying trusted ledgers, BCT, and smart contracts (Liang et al., 2019).

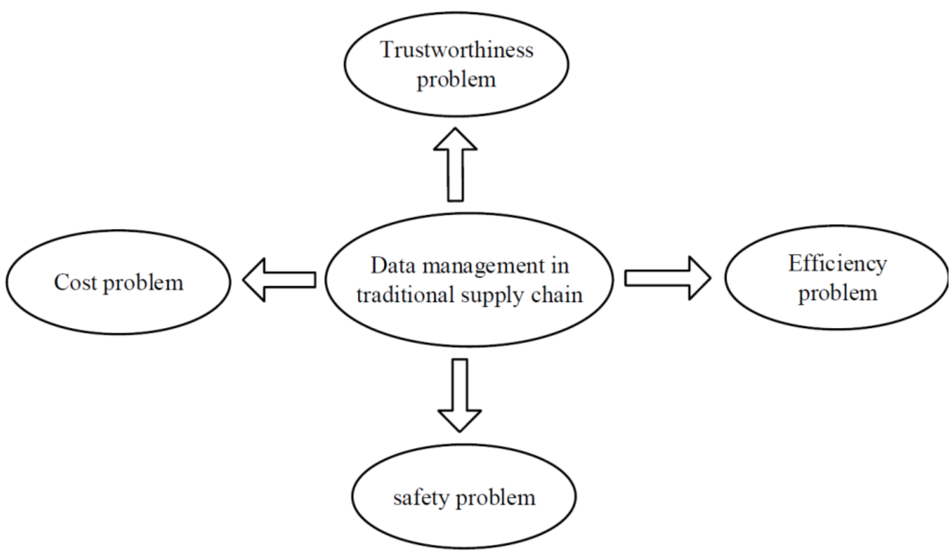


Figure 10: Data management problems in traditional supply chain

The current SC follows the linear model, which starts with the producer and importer. In the second layer, there are the exporter, processor, and wholesaler. The final layer contains the retailer and foodservice (in the case of the agriculture industry). A new circular economy model using BCT is suggested by (Casado-Vara, Prieto, la Prieta, & Corchado, 2018), as shown in

Figure 11. The model consists of five agents with five layers; producer agent (producer layer), processor agent (processor layer), retailer agent (retailer layer), processor agent (processor layer), and blockchain agent, which is synchronized with all other agents, so all date securely located in the ledger. In this model, all chain members will log and see their transactions with a decentralized system. The authors leveraged BCT to secure companies' data. The new model incorporates BCT, smart contracts, and a multi-agent system (MAS) to coordinate the food tracking process.

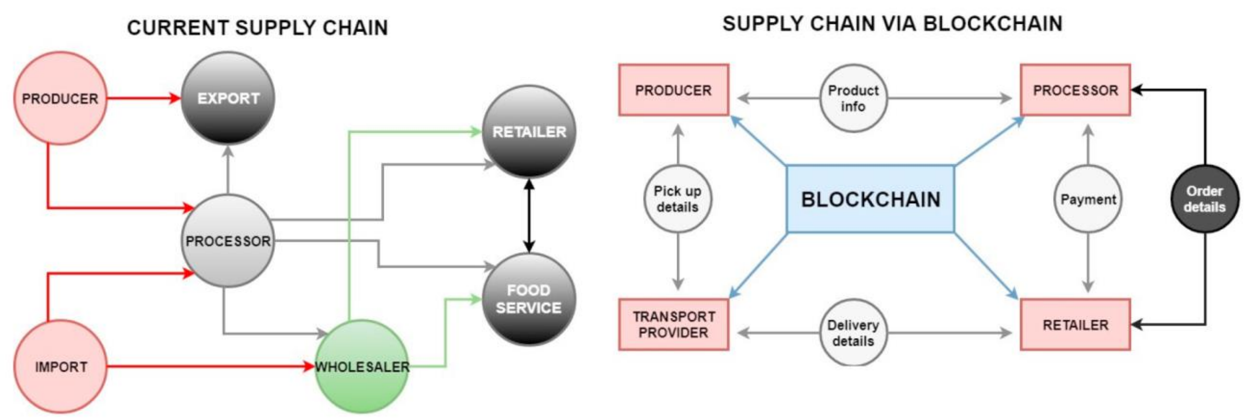


Figure 11: Traditional versus new supply chain model (Casado-Vara et al., 2018)

Forty-nine blockchain technology applications in the supply chain and logistics industry are identified by (Petersen et al., 2018). The authors clustered these applications into three categories: tracking the product, tracing back the product to its origin, and supply chain finance. They also analyzed these applications within the supply chain's three flows: material, information, and financial, as shown in Figure 12.

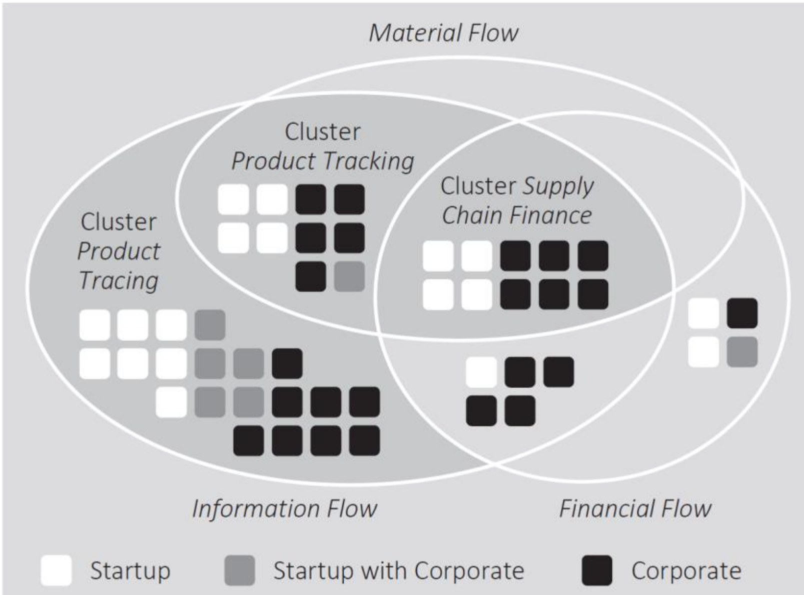


Figure 12: Matching blockchain applications with the supply chain flows (Petersen et al., 2018)

One of the significant benefits of BCT is to identify the sources of insecurity in the supply chain. In 2009, Toyota recalled 4 million vehicles due to defective gas pedals (Kshetri & Loukoianova, 2019). This recall cost the company US $2 billion, and the company could not trace which supplier had the problem as the company was receiving pedals from many suppliers. The company at that time lacks the mechanism to track the responsible suppliers for the defective pedals, and if known, the company could just recall the defective ones by code, and the cost could be much lower than the actual ones. BCT can play as a tool to track the sources of insecurity in the SCs by improving the security of both upstream and downstream flows (Kshetri, 2017). In the upstream flow, it helps track the product to its origin and identify the sources of problematic items. In the downstream, It can help in handling crises such as product recalls or defects. To strengthen this role, the regulators need to force the firms to implement BCT in their SC activities, especially in the critical fields (Kshetri, 2017).

Another major factor that affects the effectiveness of the SC is SC resilience. To enhance SC resilience, it is critical to identify the sources of risk in SC, such as geographical, economic, market, logistics, etc. (see Figure 13). BCT implementation can play a vital role in enhancing SC resilience by reducing or eliminating these sources of risks using smart contracts, asset tracking, secure and error-free order fulfillment, and cybersecurity (Min, 2019).

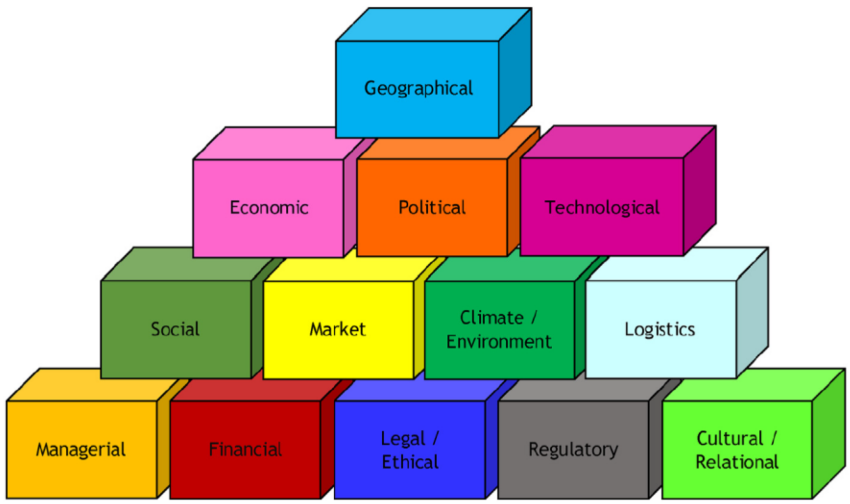


Figure 13: Sources of risk in the supply chain (Min, 2019)

Blockchain has various benefits to the supply chain value stream (Perboli, Musso, & Rosano, 2018). BCT can reduce the bullwhip effect at the producer step, help in KPI monitoring, assist in production planning, and certification and compliance to regulations. BCT helps in planning and process management for the warehouse, reducing the bullwhip effect, KPI monitoring, and tracking recall and waste. It can also reduce the bullwhip effect, KPI monitoring, and tracking the distributor's delay in delivery. Finally, the final user can benefit from the traceability in the product's recall. For a complete value ring of the blockchain in the supply chain with priorities, see Figure 14.

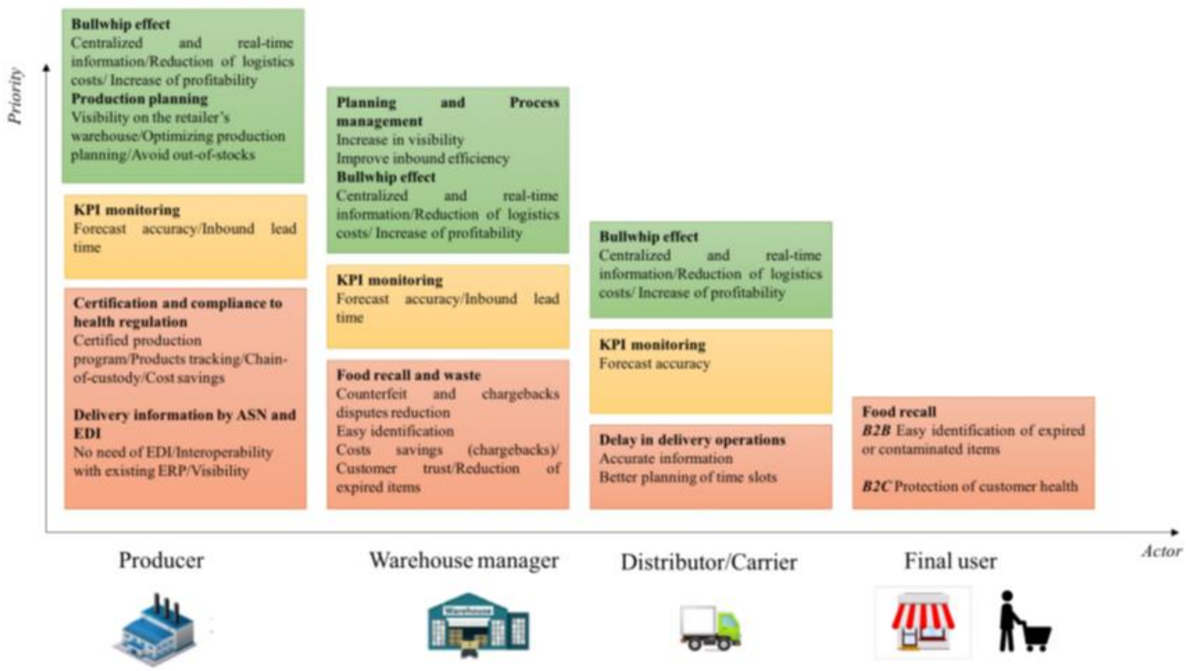


Figure 14: Blockchain in supply chain value ring (Perboli et al., 2018)

Traceability has been defined as "the ability to trace the history, application or location of an object [ISO 9001:2015]. When considering a product or service, traceability can relate to the origin of materials and parts; processing history; distribution and location of the product or service after delivery."(Benton et al., 2018). A SC traceability system has been developed by (Westerkamp, Victor, & Küpper, 2018) to model the manufacturing process as token recipes using smart contracts. The authors defined smart contracts as computer programs used to enforce rules and terms without a third party's requirement. The developed models provided complete information about projecting the product composition in the blockchain in the form of a token. This model's advantage is that products are traceable from production to customers and during the manufacturing transformation from raw material to the final product.

The blockchain application in the supply chain trading scenario has been discussed by (Barghuthi et al., 2018). The authors suggested using Practical Byzantine Fault Tolerance (PBFT) and Federated Byzantine Agreement (FBA) consensus models in the blockchain-based supply chain. The consensus is how a network of stakeholders validates each block and then incorporates it into the blockchain.

Product deletion is a critical decision for managers because problems in information gathering, understanding, and accuracy will incur high risks for the company's competitive edge (Zhu & Kouhizadeh, 2019). It is the process of removing products from the company's product portfolio. BCT can help in this strategic decision of product deletion by providing security, traceability, transparency, accuracy, verifiability, and smart execution for the SC information system.

Multiple case studies methodology has been used by (Kshetri, 2018) to build theories about the impact of blockchain and IoT technologies on supply chain management. The author used Maersk, Alibaba, Bext360, Chronicled, Provenance, Modum, Walmart, Gemalto, Intel's solution to track seafood supply chain, Lockheed Martin, Everledger companies as case studies. By analyzing the case studies, the author built theories about blockchain and IoT's impact on supply chain organizational objectives as cost, flexibility, risk reduction, quality, speed, dependability, and sustainability, as seen in Figure 15.

Supply chain performance dimension	Blockchain's roles	Mechanisms involved [Case Number].
Cost	Economic sense to generate a blockchain code even for small transactions.	Zero or low marginal costs to generate blockchain code if technologies such as IoT have already been used to detect, measure, and track key SCM processes [8].
	Crisis involving defective products (e.g., contaminated food): easily identify the source and engage in strategic Removals of affected products instead of recalling the entire product line	Detection, measurement, and tracking of key SCM processes with IoT [8].
	Allocate just the right amount of resources to perform shipping and other activities	Detection, measurement, and tracking of key SCM processes with IoT [6].
	Elimination of paper records	Digitally signed documents' secure storage and transmission can validate the identities of individuals and assets [1].
	Regulatory compliance costs can be reduced.	Auditable data can be provided to satisfy regulators [5,9].
	Supply chain partners are not able to use low quality and counterfeit ingredients	A tool to improve integrity and traceability in the food supply chains to fight against low quality and counterfeit products [3].
	Can provide data that can be used to assess useful, meaningful and representative indicators for describing quality.	Data related to temperature, humidity, motion, light conditions, chemical composition from IoT devices or sensors on equipment ([6,10].
Speed	Speed can be increased by digitizing physical process and reducing interactions and communications.	Digitally signed documents' secure storage and transmission can validate the identities of individuals and assets and minimize the needs of physical interactions and communications [1].
Dependability	Supply chain partners can expect a high level of dependability of measurement for various indicators such as quality and weights	Can be integrated with applications such as mobile robot (e.g., Case 11: Bext360's coffee supply chain)
	Exerting pressure on supply chain partners to be more responsible and accountable for their actions.	Digitally signed documents' secure storage and transmission can validate the identities of individuals, which makes it possible to know who is performing what actions, when and where [9].
	Blockchain-based digital certification as a means of increasing dependability.	Supply-chain certification processes to verify provenance [7].
	Blockchain's "super audit trail" can address challenges associated with self-reported data that are provided by supply chain partners.	Detection, measurement, and tracking of key SCM processes with IoT [2].
Risk reduction	Addressing the holistic sources of risk	Blockchain's ability to validate identities can be used to verify the provenance of items such as rough-cut diamonds and fine wines [7].
	Only parties mutually accepted in the network can engage in transactions in specific touchpoints.	Validation of the identities of individuals participating in transactions [1].
	Can ensure that software file downloaded has not been breached.	Foolproof method for confirmed identity can reduce cybersecurity-related risks [4]
Sustainability	Verifying sustainability: possible to make indicators related to sustainability more quantifiable and more meaningful.	Validation of the identities of individuals participating in the supply chain [11].
		Detection, measurement, and tracking of key SCM processes with IoT (e.g., [2], Provenance's use of mobile phones, blockchain and smart tagging, to track fish caught by fishermen)
Flexibility	Levels of network effects: Even if only a few participants use a blockchain solution, this will have a powerful effect. The power of this solution increases with the network effect.	All cases [1–11].
	Higher level of impact with deeper IoT integration in logistics and supply chain	All cases [1–11].
	Can address consumers' concern about the source of their food and beverages by providing indicators related to sustainability more quantifiable and more meaningful.	Blockchain can deliver higher value when consumers become more concerned about the sources of their foods and beverages [11]

Figure 15: Roles of blockchain in achieving supply chain objectives (Kshetri, 2018)

Blockchain-based applications with the Internet of Things (IoT), radiofrequency infrared tracker (RFID), and tracking sensors can create breakthroughs in supply chain management (SCM) and logistics (Zhu & Kouhizadeh, 2019). Solving the quality problems in SC has become a fundamental need recently because of the complexity and the global nature of SC nowadays. A blockchain-based framework has been proposed by (S. Chen et al., 2017) to improve supply chain quality management. The proposed framework consists of four layers; IoT sensor, data layer, contract layer, and business layer, as shown in Figure 16. The framework has been applied to a laptop supply chain case study with the benefits of real-time quality monitoring and control, digital identity, contract automation, logistics planning, and supply chain loan investigation assistance.

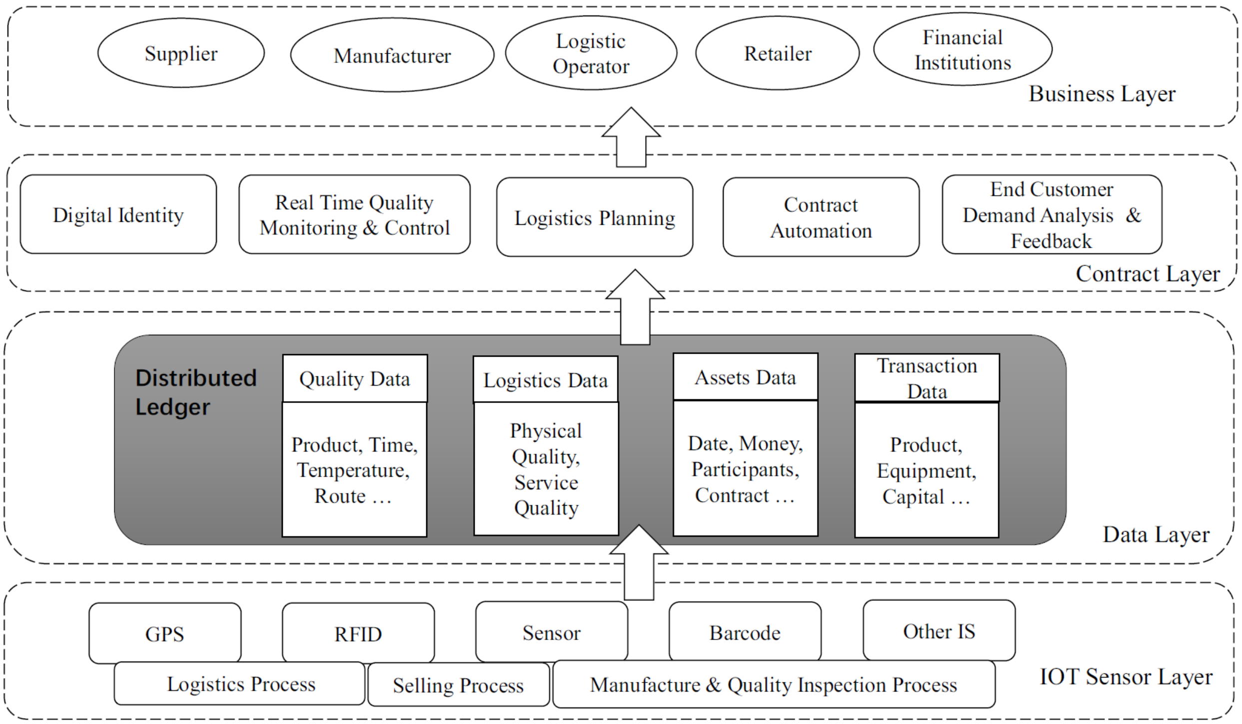


Figure 16: Blockchain-based framework for supply chain quality management (S. Chen et al., 2017)

An integrated and systematic review of both academic and practice literature has been conducted by (Y. Wang, Han, & Beynon-Davies, 2019). The review aims to achieve four research objectives; identify the drivers of blockchain adoption in the supply chain, identify the most valuable blockchain areas in the supply chain, identify the challenges facing the adoption, and develop future research agenda. First, they claimed four blockchain deployment drivers in the supply chain field: trust, reliability and security of information, supply chain disconnections and complexities, product safety, authenticity and legitimacy, and public safety and anticorruption. Second, blockchain applications' most valuable areas are extended visibility and product traceability, supply chain digitalization and disintermediation, improved data security for information sharing, and smart contracts. Third, the challenges facing this adoption are organizational and user-related challenges, technological challenges, and operational challenges. Finally, the future research areas are cryptocurrency and supply chain finance, disintermediation and reintermediation, digital trust and supply chain relationship management, blockchain, inequality and supply chain sustainability, the dark side of blockchain, and a design perspective on a blockchain-enabled supply chain.

The bullwhip effect is the increasing variations in inventory as a response to customer demand cumulating upstream from customer to retailer to distributor to manufacturer to the supplier. Blockchain can reduce the bullwhip effect in the supply chain by reducing uncertainty and overproduction through its visibility and transparency capabilities (Esmaeilian, Sarkis, Lewis, & Behdad, 2020) (see Figure 17).

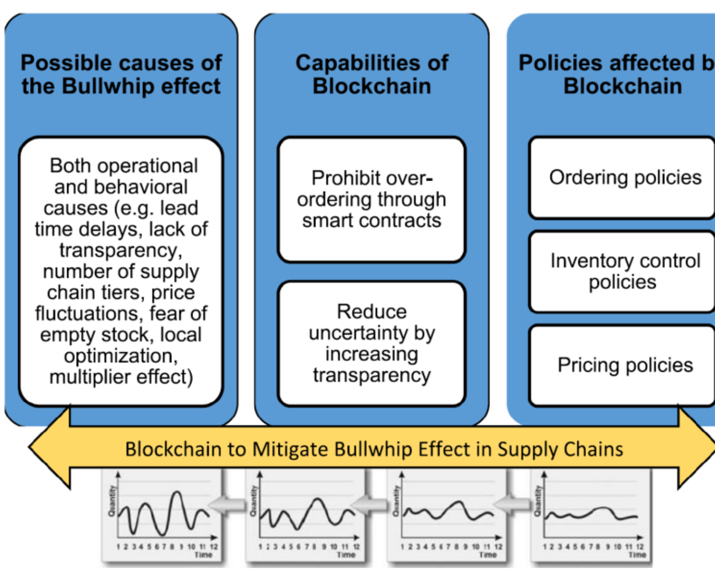


Figure 17: Bullwhip effect' causes and the blockchain remedies (Esmaeilian et al., 2020)

(Chandra, Liaqat, & Sharma, Feb 2019) investigated how blockchain technology can help eliminate or reduce the challenges facing the Halal food sector. Among the challenges facing this sector is the poor recognition of raw materials certified as Halal and suppliers' scrutiny. The Muslim community needs to ensure that every component and material dealt with the products are Halal certified and was according to Shariah, so it is vital to know the origin of products and tracking it all over the production process.

2.2.Research Gap

After conducting the SLR and examining the literature, the three pre-identified SLR questions are answered to identify the research gaps.

- SLR Q1: What are the key blockchain application areas in the supply chain context?

BCT has various application areas in the context of SC. The dominant area is food SC or food traceability. The food industry is so critical when it comes to people's lives. So, knowing everything about the food from the very beginning until it reaches the customer is crucial. Another significant area is the smart contract application. Storing every transaction, financial, or not in a ledger and being accessible from every SC partner is a huge requirement to ensure SC transparency. A complete list of all application areas from all publications is shown in APPENDIX A: LITERATURE REVIEW SUMMARY.

- SLR Q2: What are the key benefits of the implementation of blockchain in the supply chain?

BCT has numerous benefits to SC performance and effectiveness. It can increase the SC's efficiency by eliminating the intermediaries and reducing the waste of time, value, and money.

It provides data security and accuracy to the SC parties. It also provides real-time visibility and tracking for goods or services. A complete list of all benefits of the implementation of BCT in SC is shown in Table 5.

- SLR Q3: What are the key barriers or challenges facing blockchain adoption in the supply chain?

One of the various barriers to the fast adoption of BCT in SC is the lack of cooperation and participation from all SC members, including the government agencies. Another significant challenge is the scalability problem of the decentralized ledger (see Table 5).

Table 5: Benefits and challenges of blockchain' adoption in supply chain

Benefits	**Challenges**
Measuring the temperature of containers and products, especially in critical supply chains like medicine and food.	Regulatory issues and lack of governance structure as there are many regulatory uncertainties due to the world-cross nature of supply chain, which brings different countries and parties together with different regulations. Also, illegal use of blockchains may occur.
Digital Identity and authenticating a customer and a courier.	The need for the project, change, and risk management.
Cost-effectiveness and efficiency gains from saving time by eliminating manual efforts and paper processing.	Lack of cooperation and collaboration of all supply chain members, including government and resistance to a high level of transparency and information sharing.
Helps in meeting regulatory requirements and strengthen law enforcement capacity. Also,	Scalability is not enough for supply chain applications as it needs more transaction

Benefits	Challenges
reduce illegal and unethical practices in the food industry as fishing, halal (lawful in Islam), beef, pharmaceutical, etc.	throughput (such as communication malfunctions among users, data storage, and linear transaction record. The scalability issues originate from the growing number of transactions, and difficulty of the consensus protocols.
Real-time visibility, quality monitoring and control, inventory and product tracking. Also, traceability and origin tracking.	No verification mechanism ensures the raw data is correct and maintains consistent linkage between data stored in the ledger and reality.
Help to deal with recall crisis and contaminated food or drug, product deletion and reduce risk from tampering, fraud, etc.	Compiling with new regulations like the General Data Protection Regulation (GDPR) in Europe, which gives the customer the right that his data to be forgotten.
Ensures secure information sharing and builds Trust.	Not mature enough to be applied by governments.
Data security, transparency, accuracy, and privacy.	Implementation can be time-consuming.
Logistics planning, opportunities for operational improvements and enabler for strategic decisions.	Technological and network interoperability issues (the interoperability between blockchains and integration with existing IT systems need to be addressed to ensure smooth data transfer.
Smart contacts (contract automation) remove intermediaries and enable circular economy.	New knowledge is required- lack of skills.
Simplification, digitalization, and optimization of supply chain operations.	Huge resource (energy), initial capital requirement, and high implementation cost.

As shown from the literature review analysis and results, blockchain technology has many benefits to the supply chain; however, it also faces challenges through the adoption journey. One of the main benefits is the visibility and real-time access to data across the whole supply chain. The blockchain's decentralized nature allows the partners to connect to one place, the ledger, and they all have access to the same information, which reduces the bullwhip effect through the supply chain. However, making only what the customer wants at the end and going lean without safety stocks or backup plans, especially with the technology downside of attacks and shutting down, will significantly impact the supply chain performance and efficiency. The success of blockchain implementation is based on two fundamental concepts: distributed nature and data immutability (Barghuthi et al., 2018).

This research developed a dynamic model to simulate a typical multi-tier supply chain consists of the manufacturer, distributor, and retailer to measure its efficiency. The model analyzed the supply chain performance under the base case, linear supply chain, and then compare it to a with-blockchain case when all the supply chain partners have access to real-time customer demand. Then both cases are analyzed under demand disruption market conditions. Furthermore, it investigates the partial adoption of the blockchain at the early beginning and the end of the chain. Finally, the adjustment of the manufacturer’s lead time for a better supply chain performance in the partial visibility case is examined.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

This chapter covers the research methodology applied in this research. Then, it introduces the used system dynamics methodology. Furthermore, a literature review on the application of system dynamics methodology on both the supply chain sector and the adoption of new technologies is presented.

3.2. Research Methodology

The research methodology is a structured and systematic process used to formulate a research problem and discover ways to solve it. According to (Kuma, 2011), this process answers the "what and how" questions before conducting the study itself.

The first phase in the research methodology is to formulate research questions and define the research objectives. The process used to identify this research problem, questions, and objectives is shown in Figure18 .

First, the process started with identifying the general scope and field that has been interesting to the author, which is "Blockchain Technology." Then went deeply with the specific interests in this topic by selecting the supply chain sector and figuring the interactions and the dynamics of this technology adoption.

Second, categorizing the literature review "supply chain, dynamics of the supply chain, blockchain, blockchain in the supply chain, system dynamics methodology in the supply chain and technology adoption" helps connect dots and get more in-depth and specific with the research point after deciding to work on blockchain technology.

Third, identifying the research gap that has not been covered yet by researchers. An excellent source for this step is reading up-to-date papers which critique the work already done and suggested research questions and gaps that need to be fulfilled.

Finally, formulating the research questions that this research aims to answer with the primary research objective of understanding the blockchain technology's implications on the supply chain performance.

From the critical literature review discussed above, it has been identified that there are gaps and research opportunities in the blockchain supply chain integration field. Selected gaps that this research aims to fulfill are as follow:

- First, the new era of digital technologies focusing on the blockchain is still evolving, which creates the need for more research and investigations.
- Second, there is a gap in applying the system dynamics methodology as an effective tool to understand complex system dynamics in blockchain technology adoption.
- Third, a clear research opportunity has been noticed to identify dynamics associated with blockchain technology's impact on supply chain performance.

1. Develop Theoretical Framework

General
What is blockchain technology?

More Specific
Supply Chain
Blockchain Dynamics

2. Literature Review

- Supply chain system
- Dynamics of the supply chain
- Blockchain technology
- Blockchain in the supply chain
- System dynamics methodology in supply chain and technology adoption

3. Identify Research Gap

Impact of blockchain technology on the supply chain performance

4. Formulate Research Questions

- What are the implications of the blockchain technology adoption on the supply chain performance?
- How can we describe the dynamics of the blockchain technology implementation in the supply chain?

Figure 18 : Process of formulating research questions (Kuma, 2011)

3.3. System Dynamics Methodology

System dynamics (SD) is an approach of continuous simulation to model and understand complex and dynamic systems (Forrester, 1971). SD's primary goal is to help managers and decision-makers deal with the changing and dynamic environment using stock and flow and causal loop diagrams. System dynamics (SD) is a set of tools used to understand better the structure, relations, and dynamics of complex systems. It helps analyze different policies and scenarios to build and run more effective organizations (Sterman, 2000). SD is a modeling method used to easily visualize and simulate complex behavioral or social systems by decomposing them to their components and reintegrate them again into a whole. It improves the understanding of complex systems by investigating the cause and effect relationships within systems.

SD has been used in management research to investigate the complexity of management systems and the complicated interrelationships between system elements. It provides qualitative and quantitative analyses (Gunawan, Gorod, Hallo, & Nguyen, 2017). The qualitative analysis provides the causal loop diagram, while the quantitative analysis can be done using the stock and flow diagrams.

The causal loop diagram is the conceptual model that captures the structure of the system being studied and the interactions between its components. This diagram contains the relevant feedback mechanisms. These feedback mechanisms can be positive feedback (reinforcing loops) or negative feedback (balancing loops). These loops play two essential roles in the SD methodology. First, it simplifies the model representation, and second, it serves as sketches for the causal hypothesis during the model development.

The stock and flow diagram is the mathematical model of the system under investigation. It is used to quantify the system dynamics and causal relationships. This model is then translated into differential equations to be solved through a simulation run. A typical example of the causal loop and stock and flow diagrams is shown in Figure 19.

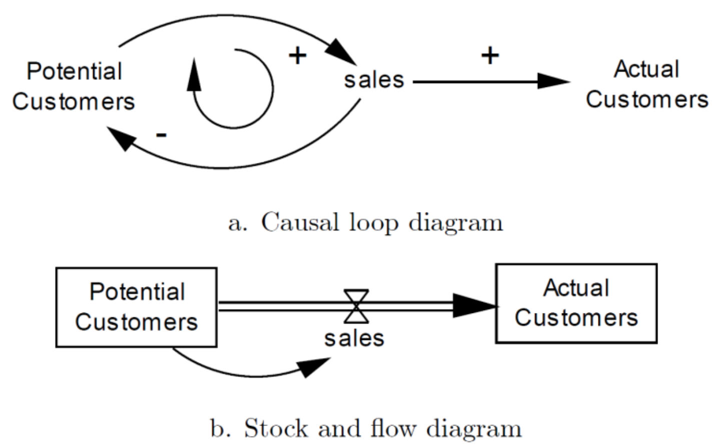


Figure 19: Example of causal loop and stock and flow diagrams (Kirkwood, 1998)

A simulation model requires two different processes to ensure its effectiveness: verification and validation. Verification is the process of checking the program for technical errors and is necessary for model assessment but not sufficient. Simultaneously, validation is a more complicated process that determines if the model represents the real world well or not by validating the data in addition to the computer and conceptual model, as shown in Figure 20. Verification and validation should be run parallel during the modeling process, and validation should test the model's individual parts and the whole model(Latuszynska & Lemke, 2013).

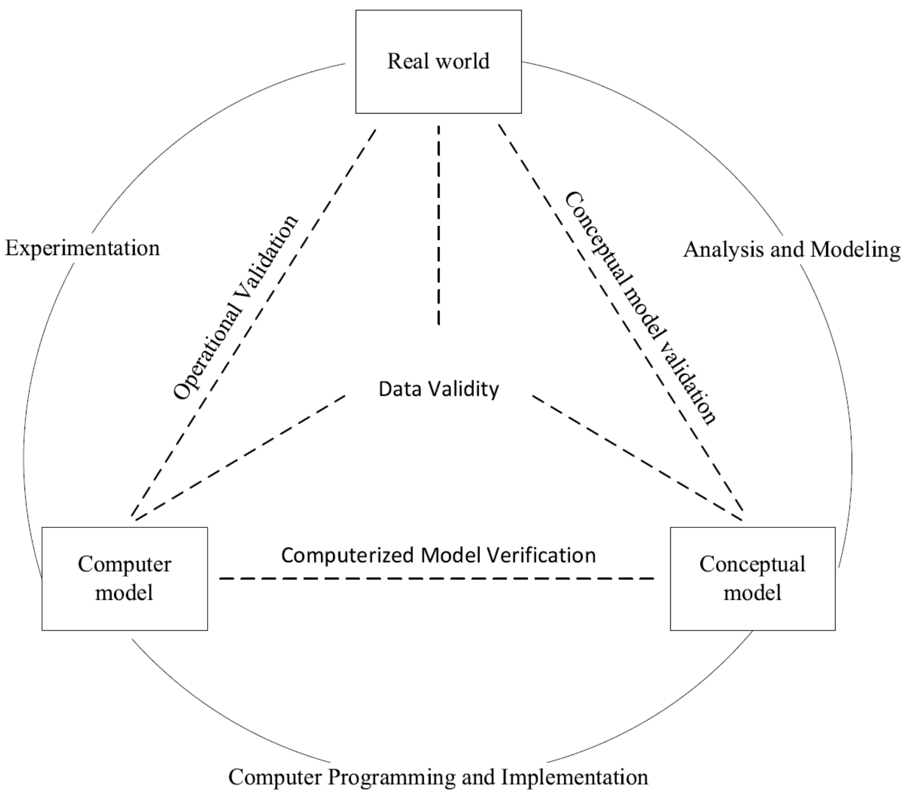


Figure 20: Simulation model verification and validation (Latuszynska & Lemke, 2013)

3.4. System Dynamics Literature in the Supply Chain and Technology Adoption

System dynamics methodology has been used excessively to analyze the supply chain to evaluate different policies and measure performance. (C.-H. Zhang, Lu, & Chen, 2016) used the SD to analyze various management scenarios for improving the supply chain inventory control system performance. It also models the RFID's impact on reducing the bullwhip effect in the supply chain and enhancing inventory control. Another application of SD in RFID simulation is done by (Qiao-Lun & Tie-Gang, 2011). The research analyzes the impact of RFID in the IoT framework and Electronic Product Code (EPC) on the reverse supply chain. The results show that the RFID-EPC improves the collector’s service levels and profits, disassembly center, and remanufacturer in the supply chain.

The bullwhip effect is also investigated using the system dynamics methodology by modeling a supply chain with two suppliers and one retail channel (Hosseini, Zare Mehrjerdi, & Mehrjerdi, 2016). The authors analyzed various policies such as third-party logistics (TPL) or vendor-managed inventory on the supply chain performance. The authors concluded that the use of VMI would reduce the bullwhip effect and the total inventory level.

The procurement planning process of the supply chain and operational transport has been analyzed using the system dynamics methodology by (Mula, Campuzano-Bolarin, Díaz-Madroñero, & Carpio, 2013). The authors tested different policies to meet the customer demand with the minimum inventories and trucks. The developed model used to evaluate the tradeoffs between the inventory on hand and the number of trucks and travels needed to meet demand.

In order to better understand the cost of quality in the supply chain, (Alglawe, Schiffauerova, & Kuzgunkaya, 2019) used the system dynamics to model an automobile manufacturing plant. The model investigated the importance of the opportunity cost in calculating the cost of quality and captured customer satisfaction dynamics. The authors also highlighted the relationships between various factors affecting the cost of quality and how they impact new customers' gaining.

The Chinese industry's diffusion of green supply chain management is analyzed by (Tian, Govindan, & Zhu, 2014) using SD and game theory. The authors analyzed the relationships of the different stakeholders in the supply chain and their intent to apply green supply chain management. The research concluded that environmental awareness is vital in diffusing the Chinese supply chain sector's green concept.

The literature on using system dynamics methodology in the sustainable supply chain has been reviewed and analyzed by (Rebs, Brandenburg, & Seuring, 2019). The authors concluded that the sustainable supply chain management-related system dynamics models integrate the social and environmental sustainability metrics, the customer expectations, and the government incentives and pressure. It is also concluded that the intra- and inter-organizational supply chain models are less dominant than the macroscopic levels of analysis.

Another vital application of system dynamics is the analysis of the new technologies. The factors affecting the adoption of the Internet of Things (IoT) are examined by developing a conceptual model using the system dynamics methodology (Tripathi, 2020). The authors found the most contributing factors to this adoption are self-configuration, communication, control and automation, cost savings, and efficient business processes. The factors that challenge this adoption are the lack of skilled IT professionals interoperability, security risks, and privacy risks. (Hsu, Lee, Trappey, Trappey, & Chang, 2016) also analyzed the performance of IoT technology on the performance of the supply chain and logistics. The research enabled the IoT to develop a logistics service provider that integrates the supply chain network's capabilities, resources, and technologies. According to the authors, the developed service improves the information flow, transparency and shorten operation time in the modeled supply chain.

The information security risks associated with adopting new technology are modeled using SD by (Y. Qian, Fang, & Gonzalez, 2012). The research used the Norwegian oil and gas industry to show how proactive investment in security management is critical and cost-effective during the operational transition. The reactive investment could only cause severe incidents. The impact of different regulatory policies on mobile voice diffusion and competition is also modeled using SD methodology in the Finnish market by (Casey & Töyli, 2012). The authors analyzed the impact of technology harmonization and mobile number portability regulatory policies on mobile service adopters.

The business model associated with adopting new technologies such as blockchain technology should be changed from centralized-isolated entities to decentralized – cooperated ones (DEHBASTEH, POUREBRAHIMI, VALMOHAMMADI, & AFSHAR KAZEMI, 2019). The authors analyzed the factors affecting blockchain technology and its impact on new business models using SD modeling. The model categorizes these determinates into three categories: cost, nodes, and transactions. It shows that increasing cooperation through nodes and gaining new nodes will generate more value for all partners. The impact of adopting new technology focusing on artificial intelligence (AI) on employment is analyzed by (Zaldo, Rivera-hernaez, & Martín-garcía, 2019) using SD simulation. The model provides insights into how new technologies can displace tasks and jobs with more continuous training.

3.5. Summary

In summary, due to the dynamic and complicated nature of the supply chain sector and the adoption of new technologies as mobile voice service, IoT, blockchain, RFID, etc., the application of system dynamics methodology has proved its usefulness, effectiveness, and applicability to analyze these systems and its interactions.

CHAPTER 4: THE PROPOSED MODEL

4.1. Model Overview

System dynamics methodology is used to model a multi-tier supply chain consists of three elements: manufacturer, distributor, and retailer. The modeled system is applied to a case study to measure the supply chain efficiency, as shown in Figure 21.

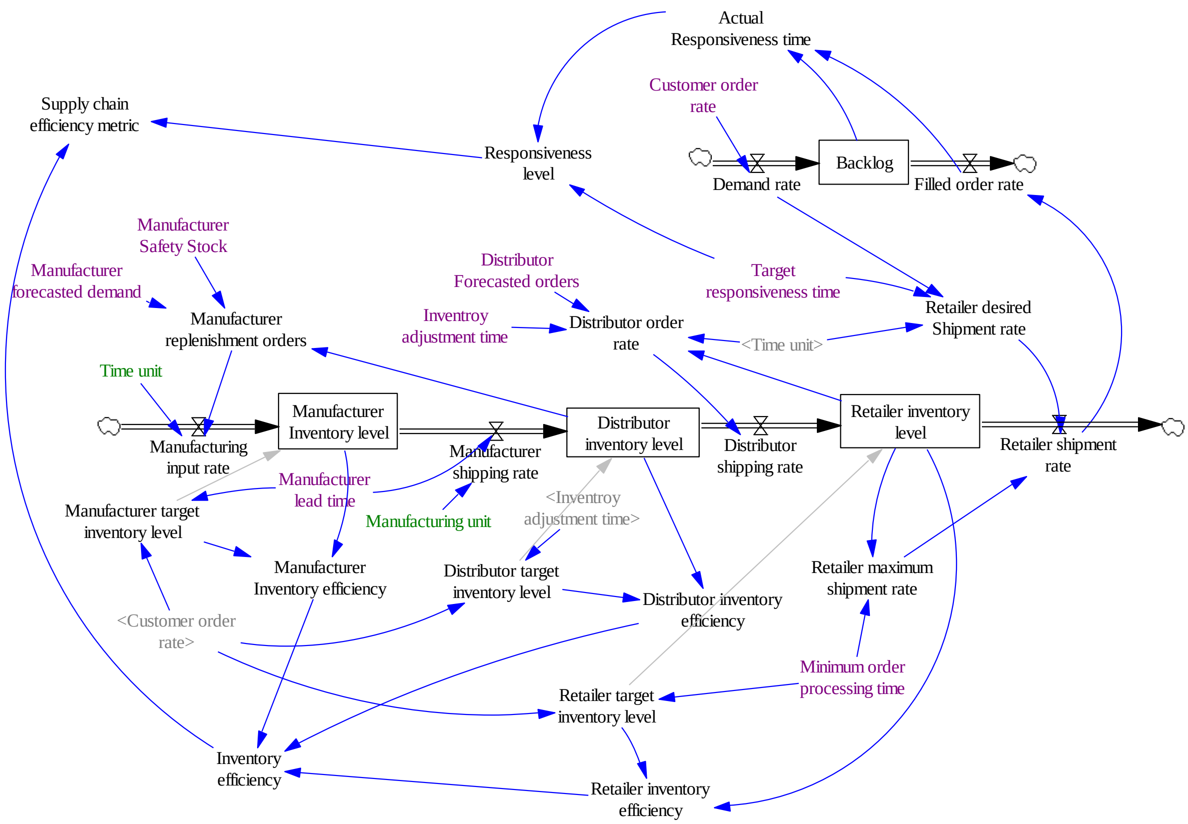


Figure 21: Dynamic supply chain model

4.2. Model Description

The modeled supply chain system consists of three components: chain system, backlog system, and supply chain efficiency system. The chain consists of manufacturer, distributor, and retailer. The backlog system is an indication of the delay between the placement and delivery of the order. Finally, the supply chain efficiency metric (SCEM) is consists of responsiveness level (RL) and inventory efficiency (IE).

4.3. Model Nomenclature

Table 6 shows the variables' nomenclature in this model and their units.

Table 6: Model nomenclature and units

Variable	Unit
▪ ART (t): actual responsiveness time at time t.	Hour
▪ B (t): backlog level at time t.	Parts
▪ COR (t): customer order rate at time t.	Parts/hour
▪ DR (t): demand rate at time t.	Parts/hour
▪ DFO: distributor forecasted orders	Parts
▪ DIE (t): distributor inventory efficiency at time t.	Dmnl
▪ DIL(t): distributor inventory level at time t.	Parts
▪ DOR (t): distributor order rate at time t.	Parts/hour
▪ DSR (t): distributor shipping rate at time t.	Parts/hour
▪ DTIL (t): distributor target inventory level at time t.	Parts
▪ FOR (t): filled order rate at time t.	Parts/hour
▪ IE (t): inventory efficiency at time t.	Dmnl
▪ IAT: inventory adjustment time.	Hour
▪ MFD: manufacturer forecasted demand at time t.	Parts
▪ MIE (t): manufacturer inventory efficiency at time t.	Dmnl
▪ MIL (t): manufacturer inventory level at time t.	Parts
▪ MLT: manufacturer lead time.	Hour
▪ MRO (t): manufacturer replenishment orders at time t.	Parts
▪ MSS: manufacturer safety stock.	Parts
▪ MSR (t): manufacturer shipping rate at time t.	Parts/hour

Variable	Unit
▪ MTIL (t): manufacturer target inventory level at time t.	Parts
▪ MIR (t): manufacturing input rate at time t.	Parts/hour
▪ MU: manufacturing unit.	Parts
▪ MOPT (t): minimum order processing time at time t.	Hour
▪ RDSR (t): retailer desired shipment rate at time t.	Parts/hour
▪ RL (t): responsiveness level at time t.	Dmnl
▪ RIE (t): retailer inventory efficiency at time t.	Dmnl
▪ RIL (t): retailer inventory level at time t.	Parts
▪ RTIL (t): retailer target inventory level at time t.	Parts
▪ RMSR (t): retailer maximum shipment rate at time t.	Parts/hour
▪ RSR (t): retailer shipment rate at time t.	Parts/hour
▪ SCEM (t): supply chain efficiency metric at time t.	Dmnl
▪ TRT: target responsiveness time.	Hour
▪ TU: time unit.	Hour

4.4. Model Components

4.4.1. Chain System

The supply chain system consists of three tiers: manufacturer, distributor, and retailer, as shown in Figure 22. The manufacturer inventory level is determined by the difference between the manufacturing input rate and the manufacturer shipping rate. To start the system in equilibrium, an initial value of the manufacturer target inventory level is used, as shown in Equation 1.

$$MIL(t) = INTEG\ (MIR(t)-MSR(t),MTIL(t)) \qquad (1)$$

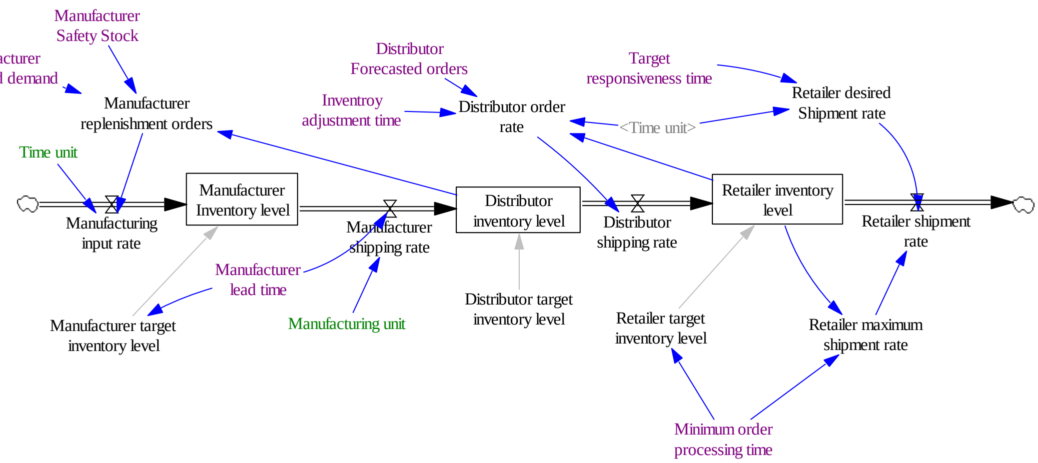


Figure 22: Chain system

The manufacturer shipping rate is controlled by stochastic manufacturing lead time and expressed as its reciprocal, as seen in Equation 2. Note that the manufacturing unit and time unit are parameters equals one that are used to keep the dimensional (unit) balance and to switch from units to rate. The manufacturer lead time is expressed in the random normal distribution function, as shown in Equation 3.

$$MSR(t) = MU/MLT(t) \tag{2}$$

$$MLT(t) = RANDOM\ NORMAL\ (Min, Max, Mean, SD, Seed) \tag{3}$$

The manufacturing input rate equals the manufacturing replenishment orders, as seen in Equation 4. The manufacturer's replenishment orders in this supply chain are based on the following channel (distributor) inventory level, manufacturer' forecasted demand, and the desired safety stock, as seen in Equation 5. If the number of units available in the distributor's warehouse is less than the forecasted demand plus the planned safety stock, then the manufacturing order will be the forecasted demand; otherwise, it is zero.

$$MIR(t) = MRO(t)/TU \qquad (4)$$

$$MRO(t) = \text{IF THEN ELSE}\ ((DIL(t)<MFD+MSS),MFD,0) \qquad (5)$$

The distributor inventory level is the difference between the manufacturer shipping rate and the distributor shipping rate, as shown in Equation 6. And the initial value is the distributor target inventory level. The distributor order rate is based on the next channel (retailer) and the distributor forecasted order. Suppose the retailer inventory level consumed in the inventory adjustment time (i.e., the time needed to adjust or refill the inventory) is less than the distributor forecasted orders. In that case, the orders will be the forecasted ones; otherwise, zero, as expressed in Equation 7. The distributor shipping rate is the same as the distributor order rate (see Equation 8).

$$DIL(t) = INTEG\ (MSR(t)-DSR(t),DTIL(t)) \qquad (6)$$

$$DOR(t) = \text{IF THEN ELSE}\ ((RIL(t)/IAT<DFO), (DFO/TU),0) \qquad (7)$$

$$DSR(t) = DOR(t) \qquad (8)$$

The retailer inventory level is the difference between retailer shipment rate and distributor shipping rate with an initial value of retailer target inventory level (see Equation 9)

$$RIL(t) = INTEG\ (DSR(t)-RSR(t),RTIL(t)) \qquad (9)$$

The shipment rate means the retailer ships what it wants to ship or what it can be shipped, whichever is less, as expressed in the minimization function in Equation 10. The maximum shipment rate depends on the retailer’s inventory level and the minimum order processing time, as indicated in Equation 11.

$$RSR(t) = MIN(RDSR(t), RMSR(t)) \qquad (10)$$

$$RMSR(t) = RIL(t)/MOPT(t) \quad (11)$$

The desired shipment rate is the rate of shipments filled within the target responsiveness time, as shown in Equation 12. The target responsiveness time is the period between placement and delivery of orders based on the various internal operations. The target responsiveness time will equal the actual responsiveness time when the desired shipment rate equals the actual shipment rate.

$$RDSR(t) = DR(t)/TRT*TU \quad (12)$$

The minimum order processing time is usually determined by the customers' proximity to the retailer's distribution centers and the order fulfillment process. It represents the minimum time required to process and ship an order, and it is expressed in a random normal function to reflect the stochastic environment, as shown in Equation 13.

$$MOPT(t) = RANDOM\ NORMAL\ (Min, Max, Mean, SD, Seed) \quad (13)$$

4.4.2. Backlog System

Order backlog indicates the delay and difference between the demand rate and the filled order rate (see Figure 23), as indicated in Equation 14. It is supposed to be the same in an ideal world, but it is not the case in the real world. A positive backlog means the company is running out of stock. While a negative backlog means there is an overproduction or over-filling stock in the warehouse.

$$B(t) = INTEG(DR(t)-FOR(t),0) \quad (14)$$

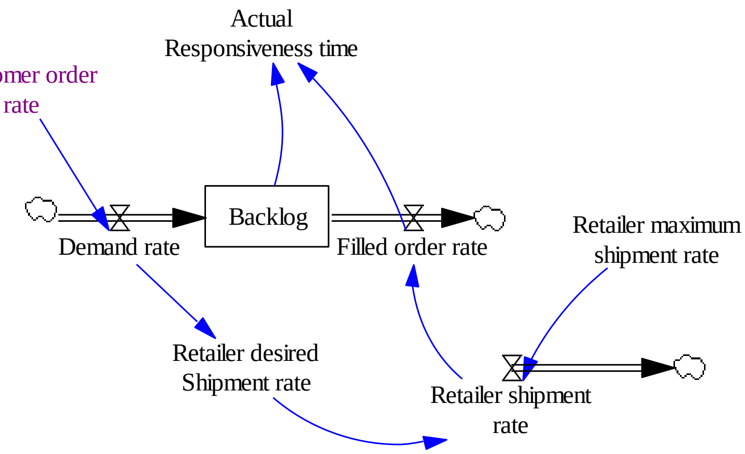


Figure 23: Backlog system

The filled order rate is numerically equal to the shipment rate (see Equation 15), but they have different concepts. The filled order rate is the information flow, while the shipment rate is the physical flow of products that leaves the warehouse. The same concept applies to the demand rate as it equals the customer order rate (see Equation 16) but from the information flow perspective. The customer order rate is expressed in a random normal function, as seen in Equation 17.

$$FOR(t) = SR(t) \tag{15}$$

$$DR(t) = COR(t) \tag{16}$$

$$COR(t) = \text{RANDOM NORMAL } (Min, Max, Mean, SD, Seed) \tag{17}$$

4.4.3. Supply Chain Efficiency Metric System

The supply chain efficiency metric is consists of two elements; inventory efficiency and responsiveness level, as shown in Figure 24, and indicated as the average of the two percentages to get a 100% score (see Equation 18). The inventory efficiency is the average of the three inventory components; manufacturer inventory efficiency, distributor inventory efficiency, and retailer inventory efficiency, as seen in Equation 19.

$$SCEM(t) = (IE(t)+RL(t))/2 \tag{18}$$

$$IE(t) = (MIE(t)+DIE(t)+RIE(t))/3*100 \tag{19}$$

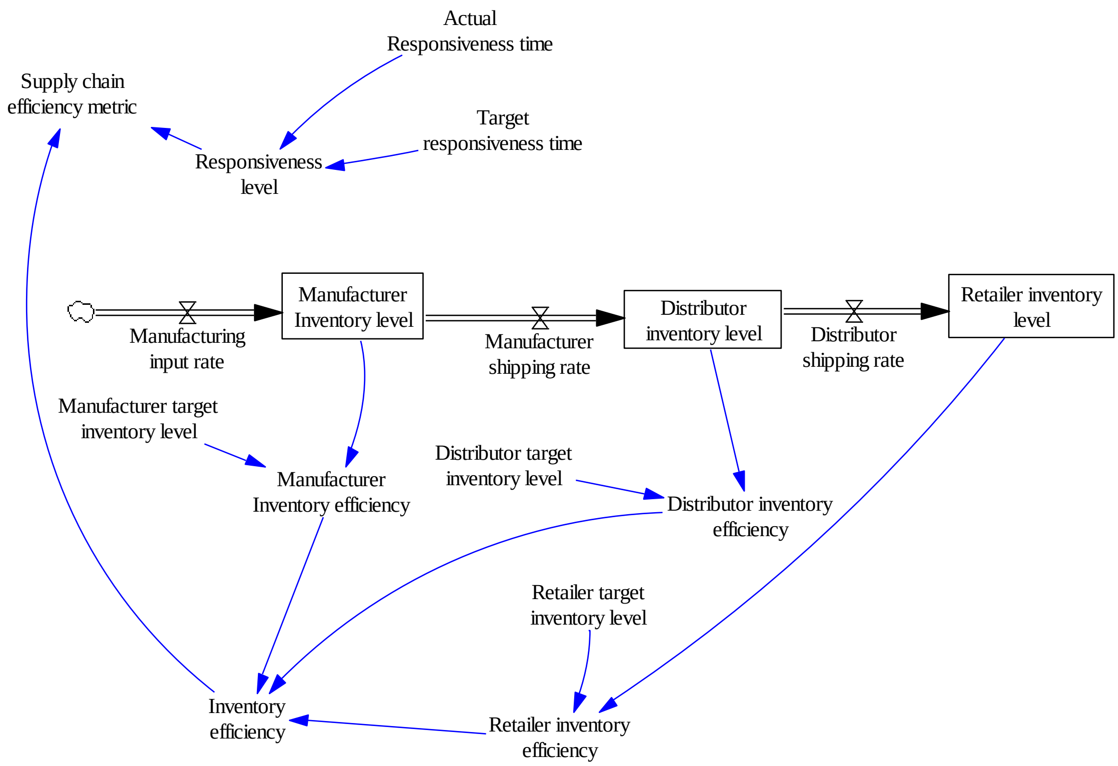


Figure 24: Supply chain efficiency metric

The manufacturer inventory efficiency can be measured as the division of the actual manufacturer inventory level and the target inventory level, whichever is less, as seen in Equation 20. If the actual inventory is higher than the target, that means there is overproduction in the system. If the actual inventory is less than the target, that means there is stockout in the system. Both cases; overproduction and underproduction (stockout) is a sign of inefficiency in the supply chain. Similarly, the distributor inventory efficiency and the retailer inventory efficiency (see Equations 21 and 22).

$$\text{MIE(t) = IF THEN ELSE((MIL(t)<MTIL(t),MIL(t)/MTIL(t),MTIL(t)/MIT(t))} \tag{20}$$

$$\text{DIE(t) = IF THEN ELSE((DIL(t)<DTIL(t),DIL(t)/DTIL(t),DTIL(t)/DIT(t))} \tag{21}$$

$$\text{RIE(t) = IF THEN ELSE((RIL(t)<RTIL(t),RIL(t)/RTIL(t),RTIL(t)/RIT(t))} \tag{22}$$

The manufacturer's target inventory level is determined by the manufacturing lead time needed to fulfill the customer order rate, as indicated in Equation 23. Similarly, the distributor’s target inventory level is the inventory adjustment time needed to meet customer orders (see Equation 24). Also, the retailer's target inventory level is the minimum order processing time needed to meet the customer order rate (see Equation 25).

$$\text{MTIL(t) = COR(t)*MLT} \tag{23}$$

$$\text{DTIL(t) = COR(t)*IAT} \tag{24}$$

$$\text{RTIL(t) = COR(t)*MOPT(t)} \tag{25}$$

The responsiveness level is the system's responsiveness to the customer orders. It can be determined as the percentage of the target responsiveness time over the actual responsiveness time, as expressed in Equation 26. The actual responsiveness time is the ratio between the backlog in the system and the filled order rate, as shown in Equation 27, using the XIDZ function to prevent the simulation error from dividing over zero.

$$\text{RL(t) = XIDZ(TRT,ART(t),1)*100} \tag{26}$$

$$\text{ART(t) = XIDZ(B(t)/FOR(t),1)} \tag{27}$$

CHAPTER 5: MODEL ANALYSIS

5.1.Introduction

In this chapter, the performance of the proposed model is analyzed under various scenarios. Each scenario investigates the impact of changing a model parameter on the supply chain efficiency metric. The software used to develop this model is Vensim ®PLE 7.2.

First, the numeric data is discussed. Second, operational and market scenarios are proposed, and model behavior is provided. Finally, a parametric analysis using Design of Experiment (DOE) is conducted to investigate the impact of different scenarios on the model performance.

5.2.Model Parameters

Table 7 shows the model parameters used in the simulation. The model is run for 160 hours counted for 8hr/shift, 1 shift/day, 20 days/month.

Table 7: Model Parameters

Parameter	**Value**	**Unit**
DFO	23	Parts
MSS	30	Parts
MFD	15	Parts
TRT	1	Hour
IAT	5	Hour
COR(t)	RANDOM NORMAL (10,20,15,5,1)	Parts/hr
MLT(t)	RANDOM NORMAL (0.1,0.2,0.15,0.005,1)	Hour
MOPT(t)	RANDOM NORMAL (6,7,6.5,0.5,1)	Hour

5.3. Operational and Market Scenarios

In order to test the applicability and verification of the model, various model scenarios are being investigated in this section. First, the developed multi-tier supply chain analysis is provided by comparing two conditions using the normal dynamic condition and from a blockchain perspective when all supply chain partners set their rates as the customer order rate. In both cases, the dynamic supply chain efficiency metric is obtained. Second, the model is examined under demand disruption conditions, and the two scenarios are compared. Third, a partial blockchain implementation with partial information visibility is tested. Finally, the adjustment of the manufacturer's lead time as an operational strategy in the partial case and its impact on the supply chain efficiency metric is investigated.

5.3.1. Dynamics of Information Visibility on the Supply Chain

In this case, all supply chain tiers' shipping and input rate tiers are set to the final customer orders. It is the ideal case of working as only as the customer needs without overproduction and without considering the risk of out-of-stock.

5.3.1.1. Dynamics of Information visibility on Manufacturer Inventory Level

In the traditional linear supply chain, the manufacturer does not have access to the actual customer demand at the end of the chain (retailer). Instead, he used its own forecasted demand and the predefined safety stock to determine its manufacturing order based on the next-tier (the distributor in this case) inventory level. This strategy can be right at the beginning of the cycle. However, it blinds over the end customer's real order rate with the continuity of everyday activities. With the application of blockchain technology, while all chain members have access to the pre-approved information, the accumulated inventory will not be the same.

In Figure 25, the manufacturer level shows an increasing trend until it reaches its maximum, then it declines again in the case of the traditional linear supply chain (LSC). However, after setting the manufacturer rate to the customer demand rate with the blockchain (WBC) implementation, the inventory level shows zero as the incoming orders the same as the outcoming orders. Here a tradeoff developed; setting the manufacturer pace as the customer pace will increase stockout risk without considering a reasonable safety stock. The manufacturer's management should evaluate and optimize between the risk of overproduction and the risk of out-of-stock and the cost of both risks.

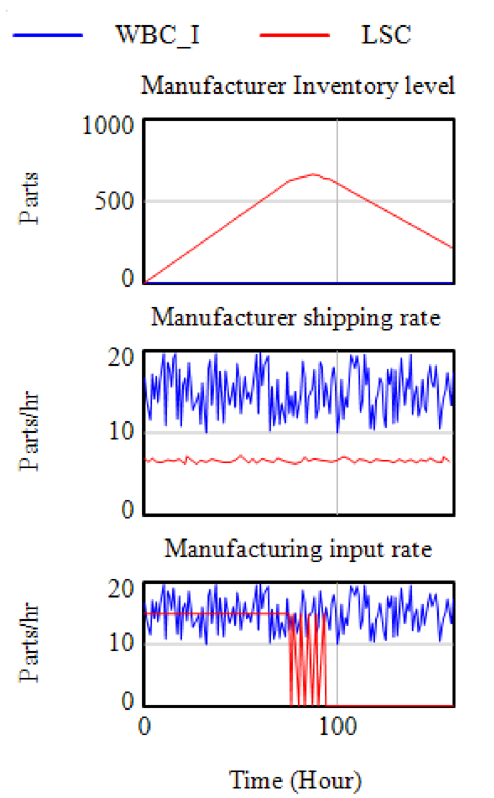


Figure 25: Manufacturer inventory level; LSC and WBC

5.3.1.2. Dynamics of Information Visibility on Distributor Inventory Level

As the distributor is the second tier in the chain, its inventory level accumulates over time, starting from negative inventory in the case of LSC, as shown in Figure 26. However, with blockchain information sharing, its inventory level becomes constant over time as the input rate equals the output rate. In this model, the inventory levels of all tiers did not set up to be non-negative stock. However, the negative stock is not a practical option; the model allows the negative values to show the possibility of running out of stock and the makeup that could happen overtime via production or shipping for the negative stock.

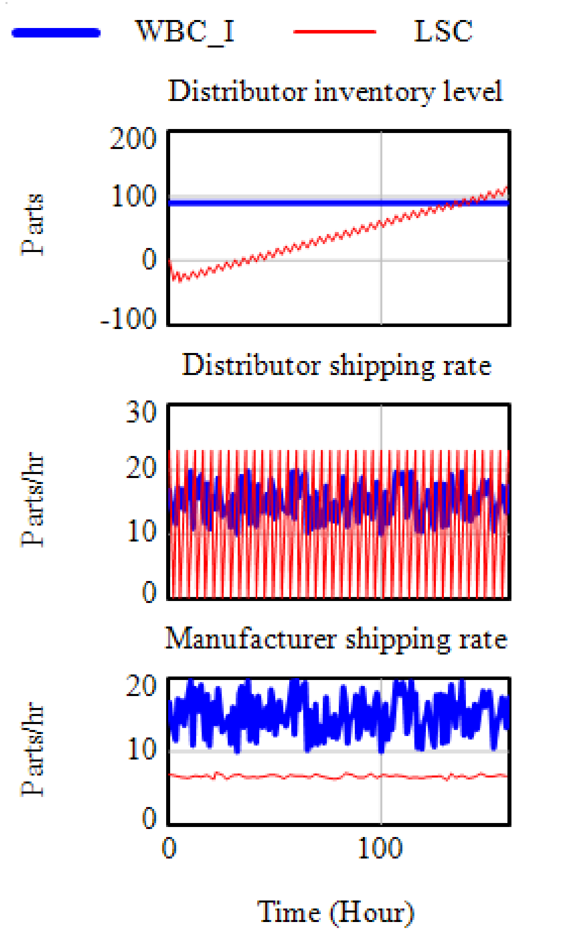


Figure 26: Distributor inventory level in LSC and WBC

5.3.1.3. Dynamics of Information Visibility on Retailer Inventory Level

Figure 27 shows the retailer inventory level in both cases, LSC and WBC. The retailer in this chain is the closest tier to the actual customer demand. So, in the LSC, the level is oscillating following the shipping rate required by the customer. However, what contributes to its dynamics, is the level of the previous tier, the distributor. In the WBC case, it is constant over time as the output equals the input.

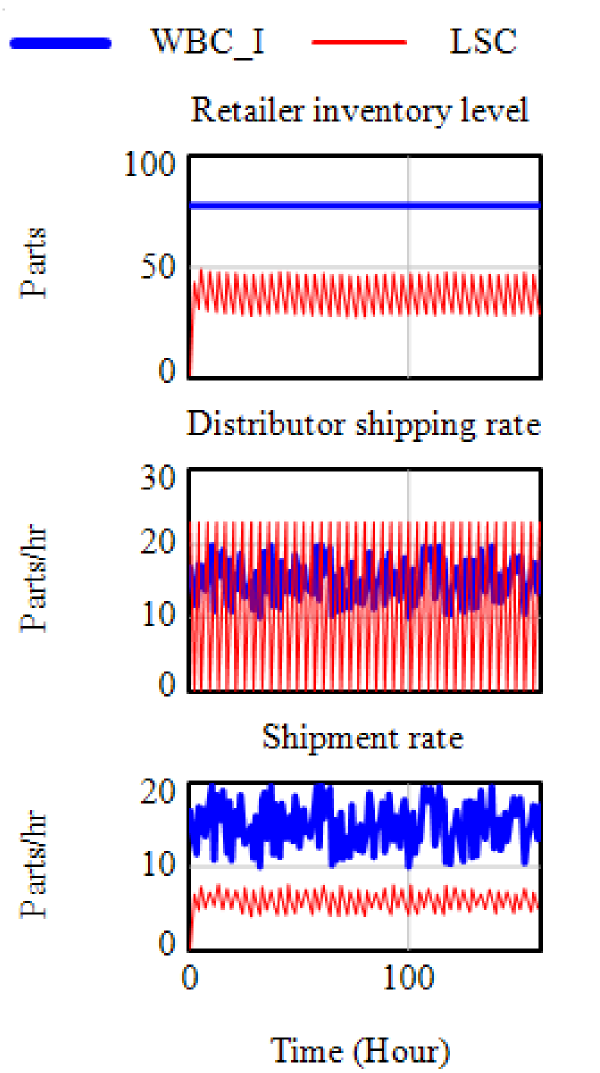


Figure 27: Retailer inventory level in LSC and WBC

5.3.1.4.Dynamics of Information Visibility on Inventory Efficiency

Figure 28 represents the inventory efficiency: the average of the manufacturer, distributor, and retailer inventory efficiencies in LSC and WBC. The retailer inventory efficiency increases in the case of WBC mainly because of the increase in the distributor inventory efficiency (previous tier). The manufacturer inventory efficiency is the highest shifting factor in this equation. The last (downstream) tier is where the previous downstream channels' inefficiencies amplify in the LSC, causing almost zero inventory efficiency.

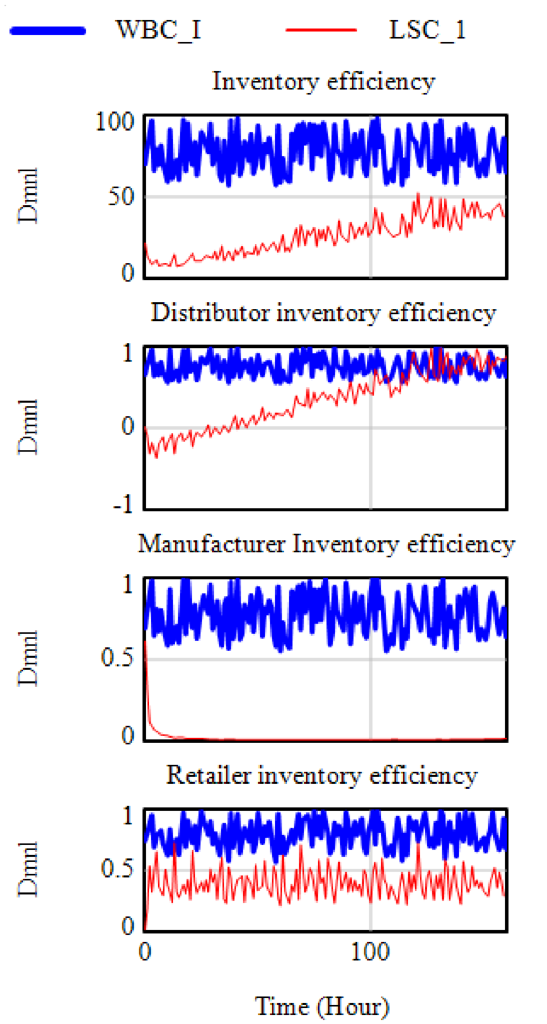


Figure 28: Inventory efficiency in LSC and WBC

5.3.1.5. Dynamics of Information Visibility on Supply Chain Efficiency Metric

Figure 29 presents the supply chain efficiency metric in the LSC and WBC. The metric is a combination of inventory efficiency and responsiveness level. In the LSC, the efficiency metric is very low but keeps increasing as the system enters the equilibrium status. The responsiveness level in LSC's case is deficient almost zero because of the significant delay between the target responsiveness time set by the supply chain members and the actual responsiveness time that keeps declining over time. A huge improvement in the supply chain efficiency is shown in the WBC case than the LSC case.

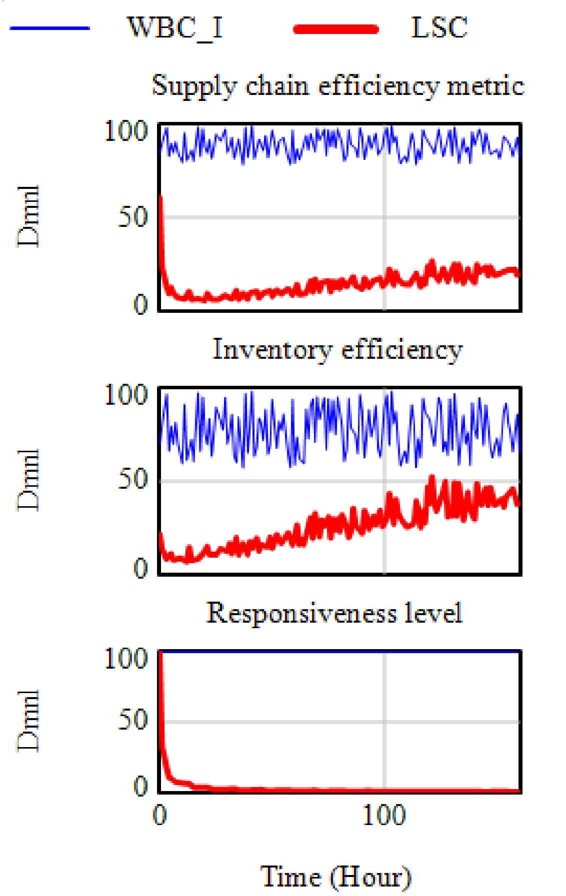


Figure 29: Supply chain efficiency metric in LSC and WBC

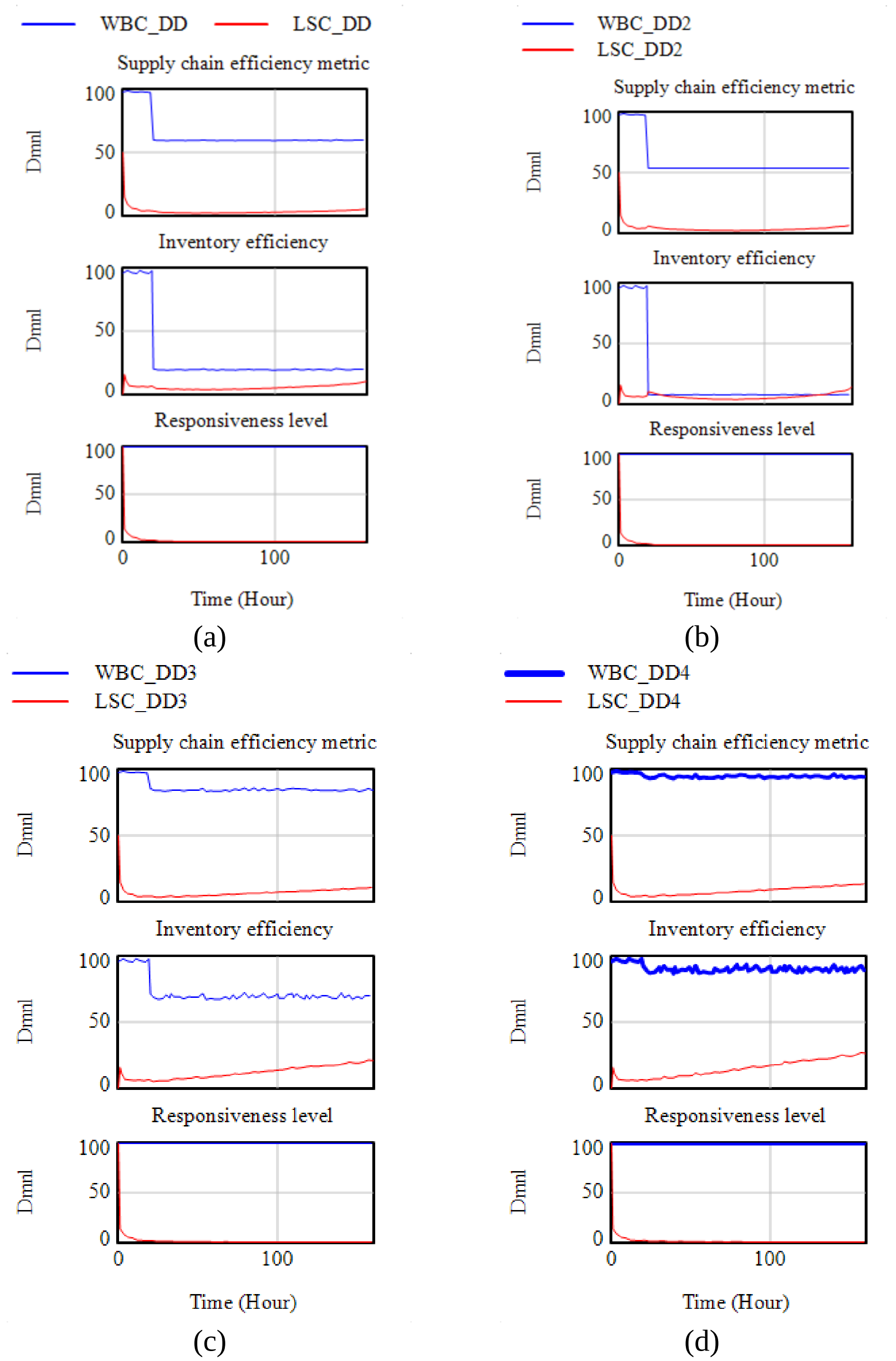
5.3.2. Dynamics of Demand Disruption on the Supply Chain

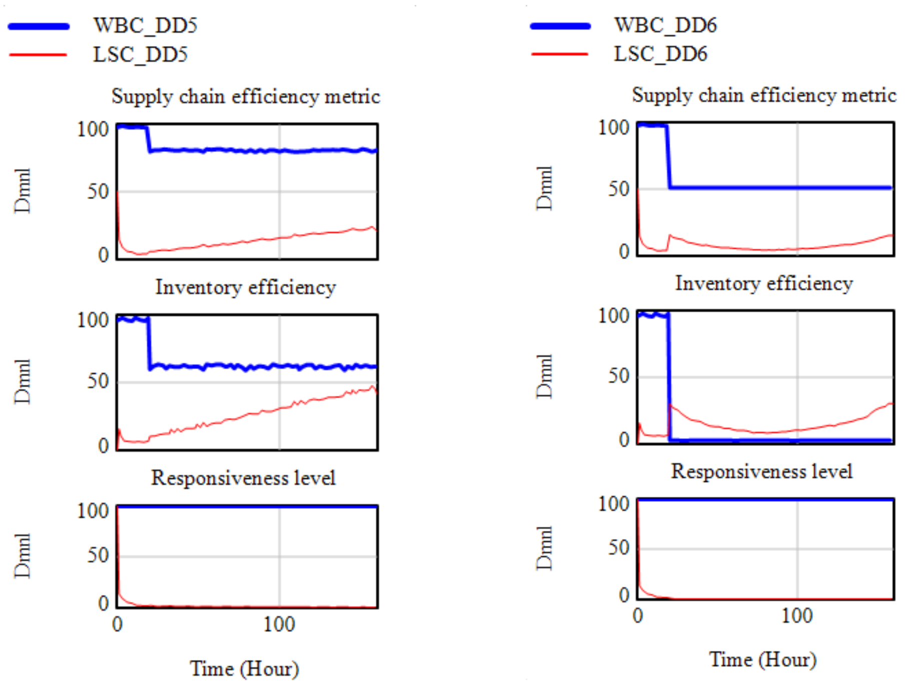
In this scenario, the impact of demand disruption on supply chain efficiency is modeled and analyzed. Various demand rate values (see Table 8) are tested in the model as a system disruption to analyze and compare its impact on the supply chain both in the linear supply chain case and the with-blockchain case. The STEP function is used to model the demand disruption. This function is useful for disturbing a model as it is an input change that generates a broad behavior response (Ventana Systems Inc, 2021).

Table 8: Demand disruption values

Demand Disruption (DD)	**Value**
DD	25+STEP(100,20)
DD2	25+STEP(300,20)
DD3	25+STEP(10,20)
DD4	25+STEP(2,20)
DD5	25+STEP(-10,20)
DD6	25+STEP(1000,20)

In the first demand disruption setting at DD, the supply chain efficiency metric is much better in the case of WBC than in the LSC case, as seen in Figure 30 (a). However, it is lower than the case without disruption. The responsiveness level reached 100% in this setting, while the inventory efficiency was satisfactory until the disruption happened, then a sharp decline appears. In the second setting at DD2 and changing the step from 100 to 300, the system has almost the same response with slightly lower supply chain efficiency and inventory efficiency as shown in Figure 30 (b).


WBC_DD
LSC_DD
Supply chain efficiency metric
Inventory efficiency
Responsiveness level
Dmnl
Time (Hour)
(a)
WBC_DD2
LSC_DD2
Supply chain efficiency metric
Inventory efficiency
Responsiveness level
Dmnl
Time (Hour)
(b)
WBC_DD3
LSC_DD3
Supply chain efficiency metric
Inventory efficiency
Responsiveness level
Dmnl
Time (Hour)
(c)
WBC_DD4
LSC_DD4
Supply chain efficiency metric
Inventory efficiency
Responsiveness level
Dmnl
Time (Hour)
(d)



(e) (f)

Figure 30: Dynamics of demand disruption

The third demand disruption happens by setting the step at only 10. Improved behavior in both cases is shown in Figure 30 (c). The inventory efficiency at DD3 is higher than in DD1 and DD2. Also, an increasing supply chain efficiency is noticed in this case. Lowering the disruption value is showing higher performance of the supply chain. The supply chain efficiency almost hit 100% by setting the demand disruption step only at two, as shown in Figure 30 (d) with higher inventory efficiency values.

Two extreme values are tested here by setting the DD as (-10) and (1000) in DD5 and DD6, as shown in Figure 30 (e) and (f), respectively. Setting the step as negative will harm the inventory efficiency and the total supply chain efficiency as well. However, since the negative value is not very high, it is still within an acceptable range. Considering an extreme disruption value at 1000, the model reflects what happened in this supply chain when a crisis as COVID

19 happens and the highly increasing demand of certain items occurs. The supply chain efficiency dropped to about 50%, and the inventory efficiency hit zero.

5.3.3. Dynamics of Partial Information Visibility on the Supply Chain

The possibility of partial information visibility in the supply chain is tested in this scenario. The complete involvement of supply chain partners in the blockchain technology is always questioned during the discussion about the extent to which the blockchain should be implemented, or if we can gain benefits from applying blockchain only partially due to restrictions like the cost of application, or governmental policies in other countries, so on.

In this scenario, the manufacturer input rate and the retailer shipment rate are set as the customer order rate. However, the manufacturer shipping rate and the distributor shipping rate are still the same as the linear supply chain case.

By running the model, the SCEM is obtained for both cases, as shown in Figure 31. It can be shown that the partial information visibility did benefit in terms of the responsiveness level to the end customer; however, it did harm the inventory efficiency. This tradeoff is because of the blindness that happens inside the manufacturer inventory and the distributor inventory. Yes, the manufacturer input rate followed the end customer request, but the manufacturer still works at its own pace. The distributor is basically controlled by the previous and following tiers without accessing the real-time data.

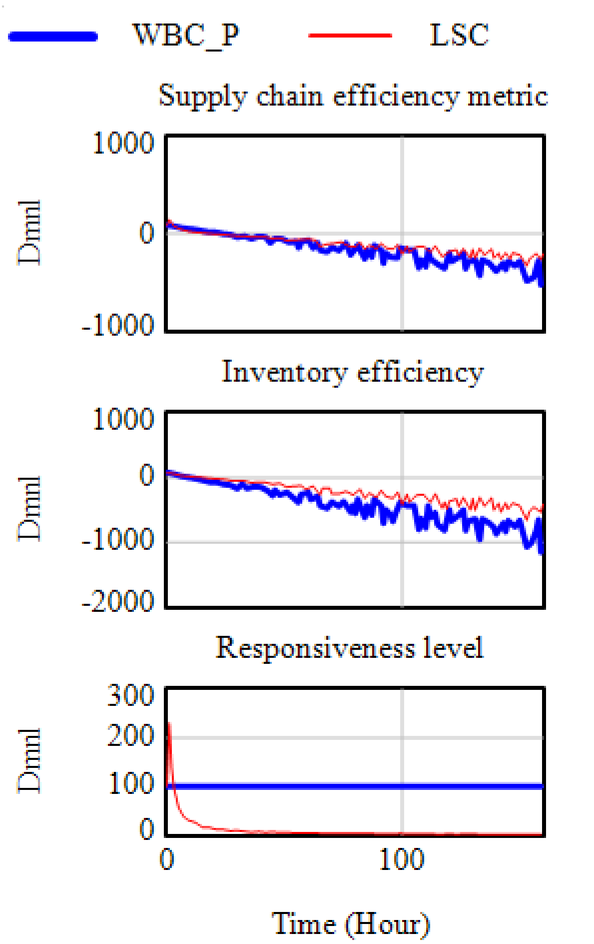


Figure 31: Supply chain efficiency metric in LSC and WBC_P

5.3.4. Dynamics of Adjusting Manufacturing Lead time in the Partial Information Visibility Case

In this scenario, the case of partial blockchain implementation with partial visibility is further investigated by examining changing the manufacturing lead time. Changing the manufacturer lead time can be a good and feasible strategy to enhance the supply chain efficiency without the full blockchain investment. To examine the impact of changing MLT on the supply chain efficiency in the partial implementation case, four values are selected as shown in Table 9.

Table 9: Manufacturing lead time values

Lead Time	Value
L1	0.1
L2	0.09
L3	0.07
L4	0.06

In the first case, as lead time set to be 0.1, a slight increase in the inventory efficiency increases the supply chain efficiency, as shown in Figure 32.

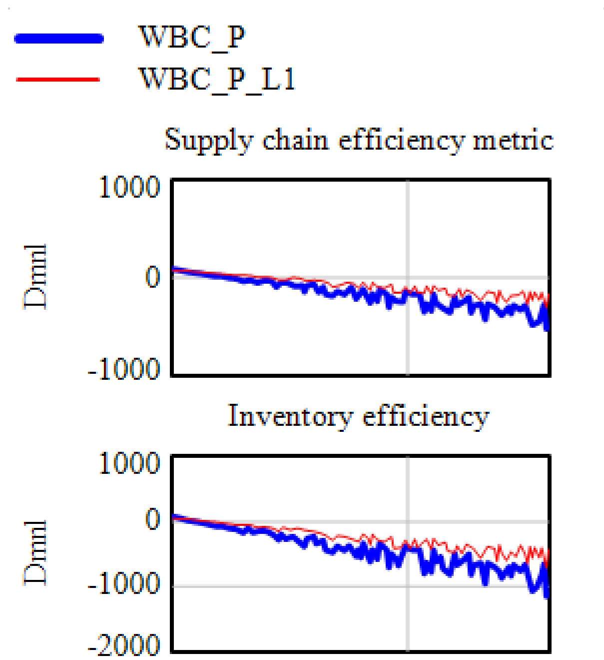


Figure 32: SCEM in WBC_P and WBC_P_L1 cases

By moving the manufacture lead time from 0.1 to 0.09 to 0.07, a noticeable improvement in the supply chain efficiency and the inventory efficiency is seen in Figure 33. Setting the manufacturer lead-time at 0.07 will enhance the supply chain efficiency to almost 70%, which is a great value to obtain in the partial information visibility case. However, continue reducing the lead time to 0.06 (L4) will drop the inventory efficiency badly as it causes negative inventory by increasing the output rate relative to the input rate (see Figure 34).

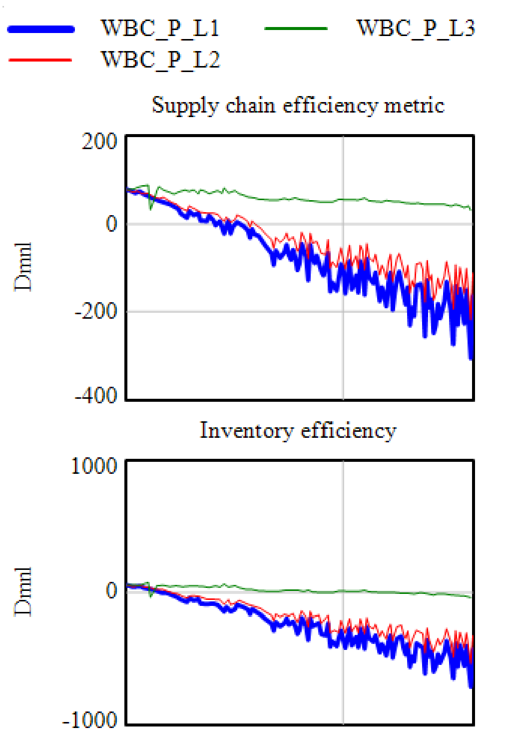


Figure 33: SCEM of WBC_P at L1, L2, L3

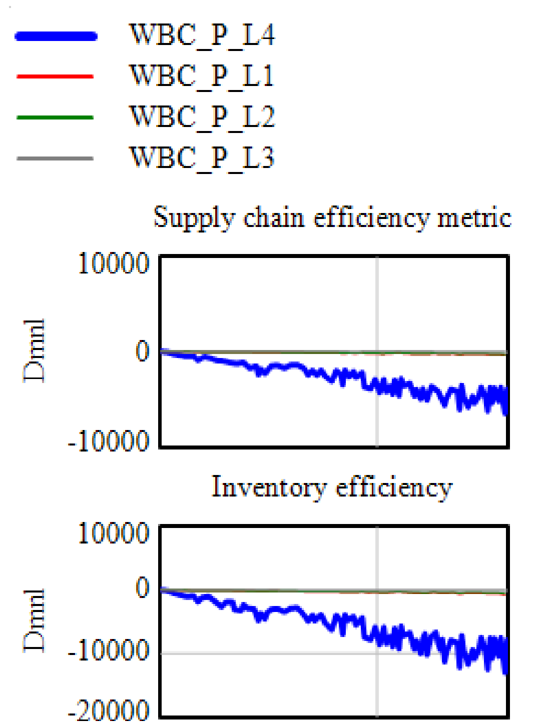


Figure 34: SCEM of WBC_P at L1, L2, L3, and L4

5.4. Design of Experiment

5.4.1. Introduction

The design of experiment (DOE) is a set of tests used to measure the individual and interactive effects of input variables that can affect the output variables. It helps to pinpoint the most and least sensitive variables that can cause problems in the model analysis. It can also be used either in process development or process troubleshooting to improve process performance or obtain a robust or insensitive process to external sources of variability (Montgomery, 2009).

When several factors in an experiment are of interest, a factorial design should be considered. In a factorial design, all possible combinations at all levels of the factors are investigated. One of these is a factorial design with k factors, each factor at two levels; low and high. Because each complete replicate of the design has 2^k runs, the arrangement is called a 2^k factorial design. In this research, Minitab16 software is used to conduct the DOE analysis. The factorial design is conducted to understand the effect of the input variables on the developed metric.

5.4.2. Parameters Selection

In the beginning, model inputs need to be examined. Six input variables are selected for this analysis: minimum order processing time, manufacturer lead time, manufacturer safety stock, inventory adjustment time, and target responsiveness time. The reason for excluding manufacturer forecasted orders and distributor forecasted orders from the analysis is that these variables are based mainly on the company's previous data and can not be changed. By using the factorial design, two levels are selected for each of these variables. So 2^6=64 runs will be carried out to monitor the response (SCEM). The selected parameters and their low and high values are shown in Table 10. Full factorial is used in this analysis without any confounding to identify the main effects.

Table 10: DOE parameters' values

Parameter	Low	High
MSS	10	50
TRT	0.5	2
IAT	2	8
COR	10	20
MLT	0.1	0.2
MOPT	3	9

First, each experiment (row values in Minitab) is logged into the Vensim model to get the response, supply chain efficiency metric. Second, the model is run, and the metric values are obtained. Third, the efficiency metric values over time for the 160 hours are logged into an excel sheet to obtain the average. Finally, this average is logged into the Minitab as the response and experiment analysis are obtained. These steps are done for the 64 experiments. All runs and their response are shown in APPENDIX C: DOE RESULTS.

5.4.3. *Normality Assumption Validation*

In order to validate the experiment and its assumption, the response of the experiment should be normally distributed. The normality can be checked with the normal probability plot, as shown in Figure 35. If the distribution is normal, the plot will reassemble a straight line.

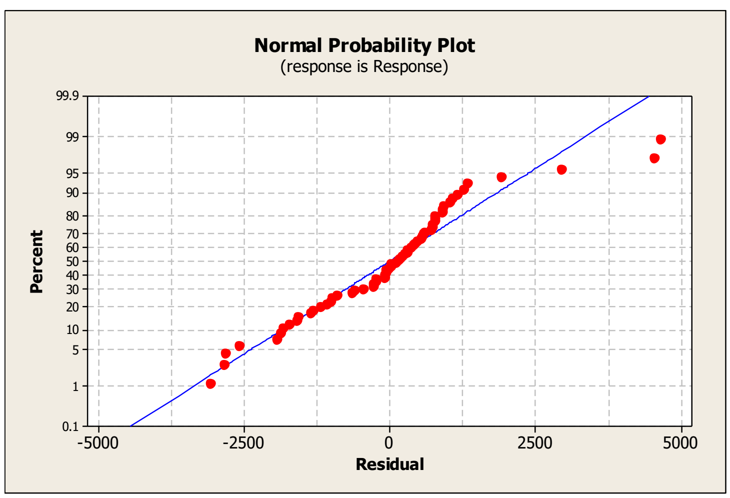


Figure 35:Normal probability plot for SCEM

5.4.4. *Significance Examination*

The significance test is conducted using Minitab to define the most significant factors on the supply chain efficiency metric. The normal plot and the Pareto chart of the standardized effects show that nine factors and factors interactions are significant on the efficiency metric at a 95% confidence level (0.05 alpha), as shown in Figure 36.

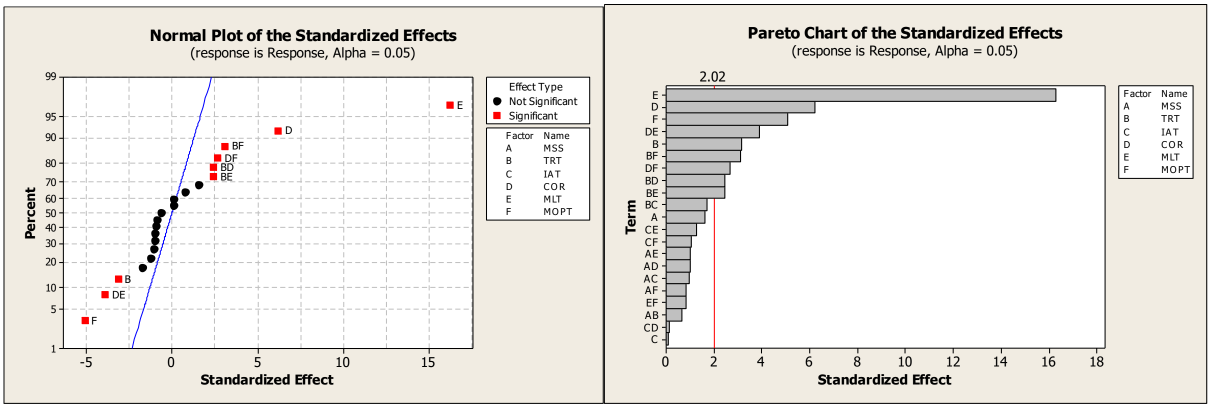


Figure 36: Significance plots

The most significant factors on the supply chain efficiency metric respectively are manufacturing lead time, customer order rate, minimum order processing time, customer order rate with manufacturing lead time interaction, target responsiveness time, target responsiveness time with minimum order processing time interaction, customer order rate with minimum order processing time interaction, target responsiveness time with customer order rate interaction, and target responsiveness time with manufacturing lead time interaction.

The major significant factor on the modeled supply chain is the manufacturing lead time as it is the first step in the chain, and any delay or change in this factor will benefit or harm the whole supply chain. The second significant factor on the metric is the customer order rate, and it can be shown from the above analysis; dynamics of demand disruption. The following factor is the minimum order processing time which is the rate at which the retailer fulfills the customer orders at the end of the supply chain. Its change can affect the responsiveness at the end or its previous tier, the distributor, which affects in return the manufacturer.

CHAPTER 6: SUMMARY, CONCLUSION, RESEARCH LIMITATIONS, FUTURE WORK, AND RESEARCH CONTRIBUTION

In this chapter, the research summary, conclusion, limitations, future work, and contribution are presented. The research goal is to understand the dynamics associated with blockchain technology implementation in the supply chain.

6.1. Summary and Conclusion

Blockchain technology has gained a lot of momentum in the last few years due to its broad and generic applications in many sectors and at different scales. It started with its unique application as a public transaction ledger of the bitcoin; cryptocurrency with the first digital currency appeared. It is a decentralized and distributed ledger consists of blocks gathered together to form the chain. These blocks record transactions through many computers, so any block cannot be altered without changing the other blocks, providing trust to verify and validate transactions without intermediates. The technology nature inspired many blockchain applications in various industries such as healthcare, transportation, manufacturing, supply chain, etc.

The supply chain becomes much more complex as it contains various members from different environments and circumstances. The need for new cooperation, coordination, and communication mechanism becomes more pressing than ever. Blockchain can play as a tool kit that provides visibility and real-time access to needed information with a secured and immutable mechanism.

In this research, an extensive literature review was conducted covering the main topics: blockchain, supply chain, blockchain implementation in supply chain, and the system dynamics methodology usage in the supply chain and technology adoption areas. The literature review identified the main benefits, challenges, and implementation areas of blockchain technology within the supply chain sector. After extensively reviewing the literature, the research gap was identified as there is no measurement system or tool to evaluate blockchain technology's impact within the supply chain.

This research aims to close this gap by providing a novel model to assess the supply chain efficiency performance from a blockchain perspective under dynamic conditions. The model captured the dynamics associated with the uncertain supply chain environment and its impact on supply chain efficiency. The analysis addressed a typical three-tier supply chain. The model consists of three components: the chain system, the backlog system, and the supply chain efficiency metric system. The chain system consists of manufacturer, distributor, and retailer. The backlog system is the indication of the delay between placement and receipt of orders. Finally, the supply chain efficiency metric consists of the responsiveness level and the inventory efficiency.

The analysis of the developed model examined the impact of implementing blockchain technology within the supply chain via information sharing and visibility. The model's performance is validated and verified through a case study. Various internal and external scenarios are then applied to obtain the supply chain efficiency metric in the linear supply chain case and with-blockchain case.

The main results are summarized as follows:

- The full implementation of blockchain in the supply chain provides real-time access to data. In this case, there is a clear improvement in the inventory efficiency as the supply chain members are only producing what customer orders at the end of the chain. There is also a significant improvement in the responsiveness level, which sums to supply chain efficiency metric improvements.
- Disrupting the supply chain system with higher or lower demand than expected can be more harmful to the inventory efficiency and supply chain efficiency in the linear supply chain case than in the with-blockchain case. The value of disruption is also playing an influential role in this analysis.
- The partial adoption of blockchain in the supply chain can be the only choice that some types of supply chains have. That partial adoption – in the modeled supply chain – is not benefiting the supply chain performance in terms of information visibility. However, having that partial access to information for the upstream supply chain's first-tier can be more beneficial if other internal management policies are considered, such as adjusting the manufacturer lead time.
- Adjusting the manufacturer lead time according to the accessed customer order data is beneficial in enhancing the inventory efficiency of the supply chain and the overall supply chain efficiency. However, results showed that there is a threshold point after which management investment in adjusting the manufacturer lead time (reducing in the case study) does not lead to further improvement in the system. It is important

to explore such threshold points in the system before making different decisions concerning improvements investments.

- Taking the decision of reducing the manufacturer lead-time via extending working hours, increasing equipment efficiency, hiring labor, training workforce, and many other initiatives is costly. So, comparing the cost of adjusting the manufacturer lead time and the full blockchain data visibility should be evaluated.
- The results signify the importance of the degree of scalability and flexibility organizations should have in order to react and adapt fast to disruption and global crisis. The cost of flexibility and scalability should also be considered.
- The main significant effect parameters affecting the modeled supply chain efficiency are the manufacturer lead time, customer order rate, and minimum order processing time.

6.2.Research Limitations

This research provided a performance metric of the supply chain to test the full and partial implementation of the blockchain technology under various operational and market scenarios. However, like many kinds of research has faced some limitations. The main limitations are:

- This research only considers one benefit or aspect of the blockchain technology implementation on the supply chain, which is real-time access to data and information sharing. Many other aspects can be investigated in future research.
- Blockchain technology adoption in the supply chain is new and immature, so the accessibility of the researchers to real data comparing the before-and-after cases was very limited.

- This research only applied the model to one case study, which hinders the generalization purpose.
- In this model, there is an assumption that the supply chain members can meet the demand disruption whenever it happens at the end of the supply chain. This fulfillment can be done through outsourcing, overtime, or other adaptation strategies that can be done to fulfill the customer needs. This assumption is basically because there is no access to actual data on how each member will adapt to the changes and at what percentage or level in both the linear supply chain case and the with-blockchain case.

6.3. Future Work

The presented work can be extended as follows:

- Releasing the model assumption made above by accessing data of actual cases that apply blockchain and faced demand disruptions.
- Obtaining actual data after applying the blockchain technology and investigates this data by plugging it into the model to understand the supply chain dynamics better
- Applying the model to different and multiple case studies to ensure its validity and generalization.
- Investigating the impact of other aspects of blockchain as the reduction of supply chain lead time and the total supply chain cost.
- Expanding the three-tier supply chain to include the supplier or other distributors or retailers. It can be horizontally or vertically cooperated.

- Conducting extensive sensitivity analysis of all model parameters involved in the model to better understand these parameters' role in supply chain performance.

6.4. Research Contribution

To the best of our knowledge, this is the first research that studies the supply chain dynamics from the blockchain technology perspective. The research developed a novel dynamic model to analyze the supply chain performance under dynamic conditions before-and-after applying blockchain technology. The model provides a quantitative measure of supply chain efficiency and examines its performance under various market and operational scenarios.

The model provides the decision-makers with a profound picture of how the supply chain dynamics can affect their decision to invest in applying blockchain technology in full or partial. It also highlights the idea that this adoption cannot be good at all levels and if this investment will payback by its benefits. The model also sheds light that some feasible management decisions to adjust one or more parameters in the supply chain that can enhance its performance to an acceptable level without the total investment in the technology adoption.

APPENDIX A: LITERATURE REVIEW SUMMARY

Author	Title	Methodology	Keywords	Application Area	Contribution
(Liu & Li, 2020)	A blockchain-based framework of cross-border e-commerce supply chain	Algorithms building; use cases	Blockchain technology; Cross-border e-commerce; Supply chain management; Product traceability;	Cross-border e-commerce SC	Introduced a BCT-based framework and provided models, methods, and algorithms for cross-border e-commerce SC.
(S. Yadav & Singh, 2020)	Blockchain critical success factors for sustainable supply chain	Principle Component Analysis (PCA); Fuzzy decision-making trial and evaluation laboratory (DEMATEL)	Blockchain; Supply chain; PCA; Fuzzy; DEMATEL	Sustainable Supply Chain Management (SSCM)	Identified six major causes that help to achieve SSCM.
(V. S. Yadav, Singh, Raut, & Govindarajan, 2020)	Blockchain technology adoption barriers in the Indian agricultural supply chain: an integrated approach	Interpretive Structural Modelling (ISM); Decision Making Trial and Evaluation Laboratory (DEMATEL) Fuzzy	Agriculture Supply Chain; Blockchain; Barriers; ISM; DEMATEL	Indian Agriculture SC	Identified the significant barriers for the BCT in the Indian agriculture SC.
(Köhler & Pizzol, 2020)	Technology assessment of blockchain-based technologies in the food supply chain	Case study analysis	N/A	Food SC	Developed a technology assessment framework composed of technique, product, knowledge, and organization.
(Sund, Lööf, Nadjm-Tehrani, &	Blockchain-based event processing in supply chains—A case study at IKEA	Case study analysis; Quorum platform	Blockchain; Traceability; Supply chain; Quorum; IBFT	Ikea- furniture retailer	Designed BC-based prototype to enable event processing by a multiplicity of actors.

Author	Title	Methodology	Keywords	Application Area	Contribution
Asplund, 2020)					
(Esmaeilian et al., 2020)	Blockchain for the future of sustainable supply chain management in Industry 4.0	Literature review analysis	Blockchain; Supply chain; Sustainability; Industry 4.0; IoT; Circular economy	SSCM and Industry 4.0	Identified the applications and capabilities of Industry 4.0 on SCM in terms of sustainability.
(Wamba, Queiroz, & Trinchera, 2020)	Dynamics between blockchain adoption determinants and supply chain performance: An empirical investigation	Hypothesis development and testing; surveys	Blockchain; Supply chain; Transparency; Digital disruption; Performance	SCM in India and the USA	Investigated the impact of BCT determinants on SC performance.
(Giovanni, 2020)	Blockchain and smart contracts in supply chain management: A game theoretic model	Prepositions development; game theory	Supply chain management; Blockchains; Smart contracts; Online platforms; Revenue sharing contract; Risk analysis; Game theory	SCM	Identified the cases that drive the implementation of BCT and smart contracts in SC.
(Z. Wang et al., 2020)	Blockchain-based framework for improving supply chain traceability and information sharing in precast construction	Algorithms building; case study	Prefabrication; Real-time information; Communication; Smart contract; Blockchain	Precast construction	Developed BCT-based information management framework for precast SC (BIMF-PSC).

Author	Title	Methodology	Keywords	Application Area	Contribution
(T.-M. Choi, Guo, & Luo, 2020)	When blockchain meets social media: Will the result benefit social media analytics for supply chain operations management?	Case studies; literature review analysis	Social media analytics; Methods; Blockchain technology; Operations management; Case studies	Supply chain operations management (SCOM)	Analyzed the usage and importance of BCT-supported social media to enhance the social media analytics for SCOM.
(Dwivedi, Amin, & Vollala, 2020)	Blockchain based secured information sharing protocol in supply chain management system with key distribution mechanism	Algorithms building	Pharmaceutical supply chain; Blockchain; Secure information sharing	Pharmaceutical SCM	Proposed BCT scheme for information sharing in the pharmaceutical SCM.
(Thakur & Breslin, 2020)	Scalable and secure product serialization for multi-party perishable good supply chains using blockchain	Algorithms building	Serialization; Blockchain; Scalability; Traceability	Perishable good SC	Developed a protocol for product serialization based on BCT.
(Lohmer, Bugert, & Lasch, 2020)	Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study	Agent-based simulation	Blockchain technology; Supply chain dynamics; Supply chain resilience; Simulation study; Industry 4.0; Capacity sharing	SC risk management and SC resilience	Developed an agent-based simulation model to analyze the impact of BCT on SC resilience.

Author	Title	Methodology	Keywords	Application Area	Contribution
(Kshetri, 2018)	Blockchain's roles in meeting key supply chain management objectives	Theory building from case studies	Auditability; Blockchain; Internet of things; Network effects; Supply chain; Sustainability	SCM	Provided the roles of BCT in achieving the SC strategic management objective: cost, speed, dependability, risk reduction, sustainability, and flexibility.
(Bumblauskas, Mann, Dugan, & Rittmer, 2020)	A blockchain use case in food distribution: Do you know where your food has been?	Use case	Blockchain; Supply Chain Management; Technology & Innovation; Food Distribution	Food SC (egg)	Proved the BCT and IoT usefulness for the accuracy and transparency in the food SC.
(Tönnissen & Teuteberg, 2020)	Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies	Multiple case study analysis	Disintermediation; Supply chain; Blockchain; Case study; Explanatory model	Operational SC and logistics	Provided an explanatory model of the value propositions, functions, and interaction of BCT on the actors in the SC.
(Yong et al., 2020)	An intelligent blockchain-based system for safe vaccine supply and Supervision	Machine learning	Vaccine safety; Vaccine blockchain; Vaccine traceability; Smart contract; Machine learning	Vaccine industry	Developed a vaccine BCT-based management system to trace and manage the information in the vaccine SC.
(Queiroz & Fosso Wamba, 2019)	Blockchain adoption challenges in supply chain: An empirical investigation of the	Hypothesis development and testing	Blockchain; Adoption; Supply chain network; Digital disruption; UTAUT (unified	Logistics and SC in the USA and India	Developed a model to understand the BCT adoption behavior on the individual level (professionals).

Author	Title	Methodology	Keywords	Application Area	Contribution
	main drivers in India and the USA		theory of acceptance and use of technology)		
(Creydt & Fischer, 2019)	Blockchain and more - Algorithm driven food traceability	Literature review analysis	Blockchain; Traceability; Food fraud; Authenticity; Food chain	Food SC	Discussed the benefits of BCT and IoT for food SC traceability.
(Schmidt & Wagner, 2019)	Blockchain and supply chain relations: A transaction cost theory perspective	Proposition development; transaction-cost theory	Digitalization; Blockchain; Supply chain management; Boundary conditions; Transaction cost theory	SCM and its relationship and governance structure	Developed a framework and propositions based on the transaction cost theory to explain blockchain characteristics' impact on transaction costs and SC governance.
(Longo, Nicoletti, Padovano, d'Atri, & Forte, 2019)	Blockchain-enabled supply chain: An experimental study	Simulation; Statistical analysis	Blockchain; Ethereum; Information Sharing; Supply chain; Trust; Industry 4.0	Information sharing and trust through the SC	Designed software connector based on BCT to enable the interaction between SC partners.
(Helo & Hao, 2019)	Blockchains in operations and supply chains: A model and reference implementation	Programming and software	Blockchain; Distributed ledger; Operations; Supply chain; Logistics;	Operations and SC	Developed reference implementation to determine the technical architecture of BCT-based logistics monitoring system (BLMS).
(Min, 2019)	Blockchain technology for enhancing supply chain resilience	Literature review analysis	Blockchain technology; Supply chain risk	SC risk management/ security	Developed a BCT architecture that can be used to improve the SC resilience

Author	Title	Methodology	Keywords	Application Area	Contribution
			management; Cryptocurrency; Blockchain architecture; Supply chain resilience		from risk/security perspectives.
(Di Vaio & Varriale, 2020)	Blockchain technology in supply chain management for sustainable performance: Evidence from the airport industry	Literature review analysis; Case study	Blockchain technology; Operations management; Supply chain management; Sustainable performance; Airport industry; Non-financial reports	SSCM; Operations management	Explored the impact of the application of BCT on the performance of the airport from the SSCM perspective.
(T.-M. Choi, 2019)	Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains	Modelling; Game-theoretic analytical study; Case study	Blockchain technology; Luxury supply chain; Fashion accessories; Platform operations; Diamond authentication and certification	Diamond SC	Built models to compare between the traditional jewelry retail network and BCT-based network.
(Behnke & Janssen, 2020)	Boundary conditions for traceability in food supply chains using blockchain technology	Case studies, Interviews	Food supply chain; Traceability; Blockchain technology; Business boundary conditions	Food SC (dairy)	Identified boundary conditions need to be met before the full implementation of BCT in food traceability SC.

Author	Title	Methodology	Keywords	Application Area	Contribution
(T. Chen & Wang, 2020)	Combined application of blockchain technology in fractional calculus model of supply chain financial system	Fractional calculus game model; Theory of nonlinear dynamics	Blockchain technology; Supply chain finance; Fractional calculus system; Credit banking system	Supply chain finance (SCF)	Applied the BCT to the SCF fractional calculus system to the credit banking system.
(T.-M. Choi & Luo, 2019)	Data quality challenges for sustainable fashion supply chain operations in emerging markets: Roles of blockchain, government sponsors and environment taxes	Analytical models; propositions development	Fashion business operations; Supply chain centralization; Emerging markets; Sustainable operations; Social welfare	Sustainable fashion SC	Developed a theoretical model and propositions to explore how BCT can help to solve the data quality problems in the sustainable fashion SC operations.
(Xu et al., 2019)	Designing blockchain-based applications a case study for imported product traceability	Software development; Case study	Blockchain; Smart contract; Adaptability; Software architecture	Imported product traceability	Developed a BCT-based traceability system.
(George, Harsh, Ray, & Babu, 2019)	Food quality traceability prototype for restaurants using blockchain and food quality data index	Prototype; Mathematical modeling	Food traceability; Blockchain Food quality index	Food (pork) traceability	Developed a restaurant prototype based on BCT to enhance product traceability and applied food quality index (FQI).

Author	Title	Methodology	Keywords	Application Area	Contribution
(Galvez et al., 2018)	Future challenges on the use of blockchain for food traceability analysis.	Literature review analysis	Blockchain; Food authentication; Agricultural and farming applications; Food chain; Traceability; Data analysis and management	Food traceability	Evaluated the potential of BCT in food SC authenticity and traceability.
(T.-M. M. Choi, Feng, & Li, 2020)	Information disclosure structure in supply chains with rental service platforms in the blockchain technology era	Analytical modeling; game-theoretic analysis	Product information disclosure game; Economics analysis; Rental service platforms; Competition; Multi-products	Rental services platform operations	Built a stylized model to investigate the product-information disclosure problem in rental services.
(Montecchi, Plangger, & Etter, 2019)	It's real, trust me! Establishing supply chain provenance using blockchain	Literature review analysis	Provenance; Quality assurance; Risk reduction; Supply chain; Blockchain; Provenance knowledge; Supply chain risk management	SC provenance	Developed a provenance knowledge framework based on BCT to enhance assurances and reduce risks.
(Y. Wang, Wang, Singgih, & Rit, 2019)	Making sense of blockchain technology: How will it transform supply chains?	Sensemaking theory; in-depth interviews; cognitive mapping; narrative analysis	Blockchains; Distributed ledger; Sensemaking; Cognitive mapping; Supply chain;	General SC	Developed three frames; the benefit frame, the application frame, and the challenge frame, to analyze how BCT can transform the SC.

Author	Title	Methodology	Keywords	Application Area	Contribution
			Exploratory study; Expert interview		
(Yang, 2019)	Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use	Questionnaire, Hypothesis testing, Technology acceptance model (TAM)	Maritime shipping; Digitalization; Blockchain technology; Technology acceptance model; Intention to use	Maritime shipping SC	Provided the expected applications, improvements that BCT can make in the maritime shipping industry.
(S. S. Kamble, Gunasekaran, & Sharma, 2020)	Modeling the blockchain enabled traceability in agriculture supply chain	Expert opinions; Interpretive Structural Modelling (ISM); Decision-Making Trial and Evaluation Laboratory (DEMATEL)	Blockchain technology; Agriculture supply chain; Sustainability; Traceability; Transparency; ISM; DEMATEL	Agriculture SC	Established the relationships between enablers of BCT implementation in the agriculture SC.
(Karamchandani, Srivastava, & Srivastava, 2020)	Perception-based model for analyzing the impact of enterprise blockchain adoption on SCM in the Indian service industry	Hypothesis testing; surveys; structural equation modeling (SEM); technology acceptance Model (TAM)	Blockchain; Enterprise blockchain (EBC); Service industry; Supply chain management (SCM); Structural equation model (SEM); Survey-based research	Service SCM	Examined the enterprise blockchain (EBC) perception among practitioners in the service industry.
(Leng, Bi, Jing, Fu, &	Research on agricultural supply	Modelling and simulation	Public blockchain; Consensus	Agricultural SC system	Proposed double-chain architecture of the

Author	Title	Methodology	Keywords	Application Area	Contribution
Van Nieuwenhuyse, 2018)	chain system with double chain architecture based on blockchain technology		mechanism; Agricultural supply chain system; Double chain architecture		agricultural SC system in China.
(Shuchih Ernest Chang, Chen, & Lu, 2019)	Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process	Comparative analysis	Blockchain; Supply chain management; Smart contract; Distributed ledger; Business process re-engineering	SCM	Proposed a BCT-based SC business process re-engineering framework.
(T.-M. M. Choi, Wen, Sun, & Chung, 2019)	The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era	Literature review analysis; Mean-variance approach	Blockchain technology; Mean-variance approach; Risk analysis; Supply chain operations	Air logistics operational risk management	Proposed how the BCT can be used in analyzing risks in air logistics risk management.
(Azzi, Chamoun, & Sokhn, 2019)	The power of a blockchain-based supply chain	Theory-built based on case studies	Blockchain; Supply chain management; Traceability systems; Decentralized systems	SCM	Presented the benefits and challenges of using BCT in SCM.
(Kamilaris, Fonts, & Prenafeta-Boldύ, 2019)	The rise of blockchain technology in agriculture and food supply chains	Literature review analysis	Blockchain technology; Digital agriculture; Food supply chain;	Agriculture and food SC	Presented potential, implications, and challenges facing the adoption of BCT in the agriculture and food industry.

Author	Title	Methodology	Keywords	Application Area	Contribution
			Barriers; Benefits; Challenges		
(L.-W. W. Wong et al., 2020)	Time to seize the digital evolution: Adoption of blockchain in operations and supply chain management among Malaysian SMEs	Hypothesis testing; technology organization-environment (TOE) framework; questionnaires, partial least square structural equation modeling (PLS-SEM), Artificial neural network analysis (ANN)	Blockchain; Operations and Supply Chain Management (OSCM)l Partial Least Squares; Structural Equation Modelling (PLS-SEM); Artificial Neural Network analysis (ANN); Technology, Organisation and Environment Framework (TOE)	OSCM among small-medium enterprises	Presented the factors affecting the adoption of BCT in the OSCM by the small and medium enterprises.
(Westerkamp, Victor, & Küpper, 2020)	Tracing manufacturing processes using blockchain-based token compositions	Literature review analysis	Supply chain; Traceability; Blockchain; Distributed ledger technology; Smart contract	Manufacturing processes in SC	Developed a SC traceability system based on BCT for manufacturing goods, including their components (manufacturing processes).
(Gonczol, Katsikouli, Herskind, & Dragoni, 2020)	Blockchain Implementations and Use Cases for Supply Chains-A Survey	Literature review analysis	Blockchain; distributed ledger technology; implementations and use cases; supply chains	General SC	Provided the benefits and barriers of the adoption of BCT in the SC.

Author	Title	Methodology	Keywords	Application Area	Contribution
(Hackius & Petersen, 2020)	Translating High Hopes into Tangible Benefits: How Incumbents in Supply Chain and Logistics Approach Blockchain	Semi-structured interviews used to develop prepositions	Blockchain; decision making; logistics; supply chain management; technology management	SC and logistics incumbents	Identified three types of practices in adopting the BCT in the SC and two groups of barriers.
(X. Zhang et al., 2020)	Blockchain-based safety management system for the grain supply chain	Algorithm building; case study	Blockchain; food safety; grain supply chain; hyperledger; smart contract	Food SC (grain)	Established an information security management system for the whole grain SC.
(Shuchih E. Chang & Chen, 2020)	When blockchain meets supply chain: A systematic literature review on current development and potential applications	Literature review analysis	Blockchain; digital ledger; distributed ledger technology; logistics; shared ledger; smart contract; supply chain management; systematic literature review; value chain	General SC	Provided a blueprint for the applications of BCT in the SC.
(Shahid et al., 2020)	Blockchain-Based Agri-Food Supply Chain: A Complete Solution	Algorithms building	Accountability; blockchain; credibility; reputation; supply chain; traceability; trust	Agri-food SC	Proposed end-to-end solution for the agri-food SC based on BCT.
(Shakhbulatov , Medina, Dong, &	How Blockchain Enhances Supply Chain Management: A Survey	Literature review analysis	Supply chain; provenance; blockchain; industries;	SCM	Analyzed and compared various BCT frameworks in terms of SCM.

Author	Title	Methodology	Keywords	Application Area	Contribution
Rojas-Cessa, 2020)			distributed ledger; supply chain management; consensus algorithms; smart contracts.		
(Z. Li et al., 2020)	A sustainable production capability evaluation mechanism based on blockchain, LSTM, analytic hierarchy process for supply chain network	Machine learning; linear regression; Analytic Hierarchy Process (AHP)	IoT; blockchain; machine learning; production capability evaluation; supply chain network	Production capability of SC network	Developed enterprise capability evaluation model and sharing system.
(Fosso Wamba, Kala Kamdjoug, Epie Bawack, & Keogh, 2020)	Bitcoin, Blockchain and Fintech: a systematic review and case studies in the supply chain	Literature review analysis	Bitcoin; Blockchain; Fintech; supply chain	General SC	Gave insights about the application of bitcoin, fintech, and BCT in SC.
(Queiroz, Fosso Wamba, De Bourmont, & Telles, 2020)	Blockchain adoption in operations and supply chain management: empirical evidence from an emerging economy	Unified theory of acceptance and use of technology (UTAUT); partial least squares structural equation modelling (PLS-SEM); hypothesis building	Blockchain technology; UTAUT; adoption; barriers; emerging economy; trust	OSCM in the emerging economy	Built UTAUT model to investigate adoption behavior and barriers.

Author	Title	Methodology	Keywords	Application Area	Contribution
(Casino et al., 2020)	Blockchain-based food supply chain traceability: a case study in the dairy sector	Case study	Supply chains and networks; supply chain management; Industry 4.0; blockchain; smart contract	Food SC (dairy)	Proposed BCT-based framework to measure food SC traceability.
(Gökalp, Gökalp, & Çoban, 2020)	Blockchain-Based Supply Chain Management: Understanding the Determinants of Adoption in the Context of Organizations	Technology-Organization-Environment (TOE), Analytic Hierarchy Process (AHP), Expert panel	Blockchain; organizational adoption; supply Chain Management; technology-Organization-Environment framework	Organizational SCM	Developed a framework to determine and rank the determinants of BCT adoption in organizational SCM.
(J. Li, Maiti, Springer, & Gray, 2020)	Blockchain for supply chain quality management: challenges and opportunities in context of open manufacturing and industrial internet of things	Literature review analysis	Blockchain; industrial internet of things; manufacturing information systems; open manufacturing; quality management; supply chain	SC quality management	Analyzed the potential applications of BCT in SC quality management.
(T. M. Choi, 2020b)	Supply chain financing using blockchain: impacts on supply chains selling fashionable products	Prepositions development; mathematical modeling; theory building	Blockchain; Coordination; Fashionable products; Mean-risk analysis; Supply chain management	SCF in the fashion industry	Built models to compare between traditional SC financing and BCT financing.

Author	Title	Methodology	Keywords	Application Area	Contribution
(T. M. Choi, 2020a)	Creating all-win by blockchain technology in supply chains: Impacts of agents' risk attitudes towards cryptocurrency	Mathematical modeling; mean-risk theory	Blockchain; cryptocurrency; mean-risk theory; risk attitudes; supply chain finance	SCF	Developed models to analyze the risk attitudes of applying BCT in SC finance.
(Y. Wang, Chen, & Zghari-Sales, 2020)	Designing a blockchain enabled supply chain	Longitudinal pilot study	Blockchain; business model; design principles; design science; longitudinal study; supply chain	SC business model in the construction sector	Designed SC business model based on BCT.
(Fan, Wu, & Cao, 2020)	Considering the traceability awareness of consumers: should the supply chain adopt the blockchain technology?	Mathematical modeling; propositions development; theory analysis	Blockchain technology; Pricing; Supply chain; Traceability awareness of consumers	Pricing strategies in SC	Modeled pricing strategies for SC with and without BCT.
(Iqbal & Butt, 2020)	Safe farming as a service of blockchain-based supply chain management for improved transparency	Simulation	Blockchain; Internet of things; Precision agriculture; Safe farming; Wireless sensor networks; ZigBee	Agriculture and farming SC	Proposed a repelling and notifying System (RNS) based on IoT and BCT.
(Jabbar, Lloyd, Hammoudeh,	Blockchain-enabled supply chain:	Literature and case studies review and analysis	Blockchain; Consensus algorithm; GS1	General SC	Proposed MOHBSChain; BC-based framework for SC.

Author	Title	Methodology	Keywords	Application Area	Contribution
Adebisi, & Raza, 2020)	analysis, challenges, and future directions		Standards; Interoperability; Scalability; Smart contract; Supply chain		
(Öztürk & Yildizbaşi, 2020)	Barriers to implementation of blockchain into supply chain management using an integrated multi-criteria decision-making method: a numerical example	Fuzzy AHP; fuzzy TOPSIS; questionnaires	Blockchain; Fuzzy AHP; Fuzzy TOPSIS; Integrated MCDM; Supply chain management	SCM	Developed fuzzy models to solve the barriers facing the BCT adoption in the SCM.
(L. W. Wong, Tan, Lee, Ooi, & Sohal, 2020)	Unearthing the determinants of Blockchain adoption in supply chain management	Hypothesis development; questionnaires; UTAUT	Blockchain; supply chain management; UTAUT; Malaysia	SCM	Examined the adoption behavior of the BCT in the Malaysian SCM.
(Treiblmaier, 2018)	The impact of the blockchain on the supply chain: a theory-based research framework and a call for action	Theory-based research framework	Information systems, Business strategy, Disruption, Value chain, Global value chain, Management strategy, Blockchain, Middle-range theorizing	SCM	Developed a framework for the impact of BCT on SCM based on principal-agent theory (PAT), transaction cost analysis (TCA), research-based view (RBV), and networking theory (NT).
(Clauson, Breeden,	Leveraging Blockchain	Narrative review of the academic; grey,	blockchain, distributed ledger,	SC in healthcare, especially	Provided an overview of the opportunities and barriers of

Author	Title	Methodology	Keywords	Application Area	Contribution
Davidson, & Mackey, 2018)	Technology to Enhance Supply Chain Management in Healthcare: An Exploration of Challenges and Opportunities in the Health Supply Chain	and industry literature	pharmacy, pharmaceutical, supply chain	pharmaceutical supply, medical device, and supplies, Internet of Healthy Things (IoHT), and public health sectors	the BCT deployment for the health SC.
(Kamath, 2018)	Food Traceability on Blockchain: Walmart's Pork and Mango Pilots with IBM	Case study	Food safety, provenance, supply chain, Walmart, IBM, traceability	Food SC	Discussed the benefits and challenges of using BCT in food SC with Walmart as a case study.
(Toyoda, Mathiopoulos, Sasase, & Ohtsuki, 2017)	A Novel Blockchain-Based Product Ownership Management System (POMS) for Anti Counterfeits in the Post Supply Chain	Algorithms building	Anti-counterfeits technology, POMS (products ownership management system), blockchain, Ethereum, security.	The post SC	Proposed a new product ownership management system (POMS) based on BCT.
(Perboli et al., 2018)	Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases	GUEST (go, uniform, evaluate, solve and test) Case study	Blockchain, hyperledger, supply chain	Logistics and SC	Introduced a standard methodology to design BCT use-cases.

Author	Title	Methodology	Keywords	Application Area	Contribution
(Zhu & Kouhizadeh, 2019)	Blockchain Technology, Supply Chain Information, and Strategic Product Deletion Management	Literature review analysis	Product deletion, supply chain management, blockchain technology, information systems	Product deletion (product management)	Provided insights about the role of BCT on the product deletion process and how it can improve the whole SC.
(Queiroz et al., 2019)	Blockchain and supply chain management integration: a systematic review of the literature	Literature review analysis	New technology, Systematic literature review, SCM practices, Disruption, Supply chain disruptions	SCM	Analyzed the current status of the implementation of BCT into SCM and provided future research agenda.
(Saberi, Kouhizadeh, Sarkis, & Shen, 2019)	Blockchain technology and its relationships to sustainable supply chain management	Literature review analysis; Propositions development	Blockchain technology; supply chain management; sustainability; barriers; research agenda	SSC	Developed propositions about the future agenda of BCT in the sustainable SC.
(Tseng, Liao, Chong, & Liao, 2018)	Governance on the Drug Supply Chain via Gcoin Blockchain	Literature review analysis and algorithm building	blockchain; drug supply chains; Gcoin	Drug SC	Suggested new Gcoin BCT as a governance structure for the data flow of drugs.
(Benton et al., 2018)	Blockchain for Supply Chain: Improving Transparency and Efficiency Simultaneously	Use cases	Blockchain, efficiency, hyperledger, private blockchain, supply chain, traceability, transparency	SCM	Illustrated the difference between the trustless mechanisms and the permissioned consensus used in SCM.

Author	Title	Methodology	Keywords	Application Area	Contribution
(D. Ghode, Yadav, Jain, & Soni, 2020)	Adoption of blockchain in supply chain: an analysis of influencing factors	Grey relational analysis (GRA); questionnaire	Blockchain technology, Supply chain, Grey relational analysis	General SC	Categorized the influencing factors into organizational, technological, operational, and social challenges.
(D. J. Ghode, Yadav, Jain, & Soni, 2020)	Blockchain adoption in the supply chain: an appraisal on challenges	Interpretive structural modeling (ISM); Interviews	Blockchain technology, Supply chain, Challenges, ISM	General SC	Developed a model for the interrelationships of the challenges facing the adoption of BCT in the SC.
(Tsiulin, Reinau, Hilmola, Goryaev, & Karam, 2020)	Blockchain-based applications in shipping and port management: a literature review towards defining key conceptual frameworks	Literature review analysis	Shipping, Supply chain, Conceptual framework, Blockchain, Maritime port management, Port community system, internet of things	Maritime	Built a framework for the BCT implementation within the maritime port environment.
(Hew, Wong, Tan, Ooi, & Lin, 2020)	The blockchain-based Halal traceability systems: a hype or reality?	Sampling; Interviews; hypothesis building and least square structural modelling	Innovation, Supply-chain management, Food industry, Food security, Blockchain, Food traceability systems, Halal orientation strategy, Institutional theory, Diffusion of innovation theory	Halal food SC	Developed integrated model consists of halal orientation strategy, institutional theory, and diffusion of innovation theory to analyze the adoption of BCT in the Halal food industry.

Author	Title	Methodology	Keywords	Application Area	Contribution
(Nandi, Nandi, Moya, & Kaynak, 2020)	Blockchain technology-enabled supply chain systems and supply chain performance: a resource-based view	Abductive research approach	New technology, Technology, Supply-chain management, Resource-based view, SCM framework, SCM performance, blockchain, Supply chain performance, Supply chain integration	Resource-based SC view	Developed propositions about BCT-enabled SC capabilities and outcomes.
(Lambourdiere & Corbin, 2020)	Blockchain and maritime supply-chain performance: dynamic capabilities perspective	Prepositions development	Dynamic capabilities, Digital technology, Blockchain technology, Maritime supply chain	Maritime	Developed propositions based on the literature about the capabilities and consequences of implementing BCT in the maritime SC.
(X. (Alice) Qian & Papadonikolaki, 2020)	Shifting trust in construction supply chains through blockchain technology	Semi-structured interviews	Blockchain technology, Supply chain management, Trust, Experience, Digital, Construction	Construction	Explained how trust and sources of trust in the construction SC are affected by BCT.
(Sander, Semeijn, & Mahr, 2018)	The acceptance of blockchain technology in meat traceability and transparency	Survey and interview	Transparency, Purchasing decision	Food SC (meat)	Evaluated the potential of acceptance of BCT as a practicable traceability and transparency system (TTS).

Author	Title	Methodology	Keywords	Application Area	Contribution
(van Hoek, 2019b)	Exploring blockchain implementation in the supply chain	Focus group; survey; and multiple case studies	RFID, Research, Framework, Implementation, Blockchain, Supply chain technology	General SC	Developed a framework for the drivers, benefits, and barriers for the adoption of BCT in SC.
(Martinez et al., 2019)	Blockchain-driven customer order management	Simulation, case study	Supply chain, Digital technology, Resource-based view (RBV), blockchain, Information processing theory (IPT)	Customer order management process of SC	Examined scenarios analysis for the impact of BCT on customer order process and operations management for a particular industrial firm.
(Hald & Kinra, 2019)	How the blockchain enables and constrains supply chain performance	Theory-driven approach based on a structured review	Supply chain performance, Supply chain management, Blockchain technology, Distributed computing, Enabling and constraining effects, Performance-related implications	SCM and SC performance	Developed a set of propositions to structure blockchain's roles that enable and constrain the SCM and performance.
(Gurtu & Johny, 2019)	Potential of blockchain technology in supply chain management: a literature review	Literature review analysis	Blockchain, Smart contract, E-commerce, Global sourcing, Supply-chain management,	SCM	Provided trends in the application of BCT in SCM.

Author	Title	Methodology	Keywords	Application Area	Contribution
			Logistics management, Disruptive technology		
(Zelbst, Green, Sower, & Bond, 2019)	The impact of RFID, IIoT, and Blockchain technologies on supply chain transparency	Surveys; Hypothesis testing; Covariance-based structural equation modeling	Internet, Technology	SC transparency	Developed a structural model to understand the combined impact of IoT, BCT, and RFID on SC transparency.
(Sheel & Nath, 2019)	Effect of blockchain technology adoption on supply chain adaptability, agility, alignment and performance	Hypothesis testing; Surveys	Information technology, Competitive advantage, Alignment, Firm performance, Adaptability, Supply chain management, Agility, Blockchain, Production, and operations management	SC alignment, adaptability, and agility	Developed a framework to test the impact of BCT on firm performance and SC parameters; alignment, adaptability, and agility.
(Y. Wang, Han, et al., 2019)	Understanding blockchain technology for future supply chains: a systematic literature	Literature review analysis	Design, Supply-chain management, Impact, Systematic literature review, New technology,	SC practices and policies	Analyzed the drivers, main focus, and challenges for the adoption of BCT in SC.

Author	Title	Methodology	Keywords	Application Area	Contribution
	review and research agenda		Information transparency		
(van Hoek, 2019a)	Developing a framework for considering blockchain pilots in the supply chain – lessons from early industry adopters	Case studies	Blockchain, Technology, Implementation, Supply chain, Logistics services, Framework, Empirical study	Global SC and logistics	Developed an enhanced framework for the mindfulness of BCT.
(Rosanna et al., 2019)	Blockchain technology: implications for operations and supply chain management	Literature review analysis	Technology, Operations management, Supply chain management, SCM practices	OSCM	Identified potential application areas for BCT in OSCM and future research agenda.
(Remko, 2019)	Unblocking the chain – findings from an executive workshop on blockchain in the supply chain	Survey; Executive Workshop	Innovation, Technology, Implementation, Information transparency	Global SC	Explored the BCT adoption rates and levels, the focus areas, the drivers, and barriers to the implementation process.
(Bai & Sarkis, 2020)	A supply chain transparency and sustainability technology appraisal model for blockchain technology	Hesitant fuzzy set; regret theory	blockchain technology; transparency; sustainability; hesitant fuzzy set; regret theory	SC transparency and sustainability	Developed performance measures of the SC transparency and sustainability based on BCT.

Author	Title	Methodology	Keywords	Application Area	Contribution
(Philipp, Prause, & Gerlitz, 2019)	Blockchain And Smart Contracts for Entrepreneurial Collaboration in Maritime Supply Chains	Expert interviews; Case study	Blockchain, Smart Contracts, Maritime Supply Chains, SMEs, Ports, Entrepreneurial Collaboration	Maritime SC, SMEs	Investigated the benefits of BCT smart contracting for the collaboration between SMEs to achieve sustainable maritime SC.
(Sidorov et al., 2019)	Ultralightweight Mutual Authentication RFID Protocol for Blockchain Enabled Supply Chains	Programming and simulation	Blockchain; distributed ledger technology; radio frequency identification.	SCM	Presented ultra-lightweight mutual authentication RFID protocol to create a secure blockchain-based SCM system.
(Fu & Zhu, 2019)	Big Production Enterprise Supply Chain Endogenous Risk Management Based on Blockchain	Programming; simulation; case study	Blockchain, big production enterprise, supply chain, endogenous risk management.	SC risk management, big production enterprises	Constructed model to analyze the risks in big production enterprises SC based on BCT.
(Mondal et al., 2019)	Blockchain Inspired RFID-Based Information Architecture for Food Supply Chain	Programming and simulation	Blockchain, food supply chain (FSC), Internet of Things (IoT), radio frequency identification (RFID)	Food SC	Created architecture for food SC using BCT, IoT, and RFID.
(Salah, Nizamuddin, Jayaraman, & Omar, 2019)	Blockchain-Based Soybean Traceability in Agricultural Supply Chain	Programming	Blockchain, Ethereum, smart contracts, traceability, Soybean,	Agriculture SC (soybean)	Proposed a framework to trace business transactions for the soybean industry based on BCT.

Author	Title	Methodology	Keywords	Application Area	Contribution
			agricultural supply chain, food safety.		
(Xiong, Xiao, Ren, Zheng, & Jiang, 2019)	A Key Protection Scheme Based on Secret Sharing for Blockchain-Based Construction Supply Chain System	Programming; simulation and modeling	Construction supply chain, private key distribution, blockchain, secret sharing.	Construction SC	Proposed a framework for the construction SC based on BCT.
(Manupati et al., 2020)	A blockchain-based approach for a multi-echelon sustainable supply chain	Mixed Integer Non-Linear Programming (MINLP); non dominated sorting genetic algorithm (NSGA-II)	Blockchain; production allocation problem; multi-echelon supply chain; smart contracts; carbon taxation policy; Mixed-integer programming	Multi-echelon sustainable SC	Developed a model for monitoring the SC performance and emissions level based on BCT.
(Nayak & Dhaigude, 2019)	A conceptual model of sustainable supply chain management in small and medium enterprises using blockchain technology	Literature review analysis; multi-criteria decision making; Interpretive Structural Modeling (ISM)	sustainable supply chain management; blockchain technology; triple bottom line; sustainability; supply chain performance; conceptual model	SSCM in small and medium enterprises	Modeled the critical success factors for the SSCM based on BCT.
(Allen, Berg, Davidson,	International policy coordination for	Literature review analysis	blockchain, international policy coordination,	International policy coordination for SC	Highlighted the policy challenges facing the adoption of BCT in SC.

Author	Title	Methodology	Keywords	Application Area	Contribution
Novak, & Potts, 2019)	blockchain supply chains		institutional cryptoeconomics, supply chain governance, trade costs	in the Asia-pacific region	
(Zheng, Zhang, Chen, & Wu, 2019)	Blockchain adoption for information sharing: risk decision-making in spacecraft supply chain	Modelling; theory building	Blockchain technology; spacecraft enterprise; supply chain; risk decision-making	Spacecraft SC, risk decision-making	Developed an analytic model for three-level spacecraft SC adoption of BCT.
(Y. Chang, Iakovou, & Shi, 2020)	Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of the- art, challenges and opportunities	Literature review analysis	supply chain management; logistics; global trade; blockchain; critical synthesis	Global SC and trade operations	Analyzed the current status, opportunities, gaps, and challenges of adopting BCT in the global SC and cross-border trade for governmental agencies and the private sector.
(Dolgui et al., 2020)	Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain	Dynamic control theory; programming and modeling	supply chain dynamics; supply chain design; supply chain engineering; scheduling: flexible flow shop; Industry 4.0; Blockchain; smart contract; cyber-physical supply chain	SCM	Developed a new model for smart contract design in SCM.

Author	Title	Methodology	Keywords	Application Area	Contribution
(Jayaraman, King, & Salah, 2019)	Improving Opportunities in Healthcare Supply Chain Processes via the Internet of Things & Blockchain Technology	Literature review; use case	blockchain; counterfeits; expiration; healthcare; Internet of Things (IoT); supply chain	Healthcare SC	Illustrated the benefits and challenges for the adoption of IoT and BCT in healthcare SC.
(O'Leary, 2019)	Some issues in blockchain for accounting and the supply chain, with an application of distributed databases to virtual organizations	Literature review analysis	Arrow's impossibility theorem; BigchainDB; blockchain; data independence; design science; distributed database; private processes; public processes; semantic models; virtual organizations	SCF and accounting	Designed a "BCT-like" system for virtual organizations.
(Rahmanzadeh, Pishvaee, & Rasouli, 2020)	Integrated innovative product design and supply chain tactical planning within a blockchain platform	Fuzzy mathematical model; fuzzy set theory; case study	open innovation; supply chain management; intellectual property; blockchain; fuzzy methods	SCM	Developed model to integrate open innovation and BCT in the tactical planning of SC.
(S. Kamble, Gunasekaran, & Arha, 2019)	Understanding the Blockchain technology adoption	Hypothesis testing; survey; structural equation modelling	Blockchain technology; technology management; technology	The user perception of BCT in the SC	Developed and validated a model to understand the user perception of BCT in the SC based on three adoption theories: technology

Author	Title	Methodology	Keywords	Application Area	Contribution
	in supply chains-Indian context		acceptance model (TAM); theory of planned behaviour (TPB); technology readiness index (TRI); supply chain management		acceptance model (TAM), technology readiness index (TRI), and theory of planned behavior (TPB).
(Ivanov, Dolgui, & Sokolov, 2019)	The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics	Literature and case studies review and analysis	supply chain dynamics; supply chain risk management; supply chain resilience; supply chain design; supply chain engineering; Industry 4.0; additive manufacturing; blockchain; big data analytics; ripple effect	SCM risk analysis	Analyzed the impact of digitalization on SC disruption risks and the ripple effect.
(Tsang, Choy, Wu, Ho, & Lam, 2019)	Blockchain-Driven IoT for Food Traceability With an Integrated Consensus Mechanism	Case study; fuzzy logic; algorithms building	Food traceability; Internet of Things; blockchain; consensus mechanism; shelf-life management	Food SC	Proposed a blockchain IoT-based food traceability system (BIFTS).

Author	Title	Methodology	Keywords	Application Area	Contribution
(Cui, Dixon, Guin, & Dimase, 2019)	A Blockchain-Based Framework for Supply Chain Provenance	Algorithms building	Internet of Things (IoT); blockchains; cloning; cyber-physical systems (CPS); device identity; edge device; physically unclonable functions (PUF); track and trace	Electronics SC	Developed BCT-based framework to track and trace electronics SC.
(Juma, Shaalan, & Kamel, 2019)	A Survey on Using Blockchain in Trade Supply Chain Solutions	Literature review analysis; case study	Blockchain technology; Dubai customs; distributed ledger; trade supply chain; world customs organization	Trade (international) SC	Analyzed the impact of BCT on the trade SC using Dubai customs case study.
(Wan, Huang, & Holtskog, 2020)	Blockchain-Enabled Information Sharing Within a Supply Chain: A Systematic Literature Review	Literature review analysis	Blockchain; information sharing; smart contract; supply chain management	Information sharing within the SC	Developed a roadmap for the BCT-enabled information sharing within the SC.

APPENDIX B: JOURNALS' STATISTICS

Journal	Count
IEEE Access	16
International Journal of Production Research	13
International Journal of Information Management	11
Supply Chain Management: An International Journal	8
International Journal of Production Economics	5
Transportation Research Part E	5
Computers & Industrial Engineering	3
Resources, Conservation & Recycling	3
Annals of Operations Research	2
Business Horizons	2
Future Generation Computer Systems	2
International Journal of Operations & Production Management	2
International Journal of Physical Distribution & Logistics Management	2
Journal of Cleaner Production	2
Journal of Manufacturing Technology Management	2
Asia & the Pacific Policy Studies	1
Automation in Construction	1
Blockchain in Healthcare Today	1
British Food Journal	1
Chaos, Solitons and Fractals	1
Cluster Computing	1
Cogent Economics & Finance	1
Digital Communications and Networks	1
Engineering, Construction and Architectural Management	1
Enterprise Information Systems	1
Food Control	1
IEEE Engineering Management Review	1
IEEE Internet of Things Journal	1

Journal	Count
Information Systems Management	1
Intelligent Systems in Accounting, Finance and Management	1
International Journal of Computer Integrated Manufacturing	1
International journal of environmental research and public health	1
International Journal of Healthcare Information Systems and Informatics (IJHISI)	1
Internet of Things	1
Journal of Enterprise Information	1
Journal of Information Security and Applications	1
Journal of Purchasing and Supply Management	1
Journal of the Operational Research Society	1
Management Research Review	1
Multimedia Systems	1
Production Planning and Control	1
Review of International Business and Strategy	1
Robotics and Computer Integrated Manufacturing	1
Soft Computing	1
Software Quality Professional	1
Technological Forecasting & Social Change	1
The Journal of the British Blockchain Association	1
Transport and Telecommunication	1
Trends in Analytical Chemistry	1
Trends in Food Science & Technology	1
Worldwide Hospitality and Tourism Themes	1
Total	114

APPENDIX C: DOE RESULTS

MSS	TRT	IAT	COR	MLT	MOPT	SCEM
50	2.0	2	10	0.2	9	19.8
10	0.5	2	10	0.1	3	-571.0
10	0.5	8	20	0.1	9	-173.2
10	2.0	2	20	0.2	9	-1373.5
50	0.5	8	10	0.2	9	-227.0
50	2.0	8	20	0.1	9	-6614.2
50	0.5	8	20	0.2	3	-131.2
10	0.5	8	10	0.1	3	-208.0
50	0.5	2	10	0.2	9	-2.4
50	0.5	8	10	0.1	9	-149.1
50	0.5	8	20	0.1	9	-115.9
10	2.0	2	20	0.1	9	-6639.6
10	2.0	8	10	0.1	3	-9445.0
10	0.5	2	20	0.2	3	-259.3
10	0.5	2	10	0.2	3	-571.0
10	2.0	2	20	0.2	3	-129.3
50	0.5	2	10	0.1	3	-237.7
10	2.0	2	10	0.2	3	12.3
10	2.0	8	20	0.2	9	-66.9
50	2.0	2	10	0.1	3	-10042.3
50	0.5	8	10	0.1	3	-176.3
50	0.5	8	20	0.1	3	-134.1
50	0.5	2	20	0.1	3	-91.7
50	0.5	2	10	0.2	3	-571.0
10	0.5	2	10	0.1	9	-13054.5
50	2.0	8	20	0.2	3	-30.4
10	0.5	8	20	0.2	3	-133.6

MSS	TRT	IAT	COR	MLT	MOPT	SCEM
50	2.0	8	20	0.2	9	-36.7
50	0.5	2	20	0.2	9	-70.0
10	2.0	8	10	0.2	3	-11.2
50	2.0	2	10	0.2	3	12.3
10	2.0	2	10	0.1	3	-11848.6
50	2.0	8	10	0.1	9	-9831.4
50	2.0	8	20	0.1	3	-33.3
10	2.0	2	20	0.1	3	-6620.3
50	0.5	8	10	0.2	3	-254.2
50	2.0	8	10	0.2	3	-8.9
50	0.5	8	20	0.2	9	-70.7
50	2.0	2	20	0.2	3	-127.5
10	0.5	8	10	0.1	9	-180.8
10	0.5	2	20	0.2	9	-963.7
10	2.0	2	10	0.2	9	-3173.8
10	2.0	8	10	0.1	9	-12113.5
10	0.5	8	20	0.1	3	-177.5
10	0.5	2	20	0.1	3	-125.3
50	0.5	2	10	0.1	9	-12086.1
10	0.5	8	20	0.2	9	-74.8
10	0.5	2	20	0.1	9	-6640.0
50	2.0	8	10	0.2	9	8.2
50	2.0	2	20	0.1	3	30.1
50	2.0	8	10	0.1	3	-7435.1
50	2.0	2	20	0.1	9	-6271.4
10	0.5	8	10	0.2	3	-256.5
10	2.0	8	20	0.1	9	-6614.2

MSS	TRT	IAT	COR	MLT	MOPT	SCEM
50	2.0	2	20	0.2	9	-263.0
10	2.0	8	20	0.2	3	-32.8
50	0.5	2	20	0.1	9	-6271.8
50	2.0	2	10	0.1	9	-12085.4
10	2.0	8	10	0.2	9	5.8
10	0.5	8	10	0.2	9	-229.3
10	2.0	8	20	0.1	3	-6218.0
10	0.5	2	10	0.2	9	-103.1
50	0.5	2	20	0.2	3	-258.3
10	2	2	10	0.1	9	-13053.8

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