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"Blockchain Technology and Operations Management: An Implementation Roadmap"

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SUMMARY

FIGURES

TABLES

INTRODUCTION

Academic research on the adoption of Blockchain Technology in the business world is gaining considerable attention during the last few years. This positive trend in the publication of new articles is mainly driven by the increasing awareness of the impacts this cutting-edge technology can have on the development, innovativeness, and survival of companies that need to continuously adapt and evolve in a dynamic and ever-changing environment. In this regard, Blockchain Technology (BT) has extensively been defined as a form of distributed ledger technology that can be successfully applied to different areas where several actors are involved.

Despite the first hype on BT application in the Financial sector with a specific focus on the cryptocurrency area, nowadays it is growing in prominence in other macro-areas, such as the Supply Chain Management (SCM) field. Indeed, given the natural engagement of different parties that need to collaborate and share information with each other, many studies have focused their attention towards the application of this technology on the SCM field. On this matter, several researchers have pointed out that Blockchain-based supply chains are radically changing the way companies do business by transforming SCM through its feature of transparency, authenticity, trust and security, reduction of cost, disintermediation, efficient operations, and reduced waste (Dutta et al., 2020; Mahyuni et al., 2020).

Other studies have focused their attention on the way in which Blockchain can enhance Sustainability throughout the Supply Chan as well as on the identification of the main industrial sectors that can be successfully improved through enhanced visibility and business process management. On this last point, although the awareness of the potential of such technology is spreading across several sectors, the adoption in the specific field of Food Supply Chain (FSC) has gained quick popularity. In fact, many authors refer to the unique strengths of this technology as the main tool that can help companies to enhance the extensively discussed food traceability, food safety, food integrity, food quality, and food delivery.

However, despite the increasing number of studies related to Blockchain applications in the business world, the full potential and possible downsides of this technology are not fully understood yet; especially with respect to Operations Management (OM). Indeed, most of these recent studies focus their attention only on the possible benefits and risks of Blockchain implementation in the specific area of Supply Chain Management, mainly focusing on the radical improvements this technology can bring to the external relationships among different actors. On the contrary, the critical impacts the technology can have on the internal company's operations are not properly understood and addressed, thereby leaving outside a pivotal aspect of the broader Blockchain implementation topic. Additionally, the current literature does not properly address another matter related to how an enterprise should practically approach and transform its operations to implement Blockchain Technology. Indeed, it is not available an implementation roadmap that properly lists and explains the main milestones that constitute the Blockchain implementation journey of an organization. In light of the foregoing, we have built on these considerations to accurately assess the potential impacts Blockchain can exhibit inside an organization as well as develop a comprehensive implementation roadmap.

The present thesis is structured as follows. In the first chapter, we present a general overview on Blockchain Technology, with a specific focus on the definition and description of its main characteristics. This is a pivotal step to get a proper idea on what Blockchain really is, how it functions and what are the main functionalities that make it a cutting-edge technology for business development.

In the second chapter, we carefully address the origins and evolution of Blockchain Technology from the late 80s until the present day. Additionally, we provide more details on the main Blockchain applications, thereby identifying the main industries where this technology is getting considerable attention.

In the third chapter, we describe the bibliometric techniques that are used to execute the literature systematization on Blockchain and Operations Management. Specifically, after searching for the most recent articles by using the BOOLEAN search in Scopus, we perform the following analyses: direct citation analysis, bibliographic coupling analysis, and co-word analysis.

The fourth chapter reports and discusses the results from the literature review performed in the previous section and identifies the main subfields of investigation. This is a pivotal step to properly map and understand the current state of the analyzed research front as well as identify the main gaps in the literature.

In the last chapter, we perform an empirical case study with the aim of investigating two of the previously identified research gaps. Specifically, by analyzing the implementation of Blockchain in the Program Management System (PMS) of a global automotive tier-one supplier, we have tried to fill in the following two gaps: the lack of studies on the impacts of Blockchain inside the organization and the lack of a proper implementation roadmap.

CHAPTER 1 – BLOCKCHAIN TECHNOLOGY

1.1 Introduction

Blockchain is a term that has come to mean different things depending on the person that uses it. For developers, it is a set of protocols and encryption technologies for securely storing data on a distributed network (Yaga et al., 2018); for business and finance, it is a distributed ledger that allows the advent of new cryptocurrencies and the optimization of companies' operations; for technologists, it is the driving force behind the next generation of the Internet; for others, instead, it is a tool for radically reshaping society and economy and taking us into a more decentralized world. Despite these different definitions, Blockchain is currently experiencing rapid evolution and it is playing a fundamental role in our lives as the implications of such technology are truly profound. In fact, for the first time in human history, collaboration and cooperation between organizations and individuals seem possible without the presence of a third-party centralized formal institution. With Blockchain, people can trust each other by transacting in large Peer-to-Peer (P2P) networks where trust is established and granted by protocols, cryptography, and computer codes. Together with this fundamental aspect of trust, this technology grants transparency and traceability, thereby allowing businesses to take advantage of these precious characteristics by applying Blockchain in their domains.

The aim of this chapter is to provide a thorough definition of this disruptive technology, as well as a general description of its main characteristics.

1.2 Blockchain definition and main characteristics

Many authors state that "a Blockchain is an encoded distributed digital ledger, in that it is stored on multiple computers and agreed upon a peer-to-peer (P2P) public or private network. Blockchains are comprised of data records or blocks. As each transaction occurs, it is put into a block. Each block is connected to the one before and after it. Each block is added to the next in an irreversible chain and transactions are blocked together—hence the term 'Blockchain'. Once these blocks are collected in a chain, they cannot be changed or deleted by a single actor. Instead, they are verified and managed using governance protocols, and any conflicts are resolved automatically using established rules" (Tijan et al., 2019; Wang et al., 2018; Yaga et al., 2018). Besides this apparently simple comprehensive definition of Blockchain Technology, the underlying functioning of this technology can instead be challenging to understand since it consists of numerous components that heavily rely on cryptographic primitives (such as cryptographic hash functions, digital signatures, and asymmetric-key cryptography) and distributed systems.

This section will address the main building blocks of this technology to better understand the larger complex system.

1.2.1 Blocks Architecture

In terms of structure, a Blockchain can be seen as a series of blocks of data that are securely chained together. New blocks are formed when the users of the network create new data or wish to update existing data. In this way, they submit candidate transactions (that represent interactions between parties) to the Blockchain network via software, such as desktop or smartphone applications, digital wallets, web services, etc., and then the software sends these transactions to the nodes of the Blockchain network (Yaga et al., 2018). Generally speaking, transactions are used to transfer digital assets as well as data and their validity and authenticity are pivotal. Additionally, when talking about nodes, which are the individual systems within the Blockchain network, we should know that generally, two types of nodes exist: full nodes and lightweight nodes. The former is a node that makes sure that the transactions are valid, in that it contains the data of the entire Blockchain. Among full nodes there are publishing nodes that have the right to publish new blocks and, on the contrary, non-publishing nodes. On the other hand, a lightweight node refers to a node that needs to pass its transactions information to full nodes since it cannot store a copy of the entire Blockchain. Thus, once new transactions have been broadcasted to the nodes of the Blockchain network, they need to wait in a queue until these nodes add them into a block, which is then published in the network.

In particular, transactions are put and stored inside the blocks, thereby becoming one of their main components. On a basic level, these transactions refer to the process in which a Blockchain user sends information (in the form of transaction inputs and outputs, addresses, public keys, etc.) to the Blockchain network. However, to be added by a node inside a block in the first place, these transactions need to be verified to make sure that they are valid, in the sense that each transaction meets the protocol requirements as well as any smart contract requirements (which will be addressed in Section 2.2.2) specific to the blockchain implementation (Yaga et al., 2018). For this reason, among the security methods adopted by Blockchain technology, one that needs to be mentioned is asymmetric-key cryptography, also known as public key cryptography, which allows the transactions to be digitally signed. This system is pivotal to granting cooperation and trust among users in untrustworthy environments given that it is a mechanism used to authenticate transactions (Zheng et al., 2017). It relies on two pairs of keys: a public key and a private key that are mathematically related to each other (Yaga et al., 2018). The former can be openly distributed to the public without compromising the security of the network and it is a long random string of numbers representing an address on the blockchain value. Although we can describe a public key as an address with a size of 65 bytes (Guo & Yu, 2022), we should highlight the fact that the two concepts are not exactly the same. Indeed, an address is an alphanumeric string of characters shorter than a public key, that is derived from the Blockchain network user's public key itself using a cryptographic hash function, along with some additional data such as version number, checksums (Yaga et al., 2018). On the contrary, the private key can be seen as a sort of password with the size of 32 bytes (Guo & Yu, 2022), that allows its owner to access his/her digital assets; it is used to sign the transactions and should be kept in confidentiality to retain its cryptographic protection (Yaga et al., 2018; Zheng et al., 2017).

Making sure that the private key is properly stored is a central factor in Blockchain technology, because if a user loses a private key, then all the digital assets or data that can be accessed with that key are lost too. Thus, the fact that whoever has a private key has complete control over the assets and data associated with it, increases the chance of being a victim of malicious attacks aimed at seizing valuable digital assets extremely interesting for the hacker. For this reason, a participant in a Blockchain network usually uses some special secure hardware as well as a software called a wallet where private keys, public keys, and associated addresses can be safely recorded and stored. Generally speaking, a public key is associated with a private key so that anyone can make an encrypted transaction to the public key address; however, that encrypted transaction can eventually be decrypted only by the user who owns the private key corresponding to that specific public key. Therefore, to make the whole system secure, the private key needs to be maintained private. Alternatively, a transaction can be encrypted by using a private key to prove that who signed that transaction has the access to the private key, and then anyone who has the public key can decrypt the transaction. In both cases, the transaction is said to be digitally signed. Therefore, asymmetric-key cryptography enables users, who do not know and trust one another, to verify and determine the authenticity of transactions while at the same time allowing the transactions to remain public (Yaga et al., 2018). The typical digital signature algorithm used in Blockchains is the Elliptic Curve Digital Signature Algorithm (ECDSA) (Zheng et al., 2017).

Once these transactions have been verified, each node adds and stores them in a specific part of the block they are building. Specifically, as illustrated in Figure 1.1, each block has two main components: a block header and block data. The former contains the so-called metadata which comprises the block number and version, the previous block hash, also known as the parent block hash that is the 256-bit hash value that refers to the previous block, a timestamp, that shows the time of the block creation, the Merkle tree root hash that is the hash value of all the transactions in the block, and a nonce, which will be addressed in Section 1.2.2.1(Golosova

& Romanovs, 2018; Sheth & Dattani, 2019; Yaga et al., 2018; Zheng et al., 2017). The block data, instead, is the one that contains the list of authentic and validated transactions as well as ledger events added to the Blockchain. In this regard, a ledger is defined as a collection of transactions (Yaga et al., 2018). The block size and the size of each transaction determine the maximum number of transactions a block can contain (Zheng et al., 2017).

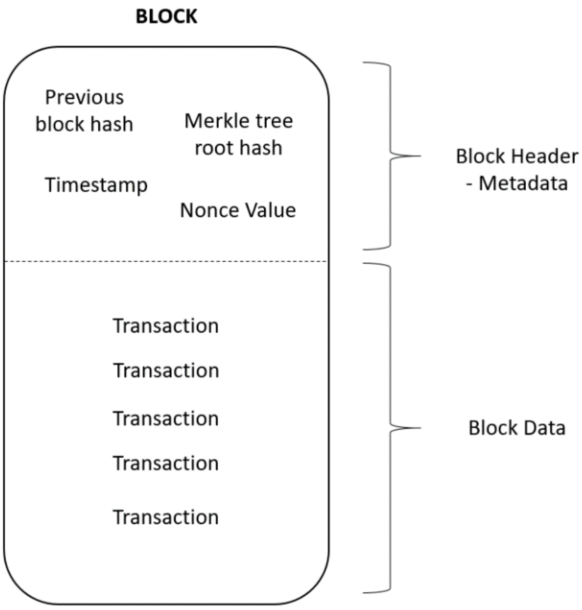

Figure 1.1 – Block structure. Source: adapted from (Sheth & Dattani, 2019).

Once the block has reached its maximum capacity, it is ready to be added to the Blockchain network. However, upon being published, a block is encrypted and a hash value is created, which represents a unique identifier of the data within that block. Hashing is a method of applying a cryptographic hash function to data, which calculates a relatively unique output, called massage digest (or simply digest), for inputs of nearly any size (Yaga et al., 2018). In other words, a standard algorithm compresses the block data (input) into a unique code that is called the hash (output). In many Blockchains, the Secure Hash Algorithm (SHA) is used as the main cryptographic hash function, which compresses the data into a 64-character hexadecimal string (Yaga et al., 2018). In Bitcoin, among the set of cryptographic hash functions, the SHA-256 (which produces a 256-bit - 32 bytes - hash value) is used mainly to verify transactions via the Proof of Work consensus mechanism (Guo & Yu, 2022). For security reasons, the hash value can be calculated from the underlying file but, on the contrary, recreating the data inside the corresponding encrypted block starting from the hash is not possible. This hash function's characteristic of being extremely difficult to revert is called collision resistance (Pilkington, 2016); additionally, different data in different blocks cannot lead to the same hash value. All these characteristics make the Blockchain inevitably safer; thus, the more blocks in the chain, the safer and more reliable the Blockchain (Golosova & Romanovs, 2018). Once the block is encrypted and the hash created, as we will see in more detail in the next section, it is finally published in the Blockchain network.

All blocks of data are securely chained to the previous one. In fact, as illustrated in Figure 1.2, in the block header of each block there is the hash digest of the previous block's header, thus forming the line of blocks that eventually gives the name to the Blockchain. This means that the hash value of the next block depends on the previous one, thereby making it impossible to alter the data in a block without altering the hash of all subsequent ones. In this regard, a block has only one parent block which is the one whose hash is contained in its block header; while, the first ever block of a Blockchain has no parent block and is called the genesis block (Zheng et al., 2017). This hashing and linking of blocks allow the Blockchain to be resistant to data modification, giving the data itself an idea of generally being incorruptible once they are published into the network.

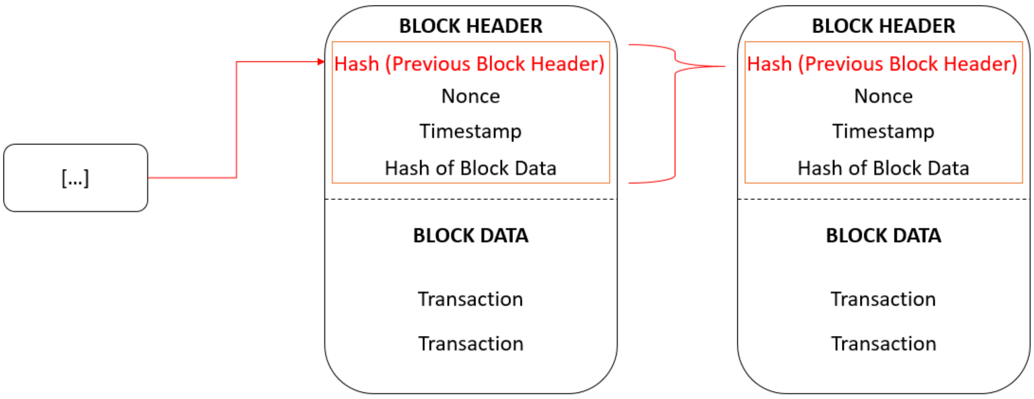

Figure 1.2 - Chain of Blocks. Source: adapted from (Yaga et al., 2018).

1.2.2 Distributed consensus models

One of the main characteristics of Blockchain Technology is the ability to grant and promote trust among users. Although this is obviously the goal, what is important is that each user trusts the system in the first place, rather than the other users. As we already know, the asymmetric-key cryptography system is used to make sure that transactions are valid and reliable, and not fraudulent; in this way, they can be safely put into a block. The next step is to add the finished block into the Blockchain; a process that requires trust and consensus among untrustworthy nodes. As a matter of fact, reaching consensus in distributed environments and networks (such as the Blockchain one) is a difficult challenge since there is no central node that ensures the ledger on distributed nodes to be all the same (Zheng et al., 2017). This challenge is related to the mathematical dilemma called the Byzantine Generals Problem which will be described in more detail in Section 2.2.1. Blockchain technology addresses this dilemma by providing a Byzantine agreement that is defined as “a long-sought means of truth-state updating and trust generation in distributed networks” (Swan, 2016). Specifically, Blockchain technology proposes different asynchronous updating algorithms, that are usually referred to as consensus algorithms. These consensus algorithms are used in a Blockchain system to reach an agreement on the adding process of new blocks as well as to build the system’s trust and store the transactions on the blocks (Guo & Yu, 2022). Hence, these consensus protocols are a set of rules that each participant in the network needs to follow, and are pivotal to guaranteeing that each transaction remains consistent for all nodes (Guo & Yu, 2022; Lim et al., 2021).

Generally speaking, when a user enters a Blockchain network, he/she has to agree to the initial state of the system recorded in the genesis block as well as to the consensus model through which blocks are added to the system (Yaga et al., 2018). With that being said, we should be aware that many consensus algorithms have been developed, such as Proof of Work (POW), Proof of Stake (POS), Proof of Authority, Proof of Elapsed Time (PoET), and many others. We will now explore in more detail the two most common ones: Proof of Work and Proof of Stake.

1.2.2.1 Proof of Work (POW)

First generation Blockchains (addressed in detail in Section 2.2.1) such as Bitcoin, use Proof of Work (POW) as the main consensus model. When two network users are willing to transact, they disclose their transaction to all nodes, each of which records the transaction into a block; once the block has reached its maximum capacity and needs to be published in the Blockchain, all nodes simultaneously perform the Proof of Work consensus model on their block (Ammous, 2016). On a basic level, POW is the algorithm of security (Golosova & Romanovs, 2018), in that it obliges each node willing to publish a block of transactions to perform a lot of work (in terms of computer calculations) to eventually prove that the node is not willing to attack the network (Zheng et al., 2017). Indeed, the publisher needs to solve a computationally intensive puzzle, which entails mathematical operations that are hard to solve but whose solution is easy to verify (Ammous, 2016; Yaga et al., 2018). Generally, the problem to which publishing nodes should find a solution consists of calculating a hash value of their block header that is lower than a target value (Yaga et al., 2018; Zheng et al., 2017). As we know, the block header contains, among other elements, a cryptographic nonce that is defined by Yaga et al., as “an arbitrary number that is only used once” (2018, p. 9). Basically, it is a number that can be combined with the input data of the block to produce different hash digests; thus, by keeping the same data but changing this nonce value, a user can obtain different digest values. With that being said, the publishing nodes should guess a nonce value such that, combined with the transaction data of their blocks, leads to a hash function output that is lower than the target value (Guo & Yu, 2022). This process is computationally intensive as well as expensive in terms of processing power because each publishing node (also called mining node) needs to randomly guess different nonce, through a trial and error approach, until one digest matches the target value, and for each attempt, it has to calculate the hash value for the entire block header.

By adjusting the target value, the difficulty of the problem that needs to be solved can be changed, thereby influencing the frequency of block publication in a way that prevents any entity to take over the block production process. In fact, the lower the target value, the higher the complexity of the computational puzzle and consequently the higher the difficulty of finding the right solution to generate the new block (Pilkington, 2016). By using this highly complex computational system, Blockchain technology can protect its network from the so-called “Sybil Attack”, where an attacker attacks the computer network by creating multiple identities (nodes) to gain influence and gain control over the network (Yaga et al., 2018). With the POW in place, this type of attack becomes almost impossible due to the high cost each node (i.e. false identities) has to sustain. Additionally, to alter the overall system and thus, make the other nodes accept an altered block, an attacker should gain control of at least 51% of the P2P network. Again, this is extremely difficult due to the high costs the POW system asks of its nodes in terms of resources, computer power, and effort consumption.

Despite the mining process being extremely time-consuming, it is also pivotal that the POW is carried on rapidly. Indeed, in this type of consensus model, a reward system (also known as the incentive model) is in place, and it allows the publisher that can solve the problem more rapidly than the others to gain a reward, usually in the form of cryptocurrency. Once a node successfully solves the Proof of Work problem, the solution is distributed to all the other full nodes that need to verify and confirm the correctness of the hash value (Ammous, 2016; Yaga et al., 2018; Zheng et al., 2017). This verification process is way easier than the POW problem-solving process, given that only one hash needs to be done to see if it solves the puzzle (Yaga et al., 2018). Once 51% of the processing power of the network votes to approve the block, each full node adds to its copy of the Blockchain the approved block and sends it again to all their peer nodes; at the same time, nodes begin adding new transactions to a new block (Ammous, 2016). Sometimes publishing nodes may decide to work together, into “pools” or “collectives”, to increase the possibility to find the right solution in a timely fashion; in this way, they split the potential reward (Yaga et al., 2018).

Although very rarely, sometimes different mining nodes might find the right nonce nearly at the same time, thereby generating valid blocks simultaneously. These blocks can almost certainly contain different transactions, thus creating different, but equally valid, versions of the Blockchain. This phenomenon implies the creation of a so-called Fork. To solve these conflicts as rapidly as possible, usually Blockchains follow a specific protocol that does not immediately confirm the transactions to avoid the possibility of having overwritten blocks. Instead, the Blockchain network waits until a new block is published on top of one of the previous blocks, and uses the longer chain as the authentic Blockchain (Buterin, 2014).

1.2.2.2 Proof of Stake (POS)

In performing POW, miners have to spend considerable effort in computer calculations, leading to increased waste of resources such as time, electricity consumption, processing, and hashing power among others. For this reason, a less-intense mining protocol, that goes under the name Proof of Stake (POS), has been developed and can be applied in the Blockchain network as the transaction confirmation mechanism.

This consensus system is based on the concept of stake. A stake is defined by Yaga et al., as "an amount of cryptocurrency that the Blockchain network user has invested into the system" (2018, p. 21). This investment can be done by sending the entire amount to a specific address, or it can be performed using a special wallet software where to hold the cryptocurrency, or otherwise, the investment can be locked utilizing a special transaction. What is important to highlight is that once the investment into the system has been done, the owner of these cryptocurrencies is no longer able to spend them. With that being said, the Proof of Stake mechanism relies on the underlying assumption that the more currencies a user owns and invests, the less likely he/she is to attack the network and therefore, the more willing he/she is to help the system to succeed (Yaga et al., 2018; Zheng et al., 2017). Thus, the POS system does not take into consideration the mining power of publishing nodes (i.e. their hash rates), but instead, looks at the amount of stake owned by a user to choose the block creators; thereby looking at the asset owners in the mining system (Swan, 2016). Indeed, the likelihood of publishing a new block is linked to the ratio of the user stake to the overall Blockchain network amount of staked cryptocurrency (Yaga et al., 2018). Therefore, the more stake a user has, the more likely he/she is to be selected as the next block publisher because when a validator submits its block, the probability that his/her block is chosen is simply the % of his/her network weight. Once the publishing node has been chosen, the creator receives the transaction fees associated with that block; however, if he/she tries to publish an invalid block, he/she will lose his/her stake (Guo & Yu, 2022). As a matter of fact, in the real world, many Blockchains start their journey by adopting a Proof of Work concept but then they gradually shift to a Proof of Stake mechanism; an example is Ethereum 2.0 which has shifted from Ethash (a kind of POW) to Casper (a kind of POS) (Guo & Yu, 2022; Swan, 2016; Zheng et al., 2017).

What is important to highlight is the fact that although miners have a stake in the mining process, they are not necessarily connected in some ways to the transactions, but they just need to validate and publish them (Swan, 2016). The choice of the mining block can be made in different ways, depending on the type of protocols and rules the Blockchain network decides to follow. Some Blockchains, such as Blackcoin, decide to randomly choose the block publisher; this alternative is usually called chain-based proof of stake (Yaga et al., 2018; Zheng et al., 2017). Basically, with this option the technology uses a formula that randomly picks a user with a stake by looking at the users' ratio of stake to the overall amount of cryptocurrency staked; thereby giving a higher chance to be chosen to those who have a higher percentage of the overall amount staked. Another option is called coin age proof of stake, and, for example, it is adopted by Peercoin (Yaga et al., 2018; Zheng et al., 2017). In this system, users with older and larger stakes have a higher probability of being chosen to mine the next block. Indeed, after a certain predetermined amount of time, the user owning the staked cryptocurrency can count to be selected to publish the next block; however, once the new block is published, the age of the staked cryptocurrency is reset and cannot be used again until the requested time has passed (Yaga et al., 2018). Although large users can publish more blocks, with the age reset and the waiting time that miners have to respect, the system impedes these larger users to dominate the network. Another option is referred to as Byzantine fault tolerance proof of stake. Through a multi-round voting system, this alternative tries to give a voice to every staked user. Indeed, in this case, the Blockchain network selects several staked users to create a proposed block, which will be voted on by all staked users. Several voting rounds may be needed before a new block is decided upon (Yaga et al., 2018). Finally, we can also encounter the Delegated proof of stake (DPoS). In this alternative, users can vote for some nodes to become delegates in publishing new blocks. Thus, the nodes that obtain the higher amount of votes become responsible for validating and publishing new blocks. Also in this case, the greater the stake owned by a user, the greater the weight of his/her vote (Guo & Yu, 2022; Yaga et al., 2018).

In light of the foregoing, the Proof of Stake system has several advantages over Proof of Work (Pilkington, 2016). Namely, it allows the Blockchain network to implement a less resource-consuming protocol, thereby reducing all the waste produced by POW; additionally, it potentially fastens up the overall consensus process pivotal for the Blockchain networks. Another important aspect is that POS decreases the likelihood of a 51% attack described in detail in Section 1.4.2. Indeed, although richer users can invest a greater amount of resources in the system, to actually control the entire system they should own at least 51% of the overall amount of cryptocurrencies staked in the entire network; something that is generally considered highly cost-prohibitive.

1.3 Permissionless vs Permissioned and Public vs Private Blockchain

After having analyzed the Blockchain functioning, it is also pivotal to understand the different types of Blockchain Technology that have been developed during the last decades. Nowadays, these different Blockchain networks mainly depend on the permission model and information access they decide to adopt. As previously discussed, the permission model refers to the system and related algorithms used to decide who can publish and validate the information in the Blockchain, while the information access refers to the users that are allowed to access the information on the network. In this regard, we can distinguish between four types of DLT variations: permissionless, permissioned, public, and private Blockchain.

As a matter of fact, permissionless Blockchain networks are decentralized ledger platforms open to anyone to participate in the consensus mechanism, publish as well as validate blocks and transactions, without needing permission from any authority (Yaga et al., 2018). On the other hand, permissioned Blockchain networks are those where a decentralized (or centralized) entity has to authorize users to publish blocks. Thus, in a permissioned ledger, an agreement protocol is used to maintain a shared version of the truth rather than a consensus mechanism (Sarmah, 2018), which is instead used in permissionless networks. In fact, given that in a permissionless Blockchain anyone can publish and validate blocks, the risk of malicious users is greater. For this reason, the consensus mechanism in these types of networks usually promotes non-malicious behavior by rewarding the publishers of protocol-conforming blocks with a native cryptocurrency (Yaga et al., 2018). On the other hand, this is not necessary for the permissioned platforms, since to participate as a member of the Blockchain network a user should be first identified and authorized.

The other distinction we should mention is between public and private Blockchain. Specifically, as it can be easily addressed by the name itself, in a public Blockchain each participant bears a similar set of rights and prerogatives (Ali et al., 2021). Bitcoin is an example of this category. In fact, it is open to anyone to join, and, thanks to the intrinsic nature of the Blockchain that guarantees transparency, everyone can monitor records, thereby making the read access open. On the other hand, a private Blockchain has closed read access. This means that the Blockchain is not open to the public, but only to a group of users or organizations among which the ledger is shared (Sarmah, 2018).

The boundaries between the terms public and permissionless, as well as private and permissioned are thin; thus, they are often used interchangeably. Although it does exist a correlation among these Blockchain types, they are not the same thing. In fact, permissioned and permissionless refer to the limited or open access to validate transactions and data, while private and public focuses more on whether a DLT network limits the read access to the users (Golosova & Romanovs, 2018). In light of the foregoing, we can conclude that all permissionless Blockchains are public, and all private Blockchains are permissioned. As a matter of fact, in a private Blockchain, where the read access is limited to only some users, the validation and publishing access is also logically restricted, thereby leading to a permissioned Blockchain. In the same way, permissionless Blockchain platforms are usually open-source software available to anyone, where every user can decide and has the right to publish blocks. It logically follows that having the right to publish and validate transactions also implies that anyone can read and access the information stored in the Blockchain. However, not all public Blockchains are permissionless. Indeed, some DLT networks can allow all users to join and audit the data on the chain, while at the same time restricting who can validate blocks; these are called permissioned public DLT networks (Vitaris, 2021). In this regard, we should highlight that perfectly fitting every single type of Blockchain into a predetermined definition is extremely difficult, especially with the increasing variety of possible combinations of components and protocols we can encounter. Thus, we should be aware that there are also hybrid Blockchains that lie in between the categories just presented. Specifically, in a hybrid Blockchain (or consortium) some transactions and records are private but can be verified when entailed, for example by giving access through a smart contract. In particular, the validation cannot be performed by every user, instead, only some members have the authority to do so. The other participants, when authorized to access the information, still have an option for validating their transactions before the implementation of the validation (Ali et al., 2021).

1.4 Advantages and Disadvantages

1.4.1 Advantages

The advantages that new and breakthrough technologies can bring to all the areas they touch are pivotal to the continuous expansion of their adoption. For this reason, understanding the main benefits of Blockchain technology is central to better comprehending the rapid success it has had and is continuing to have.

As we already know, Blockchain technology is a decentralized system where every data and transaction recorded in the blocks cannot be changed or deleted and they are made available to every network participant. This definition contains the main advantages Blockchain provides to its adopters. Namely, decentralization, trust, immutability, and transparency.

The first one refers to the underlying structure and ultimate goal of Blockchain, which is the ability to exchange data, assets, and information among participants without the need for a third-party central authority. Indeed, one of the main features of this new technology is the non-dependency on a third party for the security and safety of participants' assets, information, or capital (Ali et al., 2021). This leads us to other two correlated advantages: higher security and faster transactions. Indeed, in a system that includes a centralized entity entitled to oversee any type of transaction, every participant has a private database that is not completely shared with all the other parties involved in a given transaction. Among other things, this implies that there is a higher probability that hackers can get access to data from one of the many private databases, thereby obliging the parties to invest considerable effort, time, and money in developing an appropriate database security. With the adoption of Blockchain technology, instead, all these separated private databases can be substituted with one shared database accessible by all parties. Multiples of copies of this shared database are stored in the Blockchain itself, thereby avoiding the storage of sensitive information only in one place (Sarmah, 2018). Thus, given that the Blockchain network has no central point of failure due to its decentralization, and thanks to its adoption of cryptographic hash functions, asymmetric-key cryptography, distributed consensus models, etc., it can withstand more security attacks (Sarmah, 2018) than a centralized network. Indeed, performing fraud activities becomes more difficult given that an attacker can impact the network only if it can control at least 51% of the nodes (Sarmah, 2018). Additionally, the usage of Merkle trees and hash functions allows the inherent Blockchain data structure to be highly tamper-sensitive, making retrospective manipulations easy to detect (Sedlmeir et al., 2020). Together with this high security provided by the Blockchain, there is the ability to process transactions faster. In fact, if we think about transactions in banking organizations, the time it takes to process and initiate any type of transaction is considerably long. On the other hand, with Blockchain technology, the time spent in processing some financial activities can pass from approximately three days to several minutes or even seconds (Golosova & Romanovs, 2018). Additionally, thanks to the decentralization of the network, it is extremely easy to trace the history of any transaction, since all the transactions in the Blockchain are digitally stamped (Sarmah, 2018).

Another central characteristic of Blockchain technology linked to decentralization is trust. The Blockchain allows users, that do not know and trust each other, to actually work and transact together; all this is possible thanks to the protocols implemented as well as the enhanced security. The trust inside the network inevitably increases with the increase of transactions and records published in the Blockchain, as well as with the presence of another advantage of this technology: immutability. This refers to the fact that once the information, data, or transactions are recorded, validated, and published into the Blockchain, they cannot be changed, thereby making it almost impossible to tamper and modify the data as compared to conventional centralized networks (Sarmah, 2018). This feature increases both security and trust in the decentralized network.

Finally, the last main advantage of Blockchain is transparency. This is particularly true if we think about a public Blockchain where the read access is open to every participant. This means that everyone can check and access all the information recorded, making everything extremely transparent.

1.4.2 Disadvantages

Although highly promising in terms of the advantages the Blockchain can bring to various areas of application, it also has several disadvantages that need to be addressed. The two main interrelated disadvantages are the high energy consumption and the scalability problem.

As we have described while discussing the distributed consensus model in Section 1.2.2, the computational effort and processing power required are extremely high. When looking at Blockchain Technologies that use Proof of Work as a consensus model (such as Bitcoin), we can notice that the total high energy consumption comes from different tasks, some of which contribute more, in terms of percentage related to the overall amount of energy consumed, such as mining (i.e., solving the cryptographic puzzle), while others provide a negligible contribution such as the validation of new blocks, update of local databases, etc. Indeed, during the mining process, publishing nodes have to download up to a few Megabytes of data and perform thousands of hash computations, together with another considerable amount of corresponding computations and database operations (Sedlmeir et al., 2020). In this regard, with a study made in 2020, the authors Sedlmeir, Buhl, Fridgen, and Keller, determined the electricity consumption of Bitcoin to be between 60 and 125 TWh (Terawatt-hour) per year, that is comparable with the annual consumption of countries such as Austria (75 GWh – Gigawatt-hours) and Norway (125 GWh); where 1 TWh is equal to 1 000 GWh. However, although this enormous amount of energy consumed is disproportionate to the network’s technical performance, it is intrinsic in the nature of these POW Blockchains since they were specifically designed to be energy-intensive. In fact, they use this energy consumption characteristic to protect the network from malicious attacks. In this regard, an attacker needs to bear at least 25 to 50% of the total computing power used by publishing nodes for mining (and thus, the same proportion of total energy consumption) to be able to successfully manipulate or control the system (Sedlmeir et al., 2020).

A way to reduce this energy consumption problem can be to rely on different consensus models such as Proof of Stake. In this case, the energy consumed during the mining process is drastically lower, leading to an increase in the weight of the overall energy consumption coming from the so-called redundant operations. The redundancy concept refers to the fact that every transaction is recorded and needs to be processed by every single member of the network, thereby leading to a drastic increase in the network's costs. Hence, in the case of non-POW Blockchains, where this redundancy largely contributes to the overall energy consumption, it is necessary to find a solution that reduces redundant operations in a way that there is a lower need for electrical energy.

Interconnected with this energy consumption disadvantage and the redundancy flaw, there is the scalability problem. Scalability affects all the current existing Blockchains and it is a problem that new advances and research in the Blockchain Technology field are trying to solve. Currently, Bitcoin as well as Ethereum (which will be addressed in the next chapter) among others, have the issue that, since every transaction is recorded and processed by every node in the network, the common transaction ledger starts growing exponentially faster than the number of the network members (Ammous, 2016). This means that, with the increasing popularity and adoption of Blockchain Technology, new transactions are recorded in the network at a constant rate, thereby progressively increasing the size of the network itself. This fact translates into an increase in the computational requirements of the Blockchain and excessive storage and computational burden sustained by each network node. Given that nodes have a certain limited size, they can arrive at the point where they can no longer store the full copy of the Blockchain, thereby compromising the transparency and immutability advantages of this technology (Golosova & Romanovs, 2018). As a matter of fact, if we look at the current size of Bitcoin, it is approximately 250 GB, with an increase of almost 50 GB in the last two years; and by 2030 it can easily reach more than 1 TB in size (Blockchains, 2021). Currently, Bitcoin and Blockchain in general, still have a lower level of transaction volume rather than credit card networks such as Visa. Thus, if the Bitcoin network were to process Visa's 2 000 transactions per second, it would grow by 1 MB per three seconds (1 GB per hour, 8 TB per year) (Buterin, 2014). In the same way, also Ethereum is suffering from the same scalability problem but at a higher level since it is growing at 3x that of Bitcoin and has already crossed 1 TB in size (Blockchains, 2021). Another problem related to the increasing Blockchain size refers to the risk of having a more centralized system (Buterin, 2014; Golosova & Romanovs, 2018). In fact, in the scenario in which the size of the network becomes extremely large, it follows that only a few large nodes will have the capacity to sustain the computational requirements to validate and publish blocks, while all the others will no longer be full nodes. In this circumstance, it becomes easier to witness malicious actions where all the remaining nodes commonly agree to cheat in some profitable ways (Buterin, 2014). With that being said, we can state that there exists a clear trade-off between scale and decentralization (Ammous, 2016). In fact, the more transactions we want to record in the Blockchain, the larger should be the size of the blocks; however, the higher will be the cost of accessing and joining the network, therefore the fewer nodes there will be, thereby leading to a more centralized network (Ammous, 2016). As we will address in the next chapter, future developments in Blockchain 3.0 will aim to circumvent and eventually address this scalability problem that affects both Blockchain 1.0 (such as Bitcoin) and Blockchain 2.0 (such as Ethereum).

1.5 Conclusion

Blockchain can be defined as a peer-to-peer decentralized distributed ledger technology that makes the records of any asset transparent and immutable and works without involving any third-party intermediary. The underlying logic followed by this advanced technology is that almost any type of transaction involving an exchange of value (e.g., information, money, goods, or property) can be conducted securely and efficiently. To do so, Blockchain encrypts the transactions, then distributes them throughout the network, creating a public record that is virtually impossible to hack. This allows for a highly reliable digital system where interactions, transactions and agreements can happen without the need for a single centralized authority.

Blockchain has three main pillars: (1) a network of computers, (2) a network protocol, and (3) a consensus mechanism. The first one is critical for the overall technology functioning because it can include everyone with a computer or a small group of known entities that agree to participate. In this regard, each network participant is called a node. Each node has a copy of the entire ledger and works with other nodes to maintain the ledger's consistency and trustworthiness. The second pillar, network protocol, decides how these nodes communicate with one another; whilst the third one, the consensus mechanism, is the component that ensures trust among the participants. Indeed, it can be seen as a set of rules the network uses to verify each transaction and agree on the current state of the Blockchain.

In light of these critical characteristics, Blockchain Technology is seen as an emerging and revolutionary technology that is attracting a lot of public attention due to its capability to reduce risks as well as increase trust, transparency, and security. For this reason, understanding the basics and fundamentals of Blockchain Technology is imperative and creates foundations for both learning additional complex details and adopting the system into new promising fields.

CHAPTER 2 - BLOCKCHAIN APPLICATIONS

2.1 Introduction

As described in Chapter 1, on its most basic level, Blockchain can be defined as a new class of information technology that combines cryptography with distributed computing, both of which existed for several decades. On this point, despite the fact that Blockchain Technology became popular with the advent of Bitcoin, its evolution began well before and is continuing to evolve even nowadays. In this regard, the aim of this chapter is to explore the origins of this disruptive technology and examine the most important milestones and applications achieved from the late 1980s until the present day.

2.2 History of Blockchain

Unknown to many, is that the core idea behind Blockchain Technology emerged already in the late 1980s and early 1990s (Yaga et al., 2018). Specifically, between 1989 and 1990, Leslie Lamport developed the Paxos protocol and submitted his paper *The Part-Time Parliament* (Lamport, 1998). In this paper, the author aimed to describe how an agreement on a specific result could be achieved among an unreliable network of computers, through this Paxos consensus model (Yaga et al., 2018). At the same time, in a 1991 paper titled *How to Time-Stamp a Digital Document* and published in the Journal of Cryptography (Haber & Stornetta, 1991), physicists Stuart Haber and W. Scott Stornetta described their first work which nowadays is known as “Blockchain”. Specifically, they thoroughly analyzed a cryptographically secured chain of blocks where nobody could alter the timestamps of records. In 1992, they improved their early system by incorporating Merkle trees (also known as binary hash trees), which are a data structure used to efficiently summarize and validate large data sets (Blockchain Council, 2020). This upgrade allowed the authors to enhance the system’s efficiency, thereby enabling the collection of more documents on a single block.

Despite the findings of the previous decades, the term Blockchain gained worldwide relevance only a few years later, in 2008, thanks to the work of Satoshi Nakamoto, who was able to combine these existing discoveries in cryptography and distributed computing in new ways. In fact, he was able to create a system where a network of computers collaborates toward maintaining a shared and secured database. Although Satoshi Nakamoto is recognized as the mastermind behind Blockchain technology, very little is known about him. It has never been clarified whether it is a single individual or a pseudonym used by a larger group of people to protect their identities. Either way, in 2008, Nakamoto worked on and developed Bitcoin, which represents the first real Blockchain conceptualization and application. In 2009, the author published the whitepaper *Bitcoin: A Peer-to-Peer Electronic Cash System* (Nakamoto, 2009) where he explained the potentiality of the technology to enhance digital trust given the decentralization aspect, which implies that nobody can ever be in control of anything. Although this paper defined the blueprint that most modern cryptocurrency schemas follow, over the years this Digital Ledger Technology (DLT) has evolved resulting in new applications in different areas. Indeed, experts realized that thanks to the unique Blockchain characteristics, the underlying technology that operates Bitcoin can be separated from the currency and used for all kinds of inter-organizational cooperation (Gupta, 2017).

In light of the foregoing, to better understand the properties and applications of Blockchain Technology, we have structured the following sections as follows. Section 2.3 will explore and describe the main milestones achieved during the Blockchain evolution. On the other hand, Section 2.4 will focus on the current two main market areas for Blockchain Technology implementations which are intrinsically related to the analyzed milestones.

2.3 Blockchain Milestones

Before addressing the currently most popular Blockchain applications, it is pivotal to dive deeper into its evolution from 2008 onwards. On this point, Melanie Swan, Research Associate at the Centre for Blockchain Technologies at University College London and founder of the Institute for Blockchain Studies, in the book *Blockchain: Blueprint for a New Economy* (Swan, 2015) described three main phases of Blockchain Technology:

- *Blockchain 1.0* which refers to the cryptocurrency phase. Specifically, during this phase, applications of this emerging technology were mainly limited to cash payments, such as digital payment systems and currency transfers.
- *Blockchain 2.0* which refers to the emergence of Smart Contracts. During this phase, applications were mainly focused on certain areas of the financial industry given the ability of the evolved technology to process any type of code in the Blockchain.
- *Blockchain 3.0* refers to the expansion of Blockchain applications to other areas beyond currency, financing, and security markets. Experts realized the potentiality of applying this technology in different areas such as supply chains, manufacturing activities, governments, the health industry, and many others.

In the next sub-sections, we will go into the detail of each one of the last three stages summarized in Figure 2.1.

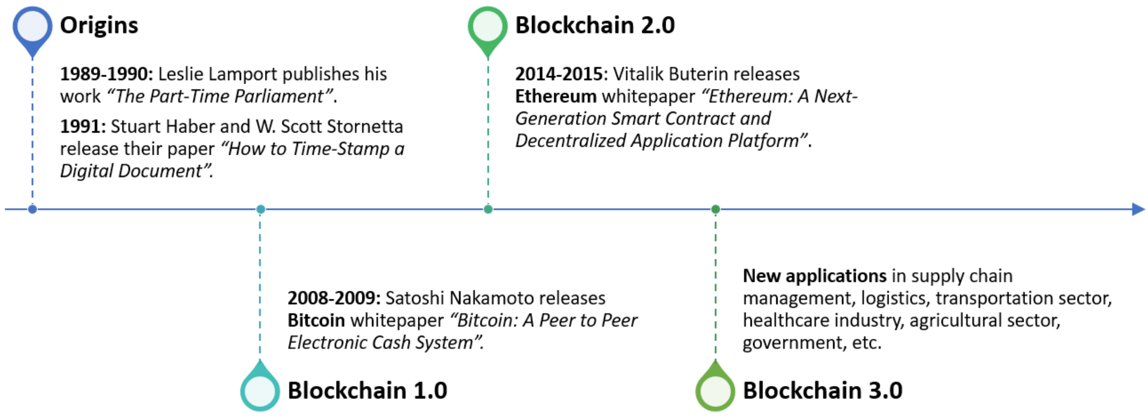

Figure 2.1 – The History of Blockchain Technology. Source: personal elaboration.

2.3.1 Blockchain 1.0: Cryptocurrency

In its first generation (Blockchain 1.0), the core idea behind Blockchain Technology was to create a new solution to tackle problems and limitations of the existing financial system. This was possible in 2008, thanks to the conceptualization of the first Blockchain in the work of Satoshi Nakamoto. The following actual implementation of this idea was in 2009, with the development of Bitcoin as a decentralized peer-to-peer (P2P) online currency that maintains a value without any backing, intrinsic value, or central issuer (Buterin, 2014).

Bitcoin became the first-ever application of the technology as well as the first digital currency to solve two fundamental mathematical problems: the Byzantine Generals problem, and the double spending problem (Chohan, 2021). Specifically, the former is a game theory problem that refers to the difficulties in agreeing on a single value or a certain decision in a decentralized system involving different processors (Lamport et al., 1982; Reischuk, 1985). For a system to exhibit a Byzantine failure there must be a system-level requirement for consensus among the members involved in the network, that needs to work otherwise the complete system will be brought down (Driscoll et al., 2004). Thus, the problem refers to the difficulty encountered in a distributed network to collectively agree on a certain truth without the presence of a trusted central party that can verify the identity of the network's members. On the other hand, the double spending problem refers to the potential flaw in a cryptocurrency or other digital cash scheme, whereby the same digital token can be spent more than once; this is possible because a digital token consists of a digital file, containing a quantified unit of value, that can be duplicated or falsified (Chohan, 2021). The main downside of this problem is the creation of a new amount of copied currencies that were previously inexistent, thereby leading to devaluation of the currency and lower users' trust. Hence, the introduction of a decentralized, distributed, and immutable online record of transactions with the application of Blockchain

Technology had made possible the achievement of the needed transparency and public access to the global financial system. This radical innovation made unnecessary the presence of a trusted authority or central server in charge of verifying the identity of the network's members as well as the authenticity of every token spent.

To better understand how Blockchain 1.0 has been able to solve these problems, we should recall the basic functioning of Blockchain described in Chapter 1. In fact, this technology can be defined as a simple distributed database made of strings of blocks, each one of them containing a record of data (i.e. network transactions) that are validated, added, and distributed by the publishing nodes (also known as miners). This mining process, by relying on a distributed consensus algorithm, is fundamental to guarantee the decentralization of the Blockchain as well as to reach an agreement among users on the transactions' validity. Although nowadays several different consensus models can be applied, as described in Section 1.2.2, Bitcoin and all the applications of Blockchain 1.0 have always relied on the Proof-of-Work (POW) system. By operating in this way, this technology can create a permanent and secure database that is essential to store records and transactions that involve value or that need to represent a secure and trusted source of information. These secured distributed records are called distributed ledgers, which, in the case of Blockchain 1.0, are mainly used to record monetary transactions, thereby allowing users to replace a multiplicity of private databases with one shared database that is trusted and accessible by all the parties involved, from every geographical location. In this way, Blockchain Technology can promote transparency and trust between users without relying on centralized third parties.

2.3.2 Blockchain 2.0: Smart Contracts

The continuous evolution and improvement of Blockchain Technology during the past decades have been possible thanks to the Bitcoin design that has provided valuable inspiration for other applications as well as a relatively large-scale proof-of-concept. This has led, in just a few years, to the emergence of the second generation of Blockchain, which has developed the capacity to execute any computer code on the Blockchain, thereby becoming something more than a secured and distributed database. Blockchain 2.0 has initially focused its new applications on financial services and industries which includes financial assets, options, swamps, and bonds (Sarmah, 2018), while its most important development has been the introduction of Smart Contracts.

In 2014, Vitalik Buterin released a whitepaper titled *Ethereum: A Next-Generation Smart Contract and Decentralized Application Platform* with the intent of focusing on the Proof of Work aspect introduced by Nakamoto and on how the blockchain concept could be applied in other areas other than cryptocurrency. Buterin understood the main limitations of the underline technology of Bitcoin. Namely, the protocol written for Bitcoin was specifically designed to handle only non-complex operations and it was drastically slower and somewhat flawed to a greater extent (Lichtigstein, 2018) thereby compromising its overall adoption. For these reasons, the author developed the concept of Ethereum, an open-source public blockchain-based distributed computing platform with scripting functionality (Lichtigstein, 2018), or to describe it with the words of the author, it is “an open-source platform that intends to provide a Blockchain with a built-in fully fledged Turing-complete programming language that can be used to create "contracts" that can be used to encode arbitrary state transition functions” (Buterin, 2014).

Basically, Vitalik Buterin used Turing-complete programming to design the Ethereum platform, which is a concept from theoretical computer science. On a basic level, Turing completeness tells us how powerful a programming language is in terms of its ability to execute any algorithm or solve any computational problem (irrespectively of the complexity) accomplishable by a computer or system given enough time, instructions, and memory. Thus, to be considered Turing complete, a system should be able to do what the theoretical machine developed by the mathematician Alan Turing (Turing machine) can do (Crypto Wallet, 2021), that is, run any program. In this regard, the underline technology of Bitcoin has been intentionally developed as Turing Incomplete to avoid the emergence of issues due to high computational complexity. On the other hand, Ethereum has been designed by Buterin as a Turing Complete Blockchain to make the technology able to create all kinds of applications and Smart Contracts using a global network of nodes. Indeed, having Turing Complete platforms allows addressing a full class of computing problems, including orchestrating uncertain future events (Swan, 2016). More specifically, in terms of code, the one used in Ethereum contracts is called “Ethereum virtual machine (EVM) code” and is written in a low-level, stack-based bytecode language, where each byte of the code represents an operation (Buterin, 2014). Being a Turing-complete code, the EVM code can encode any computation, including infinite loops. The main difference here with Turing Incomplete codes is the presence of two main factors. Firstly, there is a JUMP instruction that allows the program to jump back to a previous spot in the code; and a JUMPI instruction to do conditional jumping, which entails that the program checks the condition code bits for a status, and if true, it jumps to a designated target (Buterin, 2014). Secondly, the EVM code allows contracts to call other contracts, in a way that a set of instructions is continuously executed until the terminating condition is hit. If this is not the case, then we will have an infinite loop.

The system described in the 2014 whitepaper, was eventually launched in 2015 and has been extremely successful, attracting a large, dedicated, and active community of supporters, developers, and enterprises. It has been pivotal to the development of Blockchain 2.0 since it made possible to increment the capacity of the technology, shifting it from a distributed database supporting Bitcoin to a general public platform able to run dApps (decentralized applications) as well as Smart Contracts. Nowadays, developers have already created many decentralized applications by using Ethereum technology, which allows users to use its facilities in exchange for Ether, the main internal crypto-fuel of Ethereum used to pay transaction fees (Buterin, 2014).

As previously said, one of the central technology innovations of Blockchain 2.0 has been the development of what are called Smart Contracts. This term was coined in 1994 by American computer scientist Nick Szabo, who saw the possibility of applying the decentralized ledger to smart contracts (Sadiku et al., 2018). A smart contract can be defined as a self-executing contract that utilizes Blockchain Technology to digitally enforce, verify, or facilitate the performance or negotiation of a contract (Nzuva, 2019). Therefore, it is a programmable contract that is capable of automatically enforcing itself when pre-defined conditions are met (Sadiku et al., 2018), thus, basically, they are launched and await events or changes in conditions to update their state (Swan, 2016). Thanks to the decentralized system and the transparency granted by Blockchain Technology, these smart contracts can foster transaction credibility between contracting parties without relying on third parties as in the case of traditional contracts. This is possible because the computer code defines as well as executes and enforces the smart contract automatically without discretion. Like algorithms, smart contracts require input value and act only if certain predefined conditions are met, thereby triggering an event on the Blockchain. In this regard, the outcome of the contract can be good only if the input data are trustworthy and reliable. Generally, Blockchain cannot access data outside their network; thus, it requires an input to the system that is a sort of trusted external data feed that is called Oracle. Blockchain oracles are third-party services that send and verify real-world occurrences and submit information to smart contracts, triggering state changes on the Blockchain (Blockchain Council, 2020).

These characteristics of smart contracts allow them to bear and manage any level of complexity, thereby allowing developers and experts to use their architecture to foster the automation economy forward by developing different kinds of autonomous entities (Swan, 2016). Examples of these autonomous entities are DAOs (decentralized autonomous organizations), Dapps (decentralized applications), DACs (decentralized autonomous corporations), DASs (decentralized autonomous societies), and DCOs (distributed collaborative organizations).

2.3.3 Blockchain 3.0: Other applications

The union of smart contracts with digital currencies in the form of Blockchain 2.0, made possible the development of new applications in the financial areas. However, in recent times, experts and developers have realized that cryptocurrencies and the financial sector are just one of the possible implementations of the broader concept of Distributed Ledger Technology (DLT). In fact, distributed ledgers may contain arbitrary information, not necessarily related to money and finance (Di Francesco Maesa & Mori, 2020). This belief has led to the emergence of the third generation of Blockchain (Blockchain 3.0) which refers to the transfer of all the advantages of the technology (such as decentralization, immutability, and transparency described in Section 1.4.1) across various business sectors and industries. For example, in the healthcare industry Blockchain can be adopted to facilitate data sharing and keep track of patients' health conditions after they have been discharged from the hospital (Cole et al., 2019). In the agricultural sector, the technology can be used to enhance food safety and traceability, improve storage and access to different types of data (e.g. seed data, agricultural production data, etc.), as well as facilitate transactions among the several parties involved. In the government sector, Blockchain can be applied to voting systems as well as to provide greater identity verification (Cole et al., 2019). Other applications can be found in the charity sector to promote transparency and traceability of donations, or in the tourist industry, among many others.

Generally speaking, irrespectively to the sector in which the technology is implemented, companies are starting to adopt the Blockchain mainly to benefit from its integration with their logistics systems and supply chains. Indeed, this technology can help organizations to improve supply chain security, accessibility, visibility, and transparency, thereby facilitating inter-organizational transactions and coordinating all the parties involved. However, although with Blockchain 3.0 the underline technology is adopted for other areas other than cryptocurrencies, in practice, these new applications can still benefit from the integration with the crypto world and they are often deployed on a cryptocurrency-based Blockchain such as Ethereum or Bitcoin (Di Francesco Maesa & Mori, 2020).

In addition to expanding the general adoption of Blockchain in areas other than the financial sector, Blockchain 3.0 (as discussed in Section 1.4.2) also aims at surpassing some of the main disadvantages of the previous technology such as scalability and energy consumption. Moreover, experts are trying to develop new solutions characterized by the ability to allow different Blockchains to communicate with each other. In fact, nowadays, many different Blockchain networks are being created without, however, the existence of a protocol that grants interoperability between them. For this reason, three main Blockchain 3.0 projects named Aion, Wanchain, and Polkadot have been launched to provide a mechanism that allows the transfer of data and assets from one Blockchain to the other without needing a centralized third party (Elev8, 2019). Additionally, Blockchain 3.0 developed by companies such as Chainlink, aims to connect information stored and accessible on a Blockchain network to traditional infrastructures.

In light of the foregoing, there is an increasing awareness of the potentiality that the Blockchain can bring to many business sectors by improving transparency, speed, and responsiveness, and by streamlining the relationships among different parties; all of this can be achieved with further development of Blockchain 3.0. On this matter, some of the main applications will be discussed in the next sections where the main market opportunities will be analyzed.

2.4 Key Market Areas for Blockchain Implementation

As discussed in the previous section, it is only recently that enterprises have started realizing the enormous impact Blockchain Technology can have on their business models. Regardless of the type of industry, traditional data systems have a number of challenges that can hinder their overall efficiency. As we already know, these systems are redundant in the sense that many copies of data are separately stored and maintained by several participants, thereby requiring a constant reconciliation of the veridicality and state of these data. On this matter, another limitation consists of the impossibility of knowing where exactly the data came from or how they may have been changed in the past. All this leads to the difficulty in preserving the security of the data, given that the probability of a security breach is proportional to the number of separate databases each entity maintains. In light of these limitations, companies have started understanding the enormous potential that Blockchain has in unlocking the value trapped in the ecosystem. In fact, thanks to its implementation, the value of the roles across each ecosystem radically changes, thus giving the opportunity to cutting-edge enterprises to innovate and develop new products, services, and markets.

This radical change is mainly enabled by four key principles Blockchain provides: provenance and traceability of the data, tamper evidence of tentative change of data, control on what each entity can see and do at a data element level, and security of data through encryption and segregation of the information at a data element level. In this regard, since the emergence of this innovative technology, the most advanced companies have immediately started investing considerable resources in R&D. This activity has demonstrated to be pivotal to allow the technology to improve over time and eventually surpass the limitations it is currently facing. Since 2008, together with this R&D phase, several proof of concepts have been carried out to actually understand the value and overall potential of different implementations to disrupt markets and industries. On this point, the first proof of concpet has been Bitcoin itself, which has gradually improved thanks to the continuous investment in R&D. With the advent of Smart Contracts and more advanced Blockchain networks (such as Ethereum), several entities have started thinking about the potential of bringing BT solutions at scale. On this matter, what is certain is that this continuous evolution and sperimentation on the possible BT applications will eventually lead to the development of new products and services that will radically change the way in which enterprises do business.

This increasing awareness on the real potential of Blockchain Technology is confirmed by some key quantitative figures. Specifically, the global spending on Blockchain solutions is projected to reach 6.6 Billion USD in 2022 (an increase of more than 50% compared to the previous year) and it is expected that this spending will continue to grow in the coming years, reaching almost 19 Billion USD by 2024 (Statista, 2022). In fact, as suggested by the International Data Corporation (IDC) Worldwide Blockchain Spending Guide, Blockchain spending will continue to grow throughout the 2020-2024 forecast period with a five-year compound annual growth rate (CAGR) of 48.0% (IDC Spending Guide, 2021). From an industry perspective, as we can see in Figure 2.2, the Banking Industry leads the way in Blockchain spending, accounting for nearly 30% of the 2021 total. The next two largest industries for Blockchain spending refers to process manufacturing & resources and distributions & services, where each account for more than 20% of all worldwide spending (IDC Spending Guide, 2021).

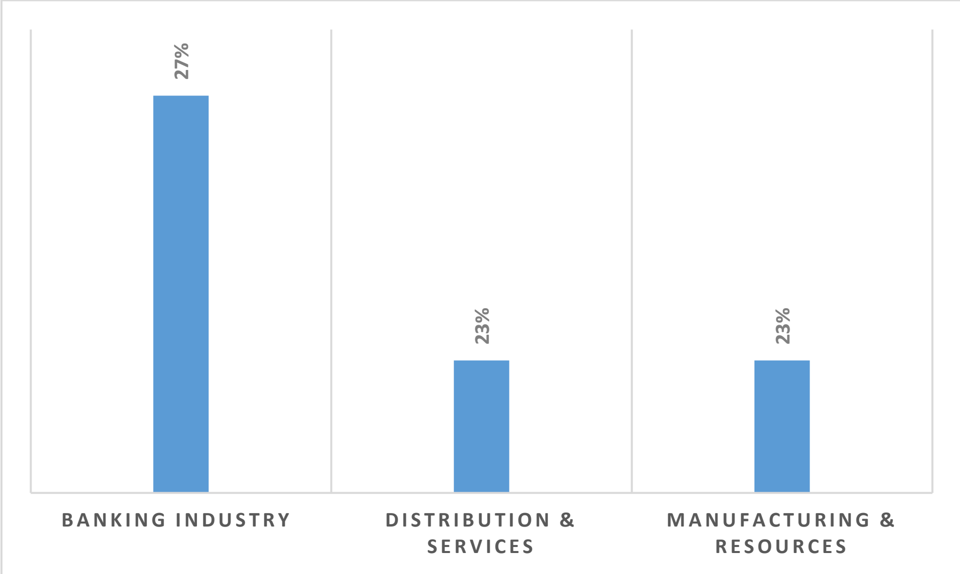

Figure 2.2 – Blockchain Spending: Top 3 Industries. Source: adapted from (IDC Spending Guide, 2021)

The growth in these sectors has been boosted by the COVID-19 pandemic which strengthened the already existing need for more resilient and transparent supply chains, financial services, asset management, and much more. To accomplish this necessity, the new main focus of Blockchain Technology implementations has been on developing tracking systems that can efficiently follow the items from the manufacturer to distribution to the end customer, as well as the related payments and settlements that come with good and currency movements and management (IDC Spending Guide, 2021). In this regard, the following sections will be dedicated to the benefits Blockchain implementations can bring to the general Banking Industry and Supply Chain Management area.

2.4.1 Blockchain and Banking Industry

As previously discussed, Blockchain is a digital collection of transactions that are tracked, recorded, and transparently shared in a decentralized network. Although in 2009 Bitcoin disrupted the financial sector inspiring the development of the hundreds of new cryptocurrencies that we hear about today, the revolution in the Banking Industry is not driven just by the crypto. Rather, it is the understanding of the broader range of Blockchain applications that have driven the transformation in this sector.

Generally speaking, the financial sector faces a range of different problems that can be addressed and eventually solved by this technology. Among others, we should highlight the process inefficiencies due to lengthy manual and paper-based processes, lack of trust, data inaccuracy and security issues, lack of reliable information and transparency on securities, high amount of data reconciliation, and high costs. In this regard, Blockchain can build a new ecosystem where the role of intermediaries and third parties is completely redefined. Indeed, it could allow the development of an automated technology solution for enhanced trust among parties where only one synchronized version of the ledger exists. Additionally, record-keeping is one of the most beneficial applications of Blockchain that can build reliable and error-free record-keeping systems, which eventually allow a quicker and real-time reconciliation process. Finally, Blockchain applied in the Banking Industry leads to capital optimization, cheap access to funds, decreased risk of fraud, and improved contractual performances due to smart contracts (Ravichandran et al., 2022). Hence, this sector can benefit from different use cases of Blockchain, starting from the most common digital currencies, to smart contracts, better customer experience, record keeping, and digital identification.

All these advantages can be seen through a practical example, the so-called Know Your Client (KYC) process. In this case, the Blockchain application can help financial institutions in assessing the identity of their customers and the type of transactions they deal with. The KYC is pivotal to actually preventing fraud and money laundry. Indeed, banks lose 15 to 20 Billion USD annually from identity fraud alone and the global anti-money laundering spending alone exceeded 8 Billion USD in 2017 (Higginson et al., 2019). These negative statistics are mainly due to the fact that the current KYC system is an extremely costly and time-consuming activity as many processes are mostly manual, thereby leaving room for human errors and possible security breaches. Indeed, it relies on the sole ability of a person to identify the right customer and detect possible misleading data provided by the customer itself. For these reasons, Blockchain key strengths (e.g., disintermediation, data handling, and trust) can be the solution for KYC issues. Indeed, the decentralized structure of the technology can eliminate costly steps in the numerous checks institutions need to perform. Furthermore, it lightens the information burden and allows banks to disseminate and share updated data. On this point, as discussed by McKinsey, Blockchain-based solutions may create up to 1 Billion USD of savings in operating costs for retail banks globally, reduce regulatory fines by 2 to 3 Billion USD, and reduce the annual losses from fraud by 7 to 9 Billion USD (Higginson et al., 2019).

2.4.2 Blockchain and Supply Chain Management (SCM)

As previously discussed, Blockchain Technology is currently attracting attention also from experts outside the Banking Industry. Indeed, thanks to its aforementioned characteristics, this technology is set to help organizations in all industries in lowering their costs while improving their performance. In this regard, Supply Chain Management (SCM) is a field that has gained special attention due to the sensible improvements it can gain through Blockchain implementation.

Generally speaking, SCM is defined as the administration of a chain of independent organizations which are directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Agi & Jha, 2022). On this matter, the focus of Blockchain applications in SCM is on allowing a set number of known parties to conduct transactions with one another directly, while improving security and transparency, ensuring contract compliance, and reducing costs (Higgins, 2021). Thus, contrarily to common cryptocurrencies applications where new types of digital coins are created, Blockchain-based supply chains tokenize different transaction-related data to create unique and verifiable identifiers for purchase orders, bills of lading, inventory units, and much more (Higgins, 2021). In this regard, each entity participating in the ecosystem (that is, belonging to the supply chain) has its own unique digital signature, which is pivotal to validating the data moving through the chain. Therefore, every step of a given transaction between different stakeholders is recorded in the shared database (i.e., the Blockchain network), providing a built-in audit trail that cannot be tempered by fraudulent actors (Higgins, 2021). In fact, each participant has its own copy of the chain, meaning that, to fraudulently change some transaction data, the bad actors should find a way to make these untruthful changes to their own chain as well as to subsequent links in the copies maintained by all the other entities in the shared network.

Although this topic will be extensively discussed in the following chapters, it is worth saying that companies willing to apply Blockchain Technology in their supply chains can reach several benefits. Among others, they can observe an increase in their overall efficiency thanks to improved communication and collaboration among parties. In fact, higher transparency and traceability inevitably lead to a reduction in waste, risk, and errors. Additionally, contract compliance contingencies encourage all parties to meet their agreed-upon obligations in a timely, complete and accurate fashion (Higgins, 2021). Another advantage refers to the possibility to trace and verify the origins and journey of materials and goods as well as their destination and who has access to them. All these gains in efficiency and reductions in stock loss and waste are pivotal to saving costs. In fact, Blockchain networks incentivize companies to eliminate paper-based workflows that are one of the main drivers of inefficiency and higher costs. Moreover, the implementation of this technology allows enterprises to integrate it with other critical SCM technologies, such as the Internet of Things (IoT) to further increase visibility, transparency, and accuracy throughout the value chain.

Although still in its infancy, there are some examples of early adopters in different industries that are willing to apply Blockchain Technology to their own supply chains. The two examples we would like to mention are the implementations made by DeBeers and Walmart.

In the first case, back in 2018 DeBeer, a company specializing in diamond mining, exploitation, retail, and trading, decided to use BT to keep track and document the movement of diamonds and other gems from the time they are dug up from the ground (Reiff, 2018). On this point, De Beer, which is the largest diamond producer in the world by value, has a long history of always trying to authenticate diamonds to insure that they do not come from conflict zones or other sources of violence (Reiff, 2018). Thus, to maintain accurate and detailed histories of individual stones, the company has invested and developed this Blockchain diamonds tracking system to assure and strengthen its reputation among its customers.

On the other hand, in August 2017 Walmart, one of the largest retailers in the world with one of the most complex supply chains, announced a Blockchain partnership with IBM and a consortium of food supply chain players (including Nestlé, Unilever, Dole, Kroger, McCormick, Tyson Foods, and others) (Roberts, 2017). These companies has been working together on a food safety Blockchain solution to add transparency to the decentralized food supply ecosystem by digitizing the food supply chain process (Sharma & Kumar, 2021). In this regard, Walmart performed two trials with IBM in which they tracked pork in China and mangos in Mexico by digitalizing on a Blockchain network the food safety processes and product information, thereby creating a single historical record of each product (Roberts, 2017). As a result, these trials were able to reduce the time to track food information from one week to 2.2 seconds (Roberts, 2017; Sharma & Kumar, 2021). This outcome has been extremely important in terms of financial and operational saving for all the participants in the ecosystem, if we think that in USA alone there are over 500 food recalls annually and an annual spend on food safety incidents of 10 to 15 Billion USD (Roberts, 2017).

2.5 Conclusion

Although Blockchain made its public debut in 2009 as the underlying technology at the basis of Bitcoin, it has been a topic of research since the early 90s. In fact, the origins of Blockchain Technology can be traced back to 1991 when the physicist Stuart Haber and cryptographer W. Scott Stornetta released a research paper titled, "*How to time-stamp a digital document*". Since then, it has been extensively studied, thereby leading this technology to evolve over the years from the first version of Blockchain1.0, to the current Blockchain 3.0, passing through Blockchain 2.0. In fact, it shifted from the initial relative simple database structure which aimed at storing documents and hashes, to the today foundation of the new form of 'digital trust', where users across the network can transfer value and information without relying on a central intermediary.

In this regard, this new form of digital trust is currently bringing and will continue to bring disruption across various industries. Indeed, this technology can help improving the ways in which companies work in several fields, thus leading to its progressive adoption in industries where digitization has been previously incorporated. A typical example of Blockchain application is in the Financial sector where many different Blockchain applications has already emerged. Another pivotal field is the Supply Chain and Logistics area, where this technology can radically increase the efficiency of all the entities involved.

CHAPTER 3 - LITERATURE REVIEW ON BLOCKCHAIN AND OPERATIONS

3.1 Introduction

Although concrete and real applications of Blockchain Technology in the business world are still in their infancy, numerous researchers have already started analyzing the possible impacts the technology can have on companies' operations. In this regard, this chapter will focus on the study of the existing literature to better understand the topics already addressed and uncover emerging as well as unstudied trends. Indeed, synthesizing past and current research findings is one of the most important tasks for advancing a particular line of research (Zupic & Čater, 2015) and providing a solid base for a productive empirical study.

In this thesis, two main steps have been performed. Firstly, a descriptive analysis has been carried out to have a general overview of the current state of the literature. Subsequently, a quantitative bibliometric analysis has been addressed to better uncover the recent trends and milestones of the research field. Specifically, by utilizing quantitative bibliometric tools, the literature review aims at minimizing subjectivity in the analysis of the current state of the literature as well as its evolution. The main focus will be on the general interactions between Blockchain Technology and Operations Management (OM), trying to discover and shed light on all the topics touched in the field of OM.

3.2 Method of Analysis

Currently, there exist several alternative ways to carry out a literature review, such as through a qualitative approach in the form of a systematic literature review, a quantitative approach in the form of meta-data, and bibliometric analysis with the science mapping approach (Donthu et al., 2021; Zupic & Čater, 2015). Although each alternative has its advantages and drawbacks, the choice of which approach to use mainly depends on the type of review the researchers want to perform and the goals they want to achieve. For instance, despite the obvious limitations of subjectivity biases derived from the qualitative nature of the research, a systematic literature review can be more appropriate when dealing with a small number of papers (e.g., between tens and low hundreds) (Donthu et al., 2021). On the other hand, meta-data and science mapping allow researchers to analyze a broader dataset and base their findings on quantitative analysis, thereby avoiding subjectivity biases.

For the goals of this thesis, bibliometric analysis has been chosen. In fact, this type of analysis is central to finding insights into the field's structure, social networks, and new emerging trends by analyzing aggregated bibliographic data coming from publication databases (Zupic & Čater, 2015). Thus, by developing structural images of the evolution of the literature in the scientific domain, we can reveal the current structure and dynamics as well as the future research avenues of the studies addressing Blockchain and Operations Management.

Bibliometric techniques are used for two pivotal and interrelated analyses: performance analysis and science mapping (Donthu et al., 2021; Gutiérrez-Salcedo et al., 2018; Zupic & Čater, 2015). The former is mainly a descriptive analysis useful to evaluate and present the performance of individual authors, institutions, journals, and countries by using qualitative and quantitative indicators. On this matter, the performance analysis uses as a point of reference the publication metric as a proxy for productivity (such as the total number of published papers), while the citation as a proxy for measuring the impact and degree of influence (such as the total number of citations or the average number of citation per paper, among others) (Donthu et al., 2021; Gutiérrez-Salcedo et al., 2018). Nonetheless, although this performance analysis is pivotal in a bibliometric literature review, due to its nature of being merely descriptive, it is also used in reviews that do not engage in science mapping. For this reason, science mapping represents the real heart of the bibliometric approach.

Science mapping aims to reveal the hidden key structure and dynamics of scientific fields by examining the relationships between research constituents (Donthu et al., 2021; Zupic & Čater, 2015). In fact, this analysis dives deeper into the intellectual interactions and structural connections, providing a spatial representation of the interrelations among disciplines, fields, documents, authors, journals, and countries (Cobo et al., 2011; Donthu et al., 2021; Small, 1999). On this point, the main bibliometric techniques are direct citation analysis, co-citation analysis, bibliographical coupling, co-word analysis, and co-authorship analysis. Table 3.1 summarizes all these five main bibliometric tools and their characteristics. In this thesis, direct citation analysis, bibliographic coupling, and co-word analysis have been carried out, leaving out the co-citation analysis and co-authorship analysis. This choice is in line with the final goal of the report, that is to provide a review of the present (bibliographic coupling) and future (co-word analysis) of the research field with a large bibliographic corpus (Donthu et al., 2021).

Technique	***Description***	***Units of analysis***	***Data requirements***
Direct citation analysis	*"Paper A directly cites paper B".* Used to identify the most influential publications, authors, or journals by looking at citation rates.	Documents Authors Journals	Author name Citations Title Journals DOI (Digital Object Identifier) References
Co-citation analysis	*"Both papers A and B are cited in the same article C".* Used to display the connections among documents, authors, or journals that are jointly cited to discover the main themes in a scientific domain.	Documents Authors Journals	References
Bibliographic coupling	*"Both papers A and B cite the same paper C".* Used to shed light on the development of themes in the research field by looking at the number of shared references.	Documents Authors Journals	Author name Title Journals DOI (Digital Object Identifier) References
Co-word analysis	Used to analyze and discover the connections among themes and topics by looking at keywords that appear in the same title, abstract, keyword list or written content of the publication.	Words	Title Abstract Author Keywords Index Full text
Co-authorship analysis	Used to show the social interactions or relationships among authors and the impact of their collaborations on the research field.	Authors Affiliations	Author Affiliation (institution and country)

Table 3.1 - Summary of the main bibliometric techniques. Source: adapted from (Cobo et al., 2011; Donthu et al., 2021; Zupic & Čater, 2015).

As shown in Table 3.1, to properly carry out the bibliometric analyses, researchers should decide among different possible units of analysis. The most common ones are authors, documents, cited references, descriptive words, and journals. Once the units of analysis have been decided, the relation among them can be represented as a graph or network, where the units are the nodes and the relations are the edges that link together the nodes (Cobo et al., 2011). In this regard, depending on the choice of the units and the corresponding represented relationships among them, different bibliometric networks can be built (Cobo et al., 2011). Specifically, three kinds of networks can be identified: collaboration networks, conceptual networks, and publication citation networks (Gutiérrez-Salcedo et al., 2018). Table 3.2 provides a description of these networks. Despite the fact that all three networks are equally important, in this thesis, only the conceptual and publication citation networks will be addressed. This is in line with the decision just described to not perform the co-citation and co-authorship analyses.

Collaboration Networks	Conceptual Networks	Publication Citation Networks
Used to shed light on the relationships among authors or institutions in a scientific field. An example is the co-author network, where hidden or regular groups of authors, relevant institutions, etc. can be discovered. In this case, the units of analysis are the authors.	Used to show the relationships between words and/or concepts that are found together in different documents. It is also called "co-words network" and is pivotal to shed light on the topics already addressed by the literature, its evolution, and possible future trends. In this case, the units of analysis are words.	Used to discover relationships among publications. The meaning of these relations strictly depends on whether a co-citation, direct citation or bibliographic coupling analysis is performed.

Table 3.2 – Description of the three bibliometric networks. Source: adapted from (Gutiérrez-Salcedo et al., 2018).

Once the desired network has been created by using the relationships among the selected units of analysis, the mapping step begins. This phase is essential in science mapping and consists of applying a mapping algorithm to the whole network to eventually build the desired map (Cobo et al., 2011). In this regard, it is worth mentioning that the type of map and information that can be extracted depend on the techniques researchers decide to apply. To actually build an understandable and useful map, it is necessary to transform the network into a low-dimension space (usually two-dimensions); thus, dimensionally reduction techniques such as the Principal Component Analysis (PCA) should be applied (Cobo et al., 2011).

Figure 3.1 illustrates the overall framework utilized in this thesis, to have a comprehensive overview of the bibliometric literature review main steps.

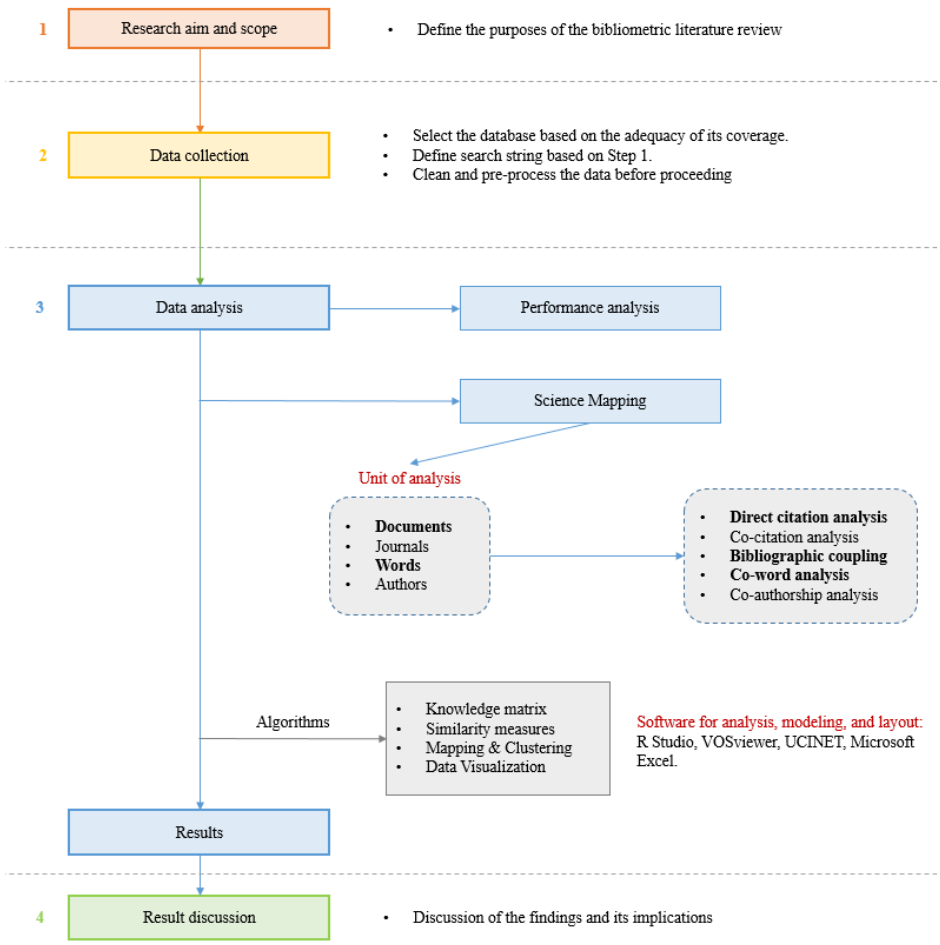

Figure 3.1 – Summary of the bibliometric analysis framework. Source: adapted from (Donthu et al., 2021; Li et al., 2021).

3.3 Research Scope and Data Collection

As previously discussed, the main goal of our literature review is to provide a comprehensive overview of the present and future status of the research field that addresses Blockchain and Operations Management together. With this objective in mind, the next step refers to the choice of the right database from which to collect the data required for the bibliometric analyses selected before (i.e., direct citation, bibliographic coupling, and co-word analysis). In this regard, as stated by Bosman et. al (2006), the value of a database should be measured in terms of functionality, ease of use, and coverage. For this reason, among several alternatives, the Scopus database has been chosen as the right source of bibliographic data. In fact, launched in 2004 by Elsevier, this multidisciplinary database positions itself as a direct rival of Web of Science (WOS) from Thomson-ISI, outperforming it in terms of coverage over scientific domains (Bosman et al., 2006). Additionally, when looking at the citation and reference data available on Scopus, Web of Science, and Google Scholar, the result is still in favor of the Scopus database. Indeed, the difference between the citation data coverage of

Scopus and Google Scholar is substantially wide, while when compared with WOS an overlap between 80 and 90% has been found (Bosman et al., 2006). Although minimal, this difference allows researchers to perform a more accurate bibliographic coupling using Scopus rather than WOS or other databases (Zupic & Čater, 2015).

To develop a comprehensive research of all the documents and publications that simultaneously address Blockchain and Operations Management, a search string has been constructed. In this regard, given the large number of different topics the general Operations Management discipline encloses, several keywords related to these many facets have been selected after reviewing the Operations Management book published by Professors Nigel Slack and Alistair Brandon-Jones in 2019 (Slack & Brandon-Jones, 2019). The research string was then created using Boolean operators AND/OR with the main goal of combining the keywords "Blockchain Technology" and "Distributed Ledger" with "Operations management", "Capacity planning", "Inventory control", "Materials planning", "Production scheduling", "Warehouse management", "MRP", "ERP", "Supply Chain", "Logistics", "Lean", "Lean manufacturing", and "Just in Time". This string has been used to search for all the combinations of these terms that could be found in the articles title, abstract, and keyword sections.

As discussed in Section 2.2.3, the development of new applications of Blockchain Technology in business areas, other than cryptocurrencies and the financial sector, has started being studied only recently. This phenomenon is confirmed by the fact that, in the Scopus database, the first document available on Blockchain and Operations Management dates back only to 2016. However, although the researchers started studying the application of Blockchain Technology on OM only six years ago, the number of documents published in such a relatively short period of time is impressive. For this reason, 2020 has been identified as the starting point of our literature review, so that all the relevant documents from that specific remarkable date until the present year have been collected. This year has been chosen by virtue of the fact that in that period an excellent bibliometric literature review has been published by researchers Musigmann, Von der Gracht, and Hartmann (2020). In fact, as stated by the researchers themselves, prior to 2020 a thorough bibliometric and co-citation network analysis of the Blockchain applications on Operations Management and, more specifically, on Supply Chain Management and Logistics had not been carried out. Thus, thanks to the results these authors achieved, this article represents an easy-to-access entry point for academics and practitioners into this recent and innovative topic (Musigmann et al., 2020). Specifically, they analyzed 613 articles from 2016 to January 2020 and classified the existing literature into five different research clusters, namely theoretical sense-making, conceptualizing and testing Blockchain applications, framing BCT (Blockchain Technology) into supply chains, the technical design of BCT applications for real-world LSCM (Logistics and Supply Chain Management) applications, and the role of BCT within digital supply chains (Musigmann et al., 2020). However, as we can intuitively guess from the title itself *Blockchain Technology in Logistics and Supply Chain Management – A Bibliometric Literature Review from 2016 to 2020*, this article focuses its bibliometric analysis on a specific field of the more general Operations Management topic. Although this can be a problem when studying an already extensively examined scientific field, it is not the case when addressing Blockchain applications. In fact, between 2016 and 2017 no document addressing both Blockchain and Operations Management (categorically excluding Supply Chain Management and Logistics) has been published, whilst between 2018 and 2019 only one article has been published in this domain. In fact, the only publication before 2020 that does not even touch the Supply Chain Management or Logistics topics is the one published by Gomaa et al. (2019). However, this article, published in the *Journal of Emerging Technologies in Accounting*, mainly focuses on the impacts that Blockchain can bring from an accounting transaction execution and tax implication point of view. Thus, we believe that the exclusion of this, although valuable, document, and the consequent utilization of the Musigmann et al. (2020) article as the starting point of our analysis, will not hinder the results presented in this thesis. Therefore, all the publications on Blockchain and Operations Management published between 2020 and July 2022 have been taken into consideration.

Once the first broad results have been obtained, the next step consisted of the reduction of the number of articles by limiting the research to the documents in the final stage of publication, written exclusively in English and that have been included in the "Business, Management, and Accounting" category. Finally, all the information related to the final set of articles has been exported using different formats, such as the RIS (Research Information Systems) format and .CSV (Comma Separate Value) format, to allow other software used during the bibliometric analyses to deploy these data as input.

3.4 Performance Analysis

Before engaging in a quantitative analysis of the articles' sample exported from Scopus, it is a standard practice to engage in a descriptive analysis of the main publications' characteristics. In fact, as addressed in Section 3.2, the starting point of any literature review, and especially of a bibliometric literature review, is the performance analysis. Table 3.3 summarizes some of the various descriptive techniques that can be carried out while performing a bibliometric performance analysis.

Publication-related metrics	Citation-related metrics	Citation-and-publication metrics
Total publications (TP) Number of contributing authors (NCA) Sole-authored publications (SA) Co-authored publications (CA) Number of active years of publication (NAY) Productivity per active year of publication (PAY)	Total citations (TC) Average citations (AC)	Collaboration index (CI) Collaboration coefficient (CC) Number of cited publications (NCP) Proportion of cited publications (PCP) Citations per cited publications (CCP) *h*-index (*h*) *g*-index (*g*) *i*-index (*i*-10, *i*-100, *i*-200)

Table 3.3 – Performance analysis tools. Source: adapted from (Donthu et al., 2021).

In this thesis, to perform some of the numerous tools listed in Table 3.3, R Studio 4.2.1 has been deployed. Specifically, the exported .CSV file has been firstly converted into a bibliographic data frame readable by the software using the following functions:

```
> library(bibliometrix)
> myfile <- ("C:/Users/Laura/scopus.csv")
> M <- convert2df(file = myfile, dbsource = "scopus", format = "csv")
```

By using the *convert2df* formula, the software has been able to create a bibliographic data frame with cases corresponding to manuscripts and variables to Field Tag in the original export file (Aria & Cuccurullo, 2017). Once the data frame has been created, the main bibliometric measures have been calculated by using the function *biblioAnalysis*:

```
> results <- biblioAnalysis(M, sep = ";")
```

This string returns an object of class “bibliometrix”, which is a list containing several information, such as the total number of manuscripts, the authors’ frequency distribution, the list of manuscripts sorted by citations, the intra-country (SCP) and inter-country (MCP) collaboration indices, the number of times each manuscript has been cited (TC), and many others.

To actually be able to organize and study all these information, the generic function *summary* has been applied to the results obtained with the *biblioAnalysis* string; where *k* refers to a formatting value that indicates the number of top articles, authors, or journals we want to see and display, while *pause* is a logical value (TRUE or FALSE) used to decide whether to pause the screen scrolling (Aria & Cuccurullo, 2017).

```
> results <- biblioAnalysis(M, sep = ";")
> options(width=100)
> S <- summary(object = results, k = 10, pause = FALSE)
```

By doing so, we have been able to see the summary of several indicators, such as the total number of published papers, which has been then plotted by using the following function:

```
> plot(x = results, k = 10, pause = FALSE)
```

Additionally, through the same *summary* function, we have been able to calculate the authors' productivity and collaboration indexes. However, to better understand the collaborations between authors belonging to different countries a two-steps analysis has been performed. Firstly, by using VOSviewer, we have been able to create a global map where the distribution of documents' publications has been displayed. Subsequently, another R Studio function has been used to analyze the actual collaboration between countries:

```
> M <- metaTagExtraction(M, Field = "AU_CO", sep = ";")
> NetMatrix <- biblioNetwork(M, analysis = "collaboration", network = "coun
tries", sep = ";")
> net=networkPlot(NetMatrix, n = dim(NetMatrix)[1], Title = "Country Collab
oration", type = "circle", size=TRUE, remove.multiple=FALSE,labelsize=0.7,c
luster="none")
```

In this regard, the first two lines have been necessary to actually create the country collaboration network, while the third line has been essential to plot and graphically visualize the network._Furthermore, the relationship between the most influential papers and their geographical location has been explored by putting together the previous global map with the number of citations. Finally, the assessment of the main source titles of the sample's documents has been addressed.

3.5 Science Mapping

3.5.1 Direct Citation Analysis

The next step of a bibliometric literature review consists of the science mapping process, starting with the direct citation analysis. Specifically, direct citation represents a simple tool that enables scholars to understand which are the most cited and thus, the most influential studies (or authors, journals, etc.) in the examined scientific field. Basically, according to this analysis, two articles are linked to one another if one, say paper A, directly references the other document, say paper B. In this regard, the more an article is directly cited by other publications, the more it is considered to be central in the research field. Thus, given that the impact of a publication is determined by the number of citations it receives (Donthu et al., 2021), it can be concluded that this analysis uses citation data as a proxy for influence (Zupic & Čater, 2015). However, although useful to provide a list of the most important articles, this simple analysis lacks the ability to provide additional information to researchers, such as possible networks of interconnections among papers, authors, and other dimensions (Zupic & Čater, 2015). In fact, it shows the direct citing relationships between articles, without creating the connection based on third party papers (Li et al., 2021). For this reason, this tool should go hand-in-hand with other bibliometric analyses, such as the bibliographic coupling. Figure 3.2 provides an example of direct citation clustering.

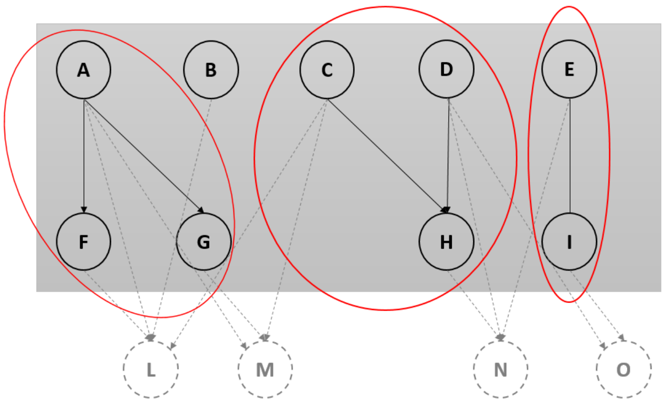

Figure 3.2 – Example of direct citation clustering. The gray box represents the documents within a dataset (A, B, C, D, E, F, G, H, I), while documents L, M, N, and O are publications outside the set that are cited by documents within the set. Solid arrows represent citations within the set, while dashed arrows represent citations to documents outside the set. Red ovals show how the documents might be clustered. Source: adapted from (Boyack & Klavans, 2010).

In practice, the direct citation analysis has been carried out using the software R Studio 4.2.1. Specifically, the *citations* function has been used to generate the frequency of the most cited articles:

```
> CR <- citations(M, field = "article", sep = ";")
> cbind(CR$Cited[1:10])
```

In this regard, *CR* refers to the column in the data frame where the cited references are stored in a single string. The main goal of this first function is to find the articles that have been cited the most by the documents belonging to the sample analyzed. This implies that the outcome of this analysis may contain publications that do not belong to our sample of articles but that are still frequently cited by them. Thus, to actually calculate the most cited articles inside the sample, the R Studio *localCitations* function has been used:

```
> CR <- localCitations(M, sep = ";")
> CR$Papers[1:10,]
```

3.5.2 Co-Citation Analysis

Co-citation analysis is defined as the frequency with which two documents of earlier literature are cited together by the later literature (Small, 1973). As a matter of fact, this analysis uses citation data as a proxy for similarity among publications. Even though in this thesis the co-citation analysis will not be carried out, it is worth explaining in more detail the reasoning why it has been left out. Generally speaking, researchers can perform a document co-citation analysis, an author co-citation analysis, or a journal co-citation analysis following the same process. Indeed, a co-citation analysis of any type relies on the same assumption that the more two items are cited together, the more likely it is that their contents are related (Zupic & Čater, 2015). Focusing now on the document co-citation analysis, we can say that its main goal is to help researchers in identifying the intellectual structure of a research field by revealing its underlying themes, thereby providing an excellent picture of the past status and main milestones of the research field (Donthu et al., 2021). To do so, a co-citation network needs to be created. This process follows a rigorous grouping principle based on cited publications and it is performed by subject-matter experts who cite publications they deem valuable and/or interesting (Donthu et al., 2021; Zupic & Čater, 2015). In this way, documents are connected to each other depending on the way writers use them, thereby making the co-citation a relationship established by the authors themselves (Small, 1973). During this clustering process, thematic subgroups containing similar works (i.e., topically coherent clusters) are created (Boyack & Klavans, 2010; Donthu et al., 2021), thus allowing researchers to easily identify the intellectual structure of the research field.

The structure of the network is not static but instead changes over time following the evolution of the scientific domain (Small, 1973). Additionally, when two papers are frequently co-cited, it means that they are also individually highly cited as well (Small, 1973). Thus, by relying only on highly-cited publications, co-citation analysis helps researchers to use objectivity to better understand the relationships among these different key ideas proposed by the most influential articles in the literature (Donthu et al., 2021; Small, 1973). However, this also implies that recent and niche papers are discarded from this analysis since the strength of the connections among publications depends on the number of authors that cite these two previous works together; that is, new and more specific studies are left out of the thematic clusters because they need time to gather citations from other researchers (Boyack & Klavans, 2010; Donthu et al., 2021). For this reason, co-citation analysis is better suited for analyzing the past structure and evolution of a well-developed and extensively studied research field. On the contrarily, the topic studied in this thesis is extremely recent and the time span analyzed is too short to allow the co-citation analysis to bring a valuable contribution to our literature review. For this reason, to successfully achieve the final goal of this thesis that is the analysis of the current and future state of the research front, we have eventually decided to leave this analysis out of our scope and focus the attention on the Bibliographic Coupling. In fact, while co-citation could be better to map older papers, the bibliographic coupling should be used to map a current research front (Small, 1999), thus providing an excellent representation of the present status of the research field (Donthu et al., 2021). Additionally, given that different authors sustain that BC is better than co-citation analysis in representing a research front (Boyack & Klavans, 2010; Zupic & Čater, 2015), we have decided to follow this trend in the literature.

3.5.3 Bibliographic Coupling (BC)

Bibliographic coupling (BC) is another science mapping analysis that connects together publications (or other units of analysis) that reference the same set of cited documents (Boyack & Klavans, 2010). Despite the evident difference with co-citation analysis, also bibliographic coupling relies on the assumption that two publications sharing common references are similar in their content (Donthu et al., 2021; Zupic & Čater, 2015). As a matter of fact, the BC's grouping process creates thematically coherent clusters by looking at the shared references (e.g., citing references - CR), thereby making recent and niche documents more visible and likely to be included in a cluster (Donthu et al., 2021). In fact, very recent papers are usually easily put together while only a few older documents are included in the clusters (Boyack & Klavans, 2010). In this regard, contrarily to co-citation relatedness that develops over time according to the evolving citation patterns, the shared references among publications are static, thereby making bibliographic coupling pivotal to analyzing all the topics of current literature and its latest developments (Li et al., 2021). Figure 3.3 provides a graphical representation of the BC's grouping process.

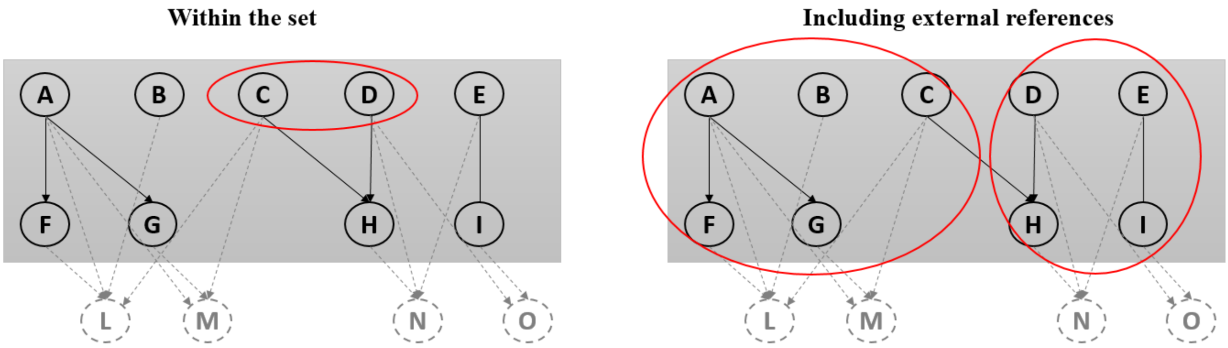

Figure 3.3 – Example of bibliographic coupling clustering. The gray box represents the documents within a dataset (A, B, C, D, E, F, G, H, I), while documents L, M, N, and O are publications outside the set that are cited by documents within the set. Solid arrows represent citations within the set, while dashed arrows represent citations to documents outside the set. Red ovals show how the documents might be clustered. Source: adapted from (Boyack & Klavans, 2010).

Before diving deeper into the several practical steps performed, some activities needed to be done to prepare the input data for the analysis. Specifically, a concrete bibliographic coupling network (under the form of a raw matrix) has been generated. Generally speaking, a coupling network can be created by using the following formula:

$$B = A * A^T$$

Where A is a bipartite network and B a symmetrical matrix $B = B^T$ (Aria & Cuccurullo, 2017). In this regard, inside the matrix, elements b_{ij} give us the idea of the number of bibliographic couplings that exist between papers i and j, that is the number of common references between each pair of publications. The strength of the coupling between the two items analyzed depends only on how high the number b_{ij} in matrix B is. In practice, a square symmetric raw matrix has been performed using Microsoft Excel, where the number of references shared between each pair of publications analyzed has been reported. By doing so, we have been able to get a first understanding on the actual similarity between papers. Indeed, the higher the number of common references, the more alike the publications. In this regard, it is worth highlighting that the diagonal cells have been filled in with a b_{ij} equal to zero, since it would not have made any sense to perform the bibliographic coupling of a paper with itself. This raw matrix has been eventually deployed as the input for the next mapping process step.

Generally speaking, to practically build the map of the network, researchers need to detect thematic clusters in the analyzed literature to eventually perform statistical analyses over the generated map as well as to make sense of the nature of the major clusters, thereby extracting useful knowledge from the underlying research field (Chen, 2017; Cobo et al., 2011; Donthu et al., 2021). On this matter, to detect the communities inside the network and split them into different subnetworks, several clustering algorithms can be used (Cobo et al., 2011). However, irrespectively to the algorithm used, the goal remains always the same; that is, to find clusters in which the publications inside them are similar to one another (the intra-cluster distances are minimized) and different from the publications in other groups (the inter-cluster distances are maximized). As stated before, in the specific case of a BC analysis, the similarity among units is detected by looking at the references of each publication. In this thesis, we have performed a three-step Bibliographic Coupling analysis: preliminary BC, Hierarchical Clustering Analysis (HCA), and Principal Component Analysis (PCA). To do so, two main software have been used: VOSviewer and UCINET 6.528.

During the first preliminary phase, VOSviewer has been deployed to have a first general overview of the current state of the literature. In fact, it has been defined as the ideal software for creating maps based on network data as well as visualizing and exploring these maps (van Eck & Waltman, 2017). In practice, the .CSV file exported from Scopus has been used as input for the software, which has eventually plotted the BC network. To arrive at this result, as suggested by van Eck & Waltman (2014), the fractional counting method has been chosen to reduce the impact that highly cited papers with a long list of references can have on our analysis. In this regard, the distinction between full counting and fractional counting is pivotal to better understand the logic behind the displayed network. Specifically, while with the full counting each link that connects two units has a full weight of one (Perianes-Rodriguez et al., 2016), with the fractional counting each citation is inversely weighted by the length of the reference list of the citing article (Small, 1999). After having plotted the bibliographic coupling network by using VOSviewer, UCINET has been deployed to perform the HCA and PCA described in the following sections.

3.5.3.1 Hierarchical Clustering Analysis (HCA)

To better understand the implications of this second step of the BC analysis, we firstly need to address the diversity between two main categories: Partitional clustering and Hierarchical clustering. The former uses an algorithm that groups together data objects into non-overlapping subsets (clusters) such that each single data object is in exactly one subset (Hanke & Wichern, 2021). On the other hand, the Hierarchical clustering algorithm produces a set of nested clusters organized as a hierarchical tree. In this thesis, the latter clustering algorithms has been chosen.

Inside the general definition of Hierarchical Clustering another distinction between Agglomerative and Divisive Hierarchical Clustering needs to be done. Specifically, the former looks at each object as an individual cluster and, at each step, merges the closest pair of clusters until only one cluster (or *k* clusters) is left. On the contrary, the Divisive approach starts with one cluster that includes all the objects of the analysis. Then, at each step, the algorithm progressively splits the clusters until each subgroup contains an item (or there are *k* clusters). For the purpose of this thesis, the Agglomerative Hierarchical Clustering Algorithm has been used, following the trend in the literature that sees this approach as the one most widely used. As a matter of fact, this algorithm is straightforward and easy to implement. Indeed, it consists of only few and repetitive steps that can be easily carried out. Specifically, after having created the BC raw matrix, UCINET has been deployed to convert this raw matrix into the right format to perform the Agglomerative Hierarchical Clustering analysis. In this regard, the steps the algorithm generally repeats are the following:

1. Compute the proximity matrix
2. Consider each object as a cluster
3. Repeat the follow until only a single cluster remains:
    a. Merge the two closest clusters
    b. Update the proximity matrix

During the process, the key step is the computation of the proximity matrix that needs to be continuously updated following the merging process of units and subgroups.

However, the main point here is that the proximity matrix strictly depends on the definition the researchers give to the distance between clusters. Generally speaking, with this algorithm the similarity between units and clusters is used as proximity measure and is defined as a numerical measure (usually between 0 and 1) of how alike two data objects are (Hanke & Wichern, 2021). Although a detailed description of all the different ways in which the Inert-Cluster Similarity can be defined is out of the scope of this thesis, it is worth listing the various options, that are single link, complete link, group average, and distance between centroids. In our case, the complete link approach has been adopted. In this regard, to group different clusters, the complete linkage defines the similarity between two clusters by looking at the two least similar (that is, the most distant) objects in the different clusters. This computation is determined by all pairs of points in the two clusters (Hanke & Wichern, 2021). Although this approach tends to break large clusters, it has the positive feature of being less sensitive to noise and outliers, thereby becoming the right choice for the goals of this thesis.

The main output of this Agglomerative Hierarchical Clustering analysis is a dendrogram, which helps researchers to better visualize how the grouping process works. In fact, this dendrogram is a bi-dimensional tree-like diagram that records and illustrates step-by-step the merging and splitting activities. Thus, it basically describes and gives preliminary information on the clustering structure of the analyzed sample. To do so, one of the two axes lists all the objects of the analysis, while the other axis displays the former distance between merged clusters. In this regard, the length of the segment that groups together two or more units is proportional to their distance; thus, the longer the segment, the higher the distance and the least the similarity between the considered units. This straightforward grouping process implies that it is not necessary to assume any particular number of clusters in advance; instead, any desired number of subgroups can be easily obtained by cutting the dendrogram at the proper level.

The result obtained from this analysis should be seen as complementary to the following mapping and clustering method: the Principal Component Analysis (PCA). In fact, by addressing the Hierarchical Clustering analysis, we have been able to have a first deeper look at the possible structure of the analyzed sample.

3.5.3.2 Principal Component Analysis (PCA)

The raw matrix previously described can be also used as input for UCINET 6.528 to perform the Principal Component Analysis (PCA) which is able to find the subgroups in the analyzed network.

From a bibliometric point of view, PCA can be defined as one of the most used dimensional reduction techniques that transform the network into a low-dimensional space (usually two-dimension) (Cobo et al., 2011) without losing any relevant information. In the same way, from a statistical point of view, it can be more accurately defined as a linear transformation technique that can be used to simplify a dataset. In fact, it chooses a new coordinate system for the data set such that, the greatest variance by any projection of the data set comes to lie on the first axis (called the first principal component), the second greatest variance on the second axis, and so on (Hanke & Wichern, 2021). In this way, PCA reduces dimensionality by eliminating the later principal components. To do so, contrarily to the previous Hierarchical Clustering Analysis, PCA requires researchers to choose in advance the number of factors (i.e., components) to retain (Conway & Huffcutt, 2003; Zupic & Čater, 2015), that is to decide the stopping rule when extracting factors. This is one of the most important choices to make during the PCA given the fact that the number of factors can affect the interpretability and practicality of the results obtained. Indeed, if researchers choose a number of components that is too low, some units may be forced to join non-representative clusters thereby hindering the possibility to discover the main topics and latent structure of the research field (Conway & Huffcutt, 2003; Zupic & Čater, 2015). On the other hand, if too many factors are used, the additional variance brought by the new component will make more difficult the interpretation of the results and will not add any additional information (Conway & Huffcutt, 2003; Zupic & Čater, 2015). Generally speaking, the literature proposes several methods to find the optimal number of factors, such as the Kaiser's criterion, the scree test, parallel analysis, a priori theory, and many others. In this thesis, the Kaiser's rule has been deployed.

This rule is a general method proposed by Kaiser (1956) that simply states that only the factors with an eigenvalue greater than one should be retained. The underlying logic is the following: the more correlated variables load into (that is, have a high correlation with) a particular component, the more central that factor is in summarizing the data. Given that the eigenvalues generally give us an idea of the data gathering's efficiency of a component, the Kaiser rule recommends that only those with an eigenvalue greater than one should be considered. This is because an eigenvalue of 1.0 means that the component contains the information of one single variable.

After having selected the number of factors, the rotation rule to apply has been chosen. Particularly, given that units (in this case documents) can load onto more than one factor (Zupic & Čater, 2015), it is essential to use a factor rotation mechanism to increase the accuracy of the interpretation of the results (Conway & Huffcutt, 2003). In this regard, two basic types of rotation mechanisms are usually used: orthogonal rotations, which assume that factors are uncorrelated, and oblique rotations, which assume instead that factors are correlated (Conway & Huffcutt, 2003; Zupic & Čater, 2015). In this thesis, the most popular orthogonal rotation of the extracted factors has been applied, namely, the Varimax method. This statistical technique attempts to clarify the relationship among factors by adjusting the coordinates of data that result from the PCA. This adjustment aims at maximizing the sum of the variance of the squared loadings, where the loadings refer to the correlations between variables and factors (Kaiser, 1958; McCain, 1990). Thus, the Varimax rotation simplifies the loading by removing the middle ground and identifying the factor upon which the unit loads (Kaiser, 1958; Hanke & Wichern, 2021). Finally, in the final phase of results' interpretation, the units of analysis with a loading higher than |0.7| have been considered as those units that bring the major contribution and thus, the core units in the component, while only units with factor loading equal or higher than |0.4| have been considered as factor members (McCain, 1990; Zupic & Čater, 2015).

3.5.4 Co-word Analysis

To have a better idea of the cognitive structure of the analyzed research front, the co-word analysis has been performed. Specifically, it is defined as the science mapping tool that uses the words found in the documents title, abstract, keywords list, or in the full text itself to establish connections and build a conceptual structure of the scientific domain (Zupic & Čater, 2015). In fact, while direct citation and bibliographic coupling use either citations or citing publications as a proxy for documents' similarity, the co-word analysis is the only method that uses the actual content of documents to construct a similarity measure (Donthu et al., 2021; Zupic & Čater, 2015). In this regard, the co-word analysis relies on the assumption that words that frequently appear together have a thematic relationship with one another (Donthu et al., 2021). Since the resulting semantic map is critical to researchers to better understand the cognitive structure of the scientific field (Boyack & Klavans, 2010; Zupic & Čater, 2015), researchers should use this tool to better understand and study the content of the thematic clusters derived from bibliographic coupling. To perform the co-word analysis both VOSviewer, where the minimum co-occurrence of keywords has been set equal to 3, and R Studio 4.2.1 have been deployed.

The first step we have performed refers to the visual representation of the co-word network. In this regard, VOSviewer has been used to plot a co-occurrence term map, while the actual network map has been displayed by using the following R Studio function:

```
> NetMatrix <- biblioNetwork(M, analysis = "co-occurrences", network = "key
words", sep = ";")

> net=networkPlot(NetMatrix, normalize="association", weighted=T, n = 30, T
itle = "Keyword Co-occurrences", type = "fruchterman", size=T,edgesize = 5,
labelsize=0.7)
```

Where the first string aims at creating the network itself, while the second one is essential to plot the keyword co-occurrence map.

Furthermore, to properly extract the thematic clusters belonging to the analyzed sample, additional coding computations has been performed in R Studio. This analysis can be addressed by applying a dimensionality reduction technique such as Multidimensional Scaling (MDS), Correspondence Analysis (CA), or Multiple Correspondence Analysis (MCA). In this thesis, we have decided to follow the example illustrated by Aria & Cuccurullo (2017), thereby choosing the CA method. To do so, the function *conceptualStructure* has been deployed to draw a conceptual structure of the analyzed scientific field, together with the K-means clustering which is essential to find the number and structure of the clusters of documents with similar content. On this point, to extract terms from titles and abstracts, the *conceptualStructure* includes natural language processing (NLP) routines and uses Porter's stemming algorithm to reduce derived words to their word stem, base, or root form (Aria & Cuccurullo, 2017). Specifically, the following code has been given as input to the software:

```
> CS <- conceptualStructure(M,field="ID", method="CA", minDegree=4, clust=4
, stemming=FALSE, labelsize=10, documents=10)
```

The main output of this formula consists of a Topic Dendrogram.

Although this output is similar to the one of the Hierarchical Clustering Analysis, in this case, we have given the number of clusters we wanted to identify as input to the software. In this way, R Studio has immediately provided us with the dendrogram already cut in the most suitable point to achieve the preselected number of clusters (4). To do so, as previously mentioned, R Studio has used the K-means clustering method, which is a straightforward algorithm based on a partitional clustering approach. Specifically, firstly, it associates each cluster with a centroid (that is the central point); secondly, it associates each keyword to the cluster with the closest centroid.

Although we have deployed several software that has been pivotal in developing a first understanding of the main recurring topics in the research field, a full and complete reading of all the articles in the analyzed sample has been necessary to actually perform the analyses described in this chapter. In fact, we have taken the PCA and cluster analysis papers' classifications as the starting point for a subsequent personal elaboration of the information extracted during the accurate reading process. In this way, we have been able to better define the thematic clusters of the literature on Blockchain and Operations Management.

3.8 Conclusion

In this chapter, we have provided a thorough description of the methodology used to perform our bibliometric literature review. In particular, several bibliometric analyses have been discussed, including direct citation analysis, bibliographic coupling, and co-word analysis. Following the trends in the literature, we have deployed these analyses to assess the current state and future trends of the research field on Blockchain Technology and Operations Management.

By using the information extracted from the Scopus database, we have been able to rank the top articles published between 2020 and July 2022 in the analyzed research field. Additionally, a BC raw matrix has been created to accurately perform the Bibliographic Coupling analysis, which has been carried out by addressing the Hierarchical Clustering and Principal Component Analyses. These analyses have been deemed pivotal to understand and study the literature conceptual structure. Finally, a co-word analysis has been deployed to examine and explore the intellectual structure of the research field. The results of these analyses are discussed in the following chapter.

CHAPTER 4 - RESULTS OF LITERATURE REVIEW

4.1 Introduction

In this chapter, we will present the results of the analyses discussed in the previous sections. Firstly, the data collection and articles sampling will be described. Then, we will provide a descriptive analysis of the publications retained by highlighting the evolution and content of the research field addressing Blockchain Technology and Operations Management.

Subsequently, we will dive deeper into the results achieved through the science mapping step. Specifically, direct citation analysis and bibliographic coupling will be thoroughly performed and discussed. In this way, we will be able to identify and study the most relevant papers in the sample by looking at the number of citations, as well as the field's structure by creating clusters among papers that share the same set of references. This last activity will be performed by means of Hierarchical Clustering Analysis and Principal Component Analysis.

Finally, the intellectual structure of the research field and its main topics will be address by performing a co-word analysis.

4.2 Data collection

To collect the documents addressing both Blockchain and Operation Management topics from the Scopus database, a research string with Boolean operators AND/OR has been created. Specifically, the keywords "Blockchain Technology" and "Distributed Ledger" have been combined with other keywords such as "Operations management", "Capacity planning", "Inventory control", "Materials planning", "Production scheduling", "Warehouse management", "MRP", "ERP", "Supply Chain", "Logistics", "Lean", "Lean manufacturing", and "Just in Time". The intent was to capture the numerous facets of the Operations Management field by inserting all the main pillars of this discipline into the research string. Subsequently, the first large sample of documents has been reduced by taking into consideration only the documents published in the "Business, Management, and Accounting" subject category. Additionally, only the publications written in English, in the final stage of publication, and published from 2020 to July 2022 have been retained. Table 4.1 summarizes the sample reduction process following the procedure just described.

Search string*	("Blockchain Technology" OR "Distributed Ledger") AND ("Operations Management" OR "Supply Chain" OR "Logistics" OR "Lean manufacturing" OR "Just In Time" OR "ERP" OR "MRP" OR "Production Scheduling" OR "Materials Planning" OR "Warehouse Management" OR "Inventory Control" OR "Capacity Planning")	
Step	***Filter***	***Number of publications***
1	Apply search string*	2.324
2	Subject area of interest "Business, Management, and Accounting"	580
3	Publications written in English	575
4	Publications in the final stage of publication	369
5	Publications from 2020 to July 2022	311

Table 4.1 – Description of the search strategy used in this thesis. Source: personal elaboration.

4.3 Performance Analysis

The performance analysis is the preliminary step that must be done to have a better understanding of the subsequent science mapping. In fact, its main goal is to describe the publications' trends and their main characteristics. In this regard, by using the R Studio 4.2.1 software, the input data for this descriptive analysis has been extracted from the bibliographic information exported from the Scopus database in .CSV format. Specifically, through the R code functions described in the previous chapter, it has been possible to perform and identify several different analysis and indicators. On this point, Table 4.2 illustrates the summary of the main characteristics of the sample of articles analyzed.

Main Information About Data	
Timespan	2020:2022
Documents	311
Sources (Journals, Books, Etc.)	141
Annual Growth Rate %	3.62
Document Average Age	0.977
Average Citations Per Doc	20.05
Average Citations Per Year Per Doc	8.429
References	19 851

Table 4.2 – Main Information about Data. Source: personal elaboration.

Diving deeper into the timespan 2020:2022, Figure 4.1 displays the annual scientific production which refers to the number of documents on Blockchain Technology and Operations Management that have been published each year from 2020 to July 2022. This information has been obtained using the R Studio function reported in the previous chapter, and it has been subsequently elaborated with Microsoft Excel.

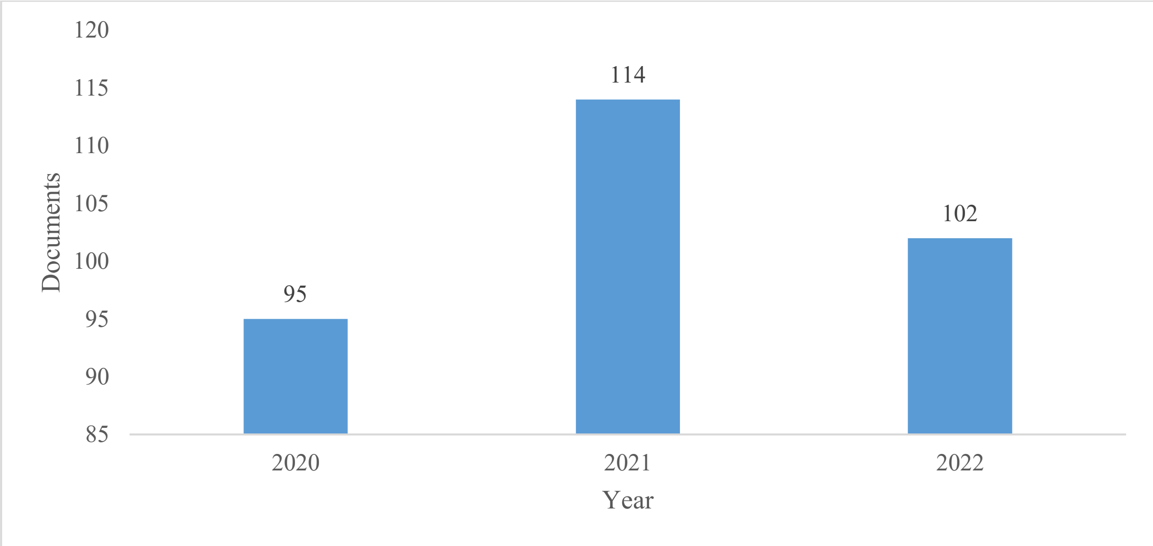

Figure 4.1 – Number of publications on Blockchain and Operations Management from 2020 to July 2022. Source: personal elaboration.

The increase in publications after 2020 with an Annual Percentage Growth Rate of 3.62%, highlights the growing interest researchers have shown in this topic during the last years. Additionally, this positive trend confirms also the curiosity and inquisitiveness manifested by forefront companies to better understand the implications as well as the applications of such cutting-edge technology in their operations. Although the data related to 2022 are not complete, the large number of documents published during only the first half of the year supports this upward trend and suggests that we can expect the same tendency during the remaining months.

The next analysis refers to the understanding of the authors' productivity and collaboration. In this regard, as summarized in Tables 4.3 and 4.4, R Studio displays the most productive authors in the given research field as well as the different indicators of authors' collaboration. On this matter, it is worth highlighting that in Table 4.4 the Documents per Author index is calculated as the ratio between the total number of articles and the total number of authors, while the co-authors per Doc index is calculated as the average number of co-authors per article. From both these indicators, we can support the intuition that these topics have arisen great interest among different authors who have decided to combine their multi-disciplinary knowledge and different backgrounds to delve into this innovative field.

#	Authors	Articles	Authors	Articles Fractionalized
1	SARKIS J	9	CHOI T-M	3.75
2	CHOI T-M	8	KUMAR A	3.18
3	KUMAR A	7	SARKIS J	3.00
4	BAI C	5	-	2.00
5	NIU B	4	NUSEIR MT	2.00
6	ZHANG J	4	RIJANTO A	2.00
7	DUAN Y	3	BAI C	1.83
8	GUNASEKARAN A	3	DE GIOVANNI P	1.50
9	JAIN R	3	GRUCHMANN T	1.50
10	KUMAR V	3	SHEEL A	1.50

Table 4.3 – Most productive authors. Source: personal elaboration.

Authors Collaboration	
Single-Authored Docs	29
Documents Per Author	0.364
Co-Authors Per Doc	3.2
International Co-Authorships %	31.83

Table 4.4 – Authors Collaboration. Source: personal elaboration.

The rapid evolution of this scientific field that is boosted by the willingness of authors of entering in contact with ideas and pairs outside their own country is confirmed once again by the international co-authorship index in Table 4.4. Indeed, it tells us that Blockchain and Operations Management studies have gained considerable attention from researchers all over the world. In this regard, to better understand the publications by country, both R Studio and VOSviewer have been used. Firstly, the CSV file from Scopus has been imported into VOSviewer to eventually extract the 61 publication countries and to have a first idea of the most influential ones, with the top four being China, United States, India, and United Kingdom. In this analysis, since 282 articles out of 311 are multi-authored, all the authors contributing to each paper have been taken into consideration.

Figure 4.2 – Visual representation of publishing activity by country. Source: personal elaboration.

Although this last analysis is useful to understand the regions from which the majority of the publications come, it does not properly identify the countries that bring the greatest contribution. In fact, even if a state registers the largest number of published articles, it does not directly imply that this specific country is also the most influential one. This is due to the fact that those articles are not necessarily the most prominent and cited ones in the given scientific field. For this reason, through the R Studio functions previously described, two additional analyses have been performed.

Firstly, as preliminary activity to better understand the correlations among countries, the Country Scientific Collaboration, which is shown in Figure 4.3, has been performed.

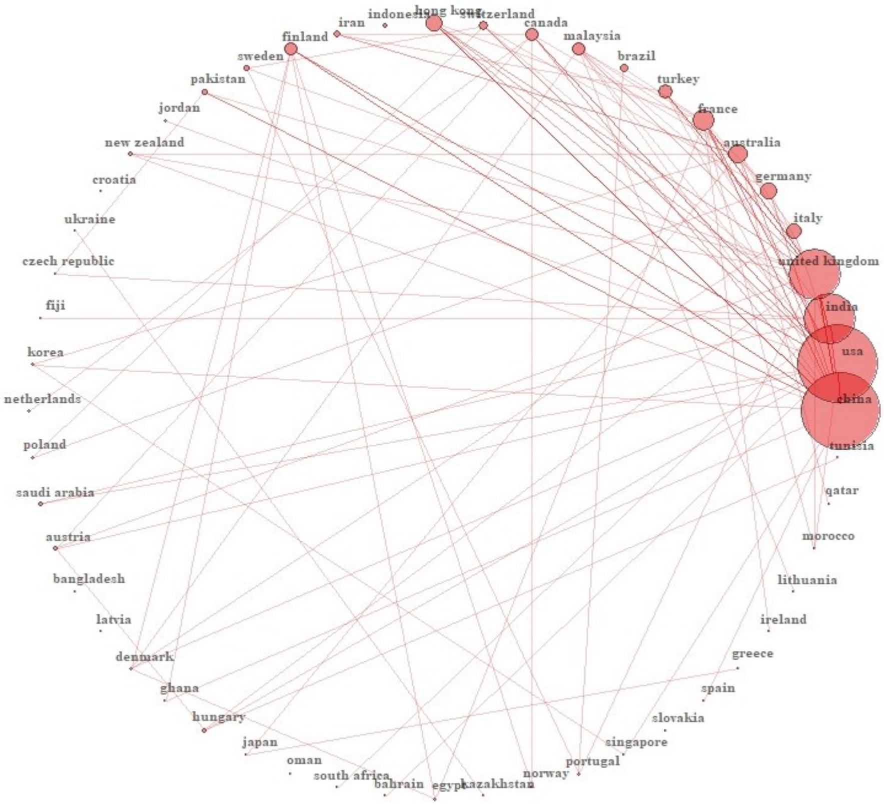

Figure 4.3 – Country Scientific Collaboration. Source: R Studio.

As we can see from Figure 4.3, the top four countries with the largest red circles are exactly the same top four countries listed before. However, with this analysis we have taken a step forward in our understanding of countries collaborations. As a matter of fact, this analysis gives us a graphical overview of the links and correlations among countries, implicitly indicating where most of the collaborations have been performed. As we can see, the highest density of connections is on the top-right part of the circle, thereby highlighting the centrality of those countries in the diffusion and creation of concepts and ideas in the research field.

The second analysis performed with R Studio builds on the preliminary step just described. In fact, the software has allowed us to dive deeper into the intuition we have developed by observing Figure 4.3. Specifically, the number of documents per country has been analyzed together with further pivotal indexes, such as the Singles Country Publications (SCP) and the Multiple Country Publications (MCP). Table 4.5 illustrates the main ten countries when looking at these indexes together. In addition, the MCP ratio has been calculated as the ratio between the MCP and the country's articles. On the other hand, Table 4.6 shows the top ten countries based on the total number of citations.

#	Country	Country articles	SCP	MCP	MCP Ratio
1	CHINA	45	21	24	0.533
2	USA	36	25	11	0.306
3	INDIA	25	19	6	0.240
4	UNITED KINGDOM	16	9	7	0.438
5	ITALY	13	13	0	0.000
6	AUSTRALIA	9	4	5	0.556
7	FRANCE	8	4	4	0.500
8	GERMANY	8	8	0	0.000
9	BRAZIL	6	5	1	0.167
10	TURKEY	6	5	1	0.167

Table 4.5 – SCP and MCP Analysis. Source: personal elaboration.

#	Country	Total Citations	Average Citations per Document
1	CHINA	1205	26.78
2	USA	1089	30.25
3	AUSTRALIA	431	47.89
4	INDIA	418	16.72
5	UNITED KINGDOM	368	23.00
6	GERMANY	292	36.50
7	BRAZIL	283	47.17
8	FRANCE	252	31.50
9	ITALY	233	17.92
10	SWITZERLAND	146	73.00

Table 4.6 – Total Citations per Country. Source: personal elaboration.

As we can see from the Tables above, the overall result of this analysis highlights that it is not possible to identify and firmly point at a single specific country as the major contributor to the scientific field. Instead, a mix of different countries brings the most to the research front. In fact, although China and the United State occupy the top two positions in both Tables (and in the previous Figures), the analysis made in Table 4.6 points out, among others, the importance of Switzerland in terms of average citations per document (a country that has not been taken into consideration in the previous analysis).

Finally, to conclude the performance analysis, the main source titles of the analyzed set of documents have been assessed. To do so, R Studio has been deployed to extract the information necessary for the analysis. As illustrated in Table 4.7, out of 311 documents analyzed, 263 appeared in international journals. Looking now at Table 4.8, which lists the journals with the highest number of articles on Blockchain and Operations Management, we can deduce that the leading journals in this scientific field are the *International Journal of*

Production Research, followed by *Transportation Research Part E Logistics and Transportation Review*, *International Journal of Production Economics*, and *Journal of Cleaner Production*. In this regard, Blockchain and Operations Management touch different areas such as engineering, operations, production, transportation, logistics, and management, which perfectly match the areas of interest of these international journals. Additionally, many of the journals listed in Table 4.8 have an Association of Business Schools (ABS) rating of 4*, such as *Management Science*, 4, such as the *International Journal of Supply Chain Management* and *Production and Operations Management*, and 3, such as the *International Journal of Production Economics,* among others. This implies that the area of research, that addresses the applications and impacts of the Blockchain on the Operations Management discipline, has received attention from some of the best journals in the field of management (Baker et al., 2020). In fact, according to the Chartered Association of Business Schools (CABS), 4* and 4 refer to journals recognized worldwide as examples of excellence and/or publishing the most original and best-executed research that has a high impact factor; 3 refers to journals publishing the most original and well-executed research but may or may not have a high impact factor; 2 refers to journals publishing original research with acceptable standards; 1 refers to journals publishing original research with modest standards, and N.R. refers to journal not rated ("Academic Journal Guide", 2021).

Source Type	***Number of Documents***	***% of Documents***
Article	263	85%
Book Chapter	29	9%
Review	19	6%
TOTAL	**311**	100%

Table 4.7 – Types of source titles in the analyzed set of documents. Source: personal elaboration.

Source Title	***Articles number***	***Citations***
International Journal Of Production Research	16	1222
Transportation Research Part E Logistics And Transportation Review	15	518
International Journal Of Production Economics	12	465
Journal Of Cleaner Production	11	447
Technological Forecasting And Social Change	9	261
Journal Of Global Operations And Strategic Sourcing	8	53
IEEE Transactions On Engineering Management	7	198
Lecture Notes In Business Information Processing	7	7
Industrial Management And Data Systems	6	97
International Journal Of Supply Chain Management	6	5
Operations And Supply Chain Management	5	53
Production And Operations Management	3	73
Management Science	1	96

Table 4.8 – Most Relevant Sources in the analyzed set of documents. Source: personal elaboration.

4.4 Direct Citation Analysis

After having performed the descriptive analysis, the science mapping step has been addressed starting from the direct citation analysis. In this regard, to identify the most influential publications on Blockchain and Operations Management, the citation network of the 311 documents has been analyzed using the R functions described in the previous chapter. As we have already discussed, the main goal of the *citations* function is to find the most cited articles by the publications belonging to the sample studied. This means that the most cited documents do not necessarily have to be included in the sample of the citing articles. Table 4.9 lists the top ten publications. As we can see, none of them belongs to the timespan 2020:2022 studied in this thesis. This means that the 311 articles analyzed mainly cite previous works published between 2016 and 2019.

Authors	***Year***	***Title***	***Source Title***	***Total Citations***
Saberi, S., Kouhizadeh, M., Sarkis, J., Shen, L.	2019	Blockchain technology and its relationships to sustainable supply chain management	International Journal Of Production Research	47
Christidis, K., Devetsikiotis, M.	2016	Blockchains and smart contracts for the internet of things	IEEE Access	28
Treiblmaier, H.	2018	The impact of the blockchain on the supply chain: a theory-based research framework and a call for action	Supply Chain Management: An International Journal	27
Wang, Y., Singgih, M., Wang, J., Rit, M.	2019	Making sense of blockchain technology: how will it transform supply chains?	International Journal Of Production Economics	24
Francisco, K., Swanson, D.	2018	The supply chain has no clothes: technology adoption of blockchain for supply chain transparency	Logistics	23
Min, H.	2019	Blockchain technology for enhancing supply chain resilience	Business Horizons	22
Saberi, S., Kouhizadeh, M., Sarkis, J., Shen, L.	2019	Blockchain technology and its relationships to sustainable supply chain management	International Journal Of Production Research	22
Kamble, S., Gunasekaran, A., Arha, H.	2019	Understanding the blockchain technology adoption in supply chains-indian context	International Journal Of Production Research	20
Wang, Y., Singgih, M., Wang, J., Rit, M.	2019	Making sense of blockchain technology: how will it transform supply chains?	International Journal Of Production Economics	20

Kouhizadeh, M., Sarkis, J.	2018	Blockchain practices, potentials, and perspectives in greening supply chains	Sustainability	19

Table 4.9 – Top 10 most cited documents in general. Source: personal elaboration.

Although useful, to properly understand the most influential articles inside our sample, another index has been calculated through the *localCitations* function; namely, the local citations (LCS) index. Specifically, the local citations index measures how many times a document included in the analyzed collection has been cited by other documents also present in the collection; in other words, it measures an article's popularity within the network of 311 publications (Kent Baker et al., 2020). Together with this index, the global citations (GCS) index, which refers to the number of times other works cite an article in the database including works in other research areas and disciplines (Kent Baker et al., 2020), has been taken into consideration. Table 4.10 shows the result of this analysis displaying the top ten most cited articles within the dataset, where column *"#"* indicates the number assigned to the documents while performing the Bibliographic Coupling analysis described in the following sections.

#	***Authors***	***Year***	***Title***	***Source Title***	***LCS***	***GCS***
8	Babich, V.; Hilary, G.	2020	Distributed ledgers and operations: What operations management researchers should know about blockchain technology	Manufacturing Service Operations Management	28	168
105	Pournader, M.; Shi, Y.; Seuring, S.; Koh, S.C.L.	2020	Blockchain applications in supply chains, transport and logistics: a systematic review of the literature	International Journal Of Production Research	28	236
12	Bai, C.; Sarkis, J.	2020	A supply chain transparency and sustainability technology appraisal model for blockchain technology	International Journal Of Production Research	26	171
40	Dutta, P.; Choi, T.-M.; Somani, S.; Butala, R.	2020	Blockchain technology in supply chain operations: Applications, challenges and research opportunities	Transportation Research Part E Logistics And Transportation Review	22	184
72	Kouhizadeh, M.; Saberi, S.; Sarkis, J.	2021	Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers	International Journal Of Production Economics	22	226
131	Tönnissen, S.; Teuteberg, F.	2020	Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies	International Journal Of Information Management	21	129

65	Kamble, S.S.; Gunasekaran, A.; Sharma, R.	2020	Modeling the blockchain enabled traceability in agriculture supply chain	International Journal Of Information Management	20	260
36	Dolgui, A.; Ivanov, D.; Potryasaev, S.; Sokolov, B.; Ivanova, M.; Werner, F.	2020	Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain	International Journal Of Production Research	19	192
27	Choi, T.-M.; Feng, L.; Li, R.	2020	Information disclosure structure in supply chains with rental service platforms in the blockchain technology era	International Journal Of Production Economics	18	95
87	Manupati, V.K.; Schoenherr, T.; Ramkumar, M.; Wagner, S.M.; Pabba, S.K.; Inder Raj Singh, R.	2020	A blockchain-based approach for a multi-echelon sustainable supply chain	International Journal Of Production Research	16	97

Table 4.10 – Most cited documents in the analyzed set. Source: personal elaboration.

According to the global citations, Kamble et al. (2020) generates the most citations with 260 citations, followed by Pournader et al. (2020) with 236 citations. However, when looking at the local citations, the authors that generated the most citations are Babich & Hilary (2020), along with Pournader et al. (2020) with 28 citations each. In light of this analysis, we can state that, in the analyzed sample, there is not a specific author that outstands the others. In fact, none of them is able to place more than one article among the top ten cited publications. Nonetheless, it is worth highlighting that Pournader et al. (2020) ranked in the top two both looking at LCS and GCS, indicating a good influence exerted by this document on the research field.

To better visualize what we have just described, VOSviewer has been used. Specifically, this software has been deployed to create the citation network of the 311 publications analyzed. The output is displayed in Figure 4.4.

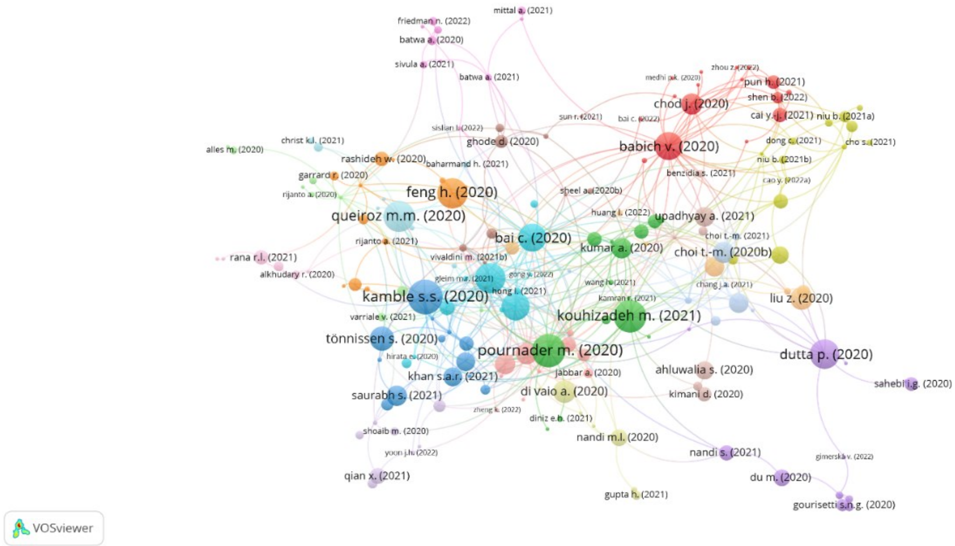

Figure 4.4 – Citation network of the analyzed sample. Source: VOSviewer.

In this visualization, we are able to analyze the citations ties between different papers, where each node refers to an article and reports the first author's name as well as the year of publication. These links intuitively exist only when document A appears among the cited references of document B or vice versa. In this regard, by just looking at the output of the software, it is not possible to understand the direction of the link; that is, it is not possible to understand which paper cites the other document. However, to practically calculate these linkages, VOSviewer takes as a point of reference the following documents' information: a combination between the first author's name, publication year, volume number, and initial page or article number, together with the DOI (Document Object Identifier). In the case in which the volume number is not available, the system substitutes this information with the source title and the first name number. Thus, a citation tie exists only when one document includes, in its cited references, the previously listed combination of details of another document. Once again, in our case, it is not possible to identify the most influential paper in absolute terms. Indeed, no node is visibly larger than the others; instead, among the larger nodes we can observe a good size homogeneity. Nonetheless, it is worth highlighting that the larger nodes refer to exactly the same articles listed in Table 4.10, thereby strengthening the robustness of our direct citation analysis.

4.5 Bibliographic Coupling

Although the direct citation analysis is an extremely useful tool to get a better understanding of the analyzed sample, it needs to be accompanied by other types of analysis that can better catch the interconnections among units. As previously discussed, we have decided to directly perform the bibliographic analysis without addressing the co-citation analysis. This choice has been made to actually pursue the final objective of this thesis; that is, to analyze the current research front of the literature. In light of this choice, the bibliographic coupling has been performed. Starting from the 311 publications addressing Blockchain and Operations Management, a screening process has been applied to reduce the number of documents to only the most influential ones. To do so, only the publications that have exhibited, at the time of the analysis, at least three citations have been retained thus leading to a new sample of 156 articles[1]. By doing so, we have been able to prevent the possibility of considering niche articles that could have partially compromised the consistency as well as the soundness of our results.

During the first step of the analysis, all pairs of articles have been examined to assess the degree of overlap between their references; in other words, each pair of articles has been thoroughly scrutinized to see if the same set of references has been cited in the pair. The output of this first analysis has been a raw matrix[2] in which we have inserted the number of common references cited by the pair of publications analyzed. In this regard, the diagonal values have been ignored by putting a value equal to zero. Additionally, the documents have been labelled by using the correspondent numbers, from #1 to #156, reported in Appendix A.

At a first glance, we can see that the pairs of articles with the highest number of common references are Paper #28 – Paper #27 (48), Paper #58 – Paper #2 (37), Paper #55 – Paper #56 (31), Paper #118 – Paper #2 (25), Paper #48 – Paper #17 (22), and Paper #81 – Paper #77 (21). Although these high values can indicate a high degree of content commonality among these papers, further analyses are needed to better understand and discover the thematic clusters in the recent literature. To accomplish this objective, two software have been deployed: VOSviewer and UCINET 6.528.

Firstly, the .CSV file containing all the sample's information has been exported from Scopus and given as input to VOSviewer. In this preliminary analysis, as described above, only the 156 articles that counted at least three citations have been taken into consideration and the procedure described in the previous chapter has been followed. Figure 4.5 shows the output map given by the software.

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[1] Refer to Appendix A to have a comprehensive view of the 156 articles considered for the Bibliographic Coupling Analysis.

[2] Refer to Appendix B to see the raw bibliographic coupling matrix.

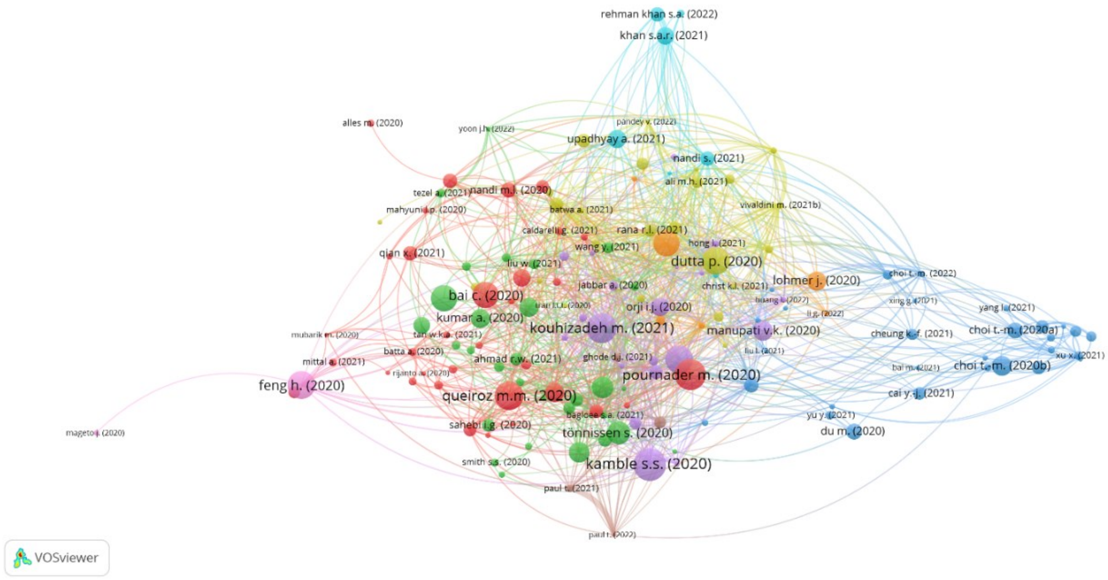


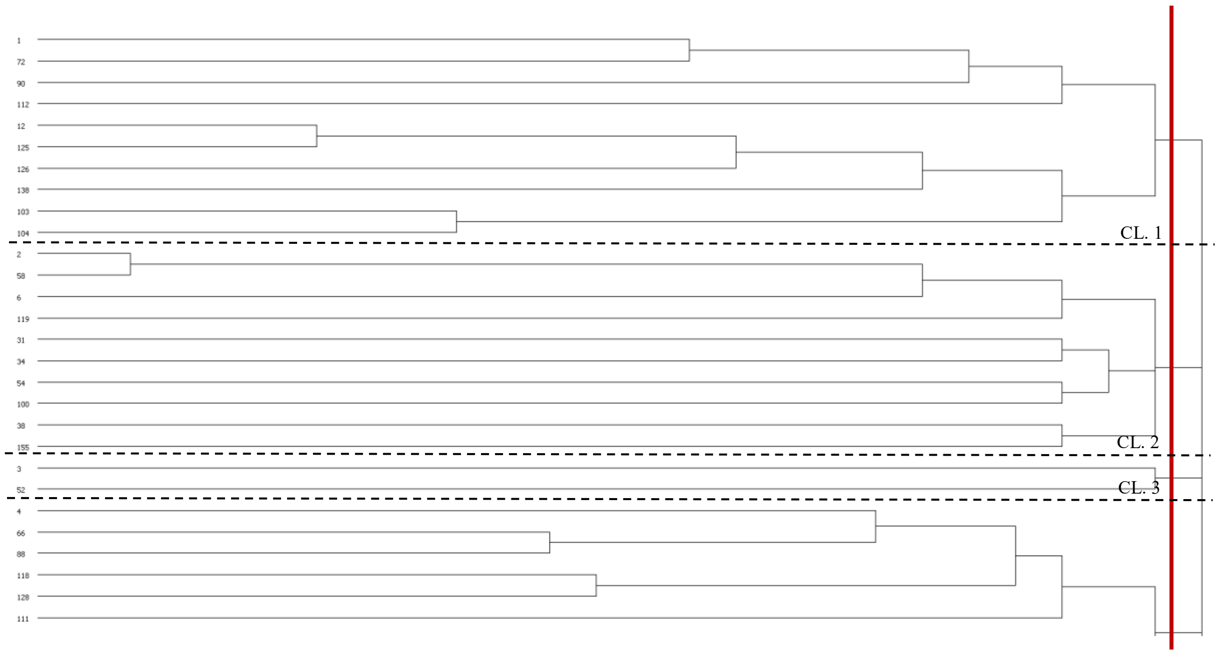
Figure 4.5 – Bibliographic Coupling network representation. Source: VOSviewer.

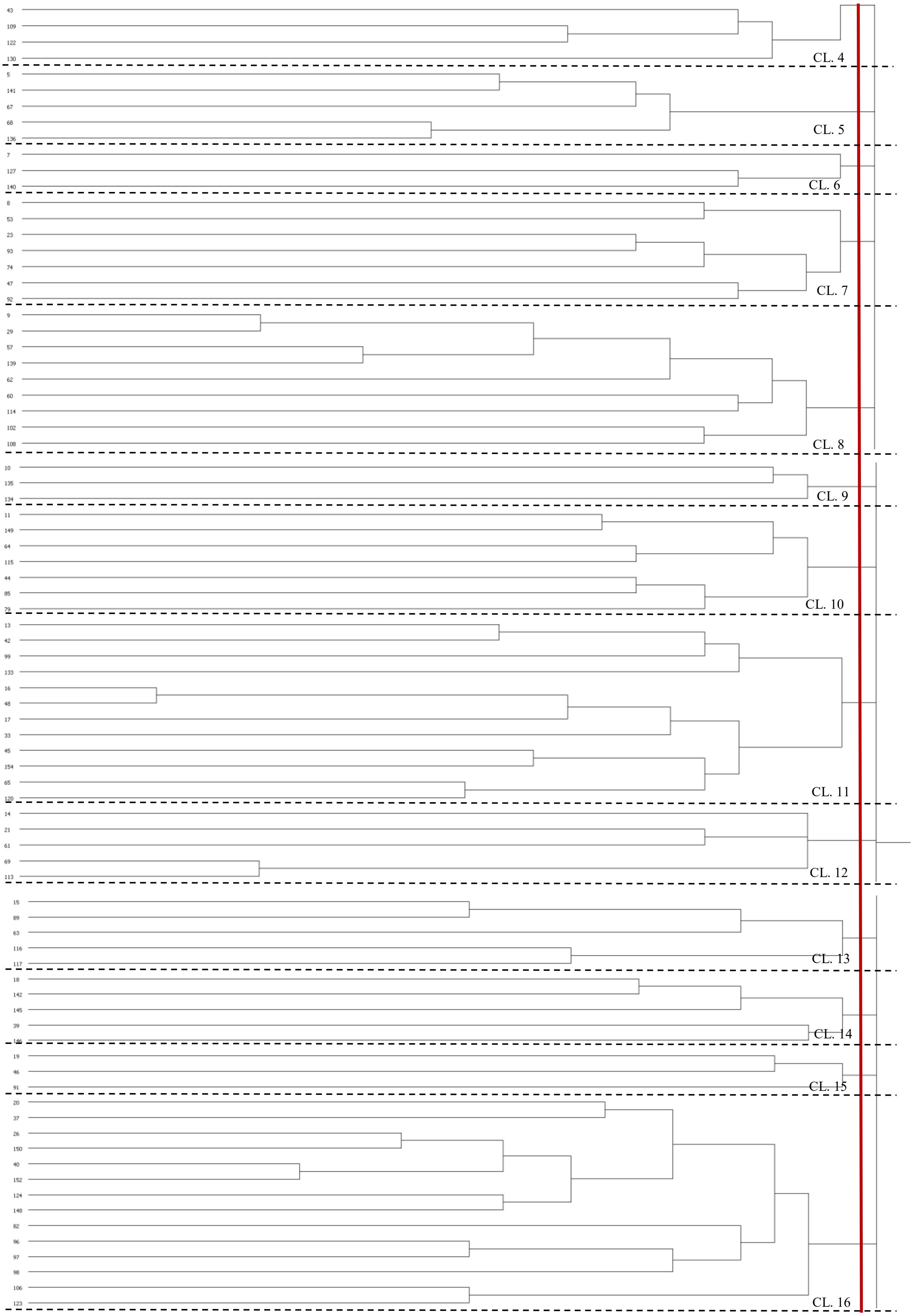
As we can see, the software has mapped the 156 units and divided them into nine different clusters which are indicated through different colors (i.e., red, pink, yellow, blue, green, etc.). In this way a breakdown of the Blockchain and Operations Management literature into subfields is obtained. Additionally, in this visualization, the size of each cluster reflects the number of publications belonging to that specific cluster, thereby indicating that larger clusters include more publications. The distance between different clusters approximately indicates the relatedness of the clusters (van Eck & Waltman, 2017) in terms of shared references. Thus, clusters that are located closer to each other tend to be strongly related in terms of citing references, while clusters that are located further away from each other tend to be less strongly related (van Eck & Waltman, 2017). In Figure 4.5, we can see that only few clusters (precisely, the three clusters at the extremities of the map) are visibly separated and distant from the other subgroups. Indeed, although the publications that lie in the center of the map theoretically belong to different clusters, these subgroups are extremely close to each other. This phenomenon drastically hinders the possibility of clearly identifying separated thematic clusters inside our sample; and it might mistakenly induce at braking larger clusters into smaller ones. Nonetheless, we can deduce that publications apparently belonging to different clusters treat instead the same general topic, but they may differ only in some applications or specific details that make them differentiate from the main common theme.

Although this preliminary clustering analysis has given us precious insights and is extremely useful to graphically distinguish the possible several subgroups, two additional analyses have been performed: Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA).

4.5.1 Hierarchical Cluster Analysis (HCA)

To dive deeper into the grouping process of the 156 articles belonging to our set, UCINET 6.528 has been deployed to perform the Agglomerative Hierarchical Clustering Analysis. According with what has been previously discussed, this analysis has been performed using the Complete Link method. The first output UCINET has given to us is a Dendrogram that is critical to the visualization of the overall Hierarchical Clustering grouping process performed by the software. This process is shown in Figure 4.6, where a red line has been added to visually indicate the point in which we have decided to cut and stop the grouping process. In our specific case, we have decided to cut the dendrogram at the highest level possible, thereby placing the red line as close as possible to the right side of the graph. In fact, it would have been pointless and counterproductive to place the cutting line close to the left side of the graph (where the corresponding numbers of each article are listed), as this choice would have generated a number of clusters slightly lower or even equal to the number of publications analyzed. Hence, this would have hindered the detection of the thematic clusters inside the literature addressed. By doing so, 29 clusters have been identified.

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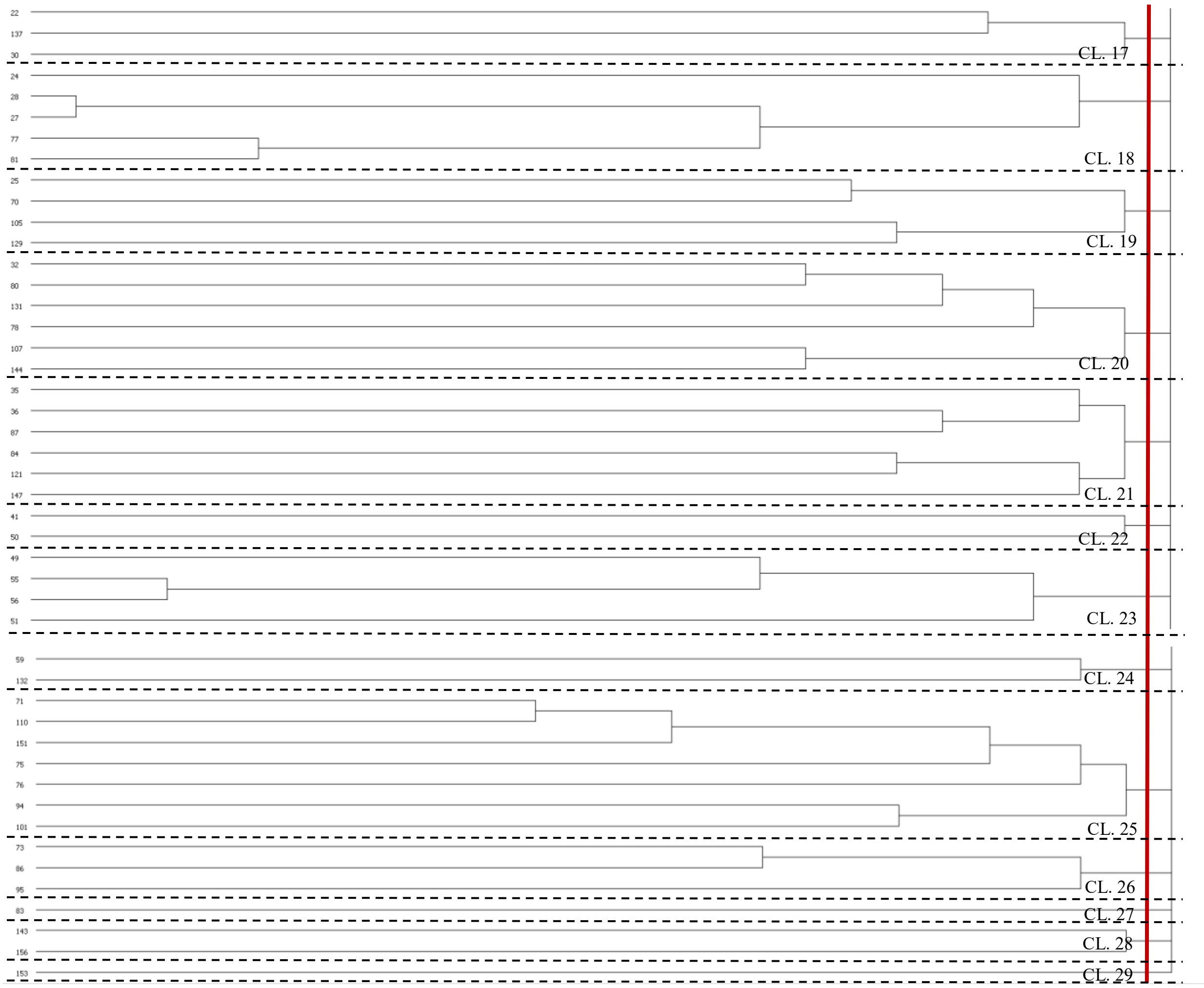

Figure 4.6 – Hierarchical Clustering Dendrogram. Source: adapted from UCINET.

As we have highlighted in the previous chapter, one of the characteristics of the Hierarchical Clustering algorithm is the fact that it does not need a pre-defined number of clusters. Although this feature can be identified as a unique strength, it is not free from drawbacks. One of them is the difficulty in finding the most appropriate number of clusters, thus making it impossible to completely eliminate subjectivity biases. Another point that is worth highlighting is the interpretation of the length of the segments that link and group together papers and clusters. As previously discussed, the shorter the distance of these lines, the more alike the articles and/or clusters. Thus, by just looking at Figure 4.6, we can have an idea of how much alike the items are. For instance, we can easily deduce that articles #28 and #27, followed by articles #2 and #58 are those with the highest similarity between them (in accordance with what we have seen by looking at the raw matrix previously described).

Together with this similarity analysis, Figure 4.6 shows the overall number of clusters we have identified, which is 29. The size of these clusters varies from a maximum of fourteen articles to a minimum of one article (which has been identified in two cases, thus leading to 27 actual clusters). In this latter case, it means that that particular publication does not exhibit any particular similarity with none of the other 155 articles analyzed, thereby indicating either a high degree of specificity of the article itself or the fact that it addresses a completely different topic. When we compare the HCA dendrogram result with the previous preliminary BC analysis which gave us a total of 9 clusters, we can practically see the limitation of the Complete Link approach that we mentioned in the previous chapter. Indeed, although useful to visually represent the steps of the clustering algorithms, the HCA tends to break large clusters into smaller ones. This drawback compromises our ability to detect the main thematic clusters available in the analyzed literature. In fact, by dividing large clusters into smaller subgroups, we may lose valuable information on the general topics discussed in the research field and, instead, focus our attention on niche studies that are outside the scope of our bibliometric literature review.

Another UCINET output of the Hierarchical Clustering Analysis is the vertical icicle plot. This graph represents an alternative way to display the same hierarchical data and show the steps of the cluster formation. In this case, the symbol X indicates the existence of a group and the relative homogeneity between the publications analyzed. Figure 4.7 shows the icicle plot relative to our analysis. Specifically, a first general overview of the analysis has been displayed, which is then divided in half in correspondence to the red line to better see the articles data as well as the grouping steps.

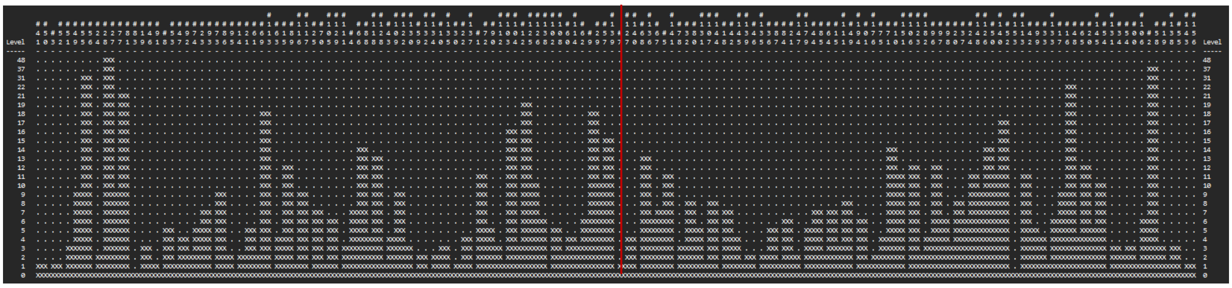

Figure 4.7 – Icicle Plot General Overview. Source: adapted from UCINET.

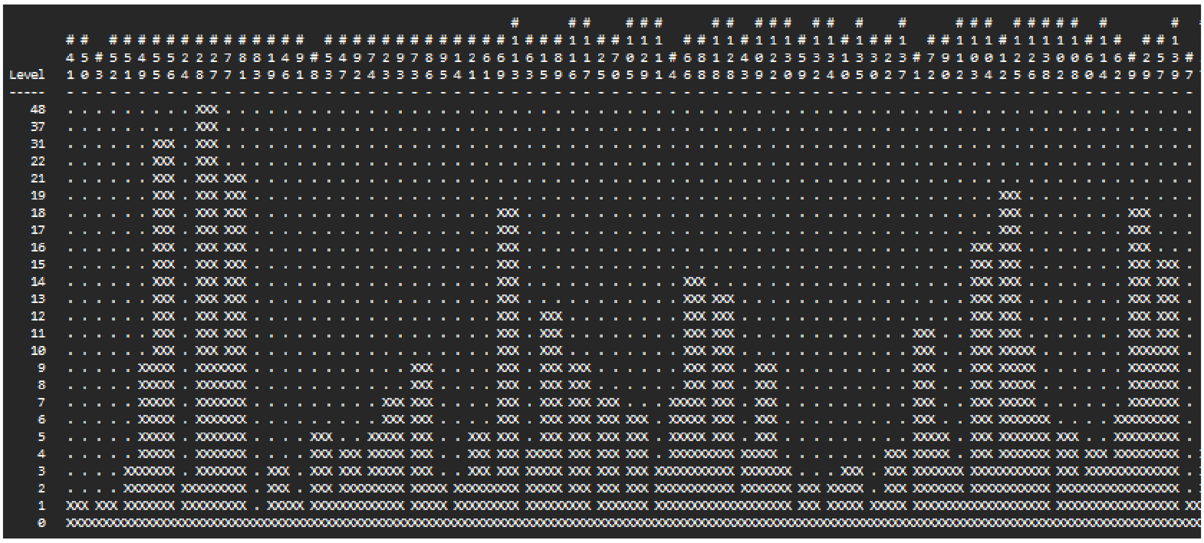

Figure 4.7.1 – Icicle Plot (I Half). Source: adapted from UCINET.

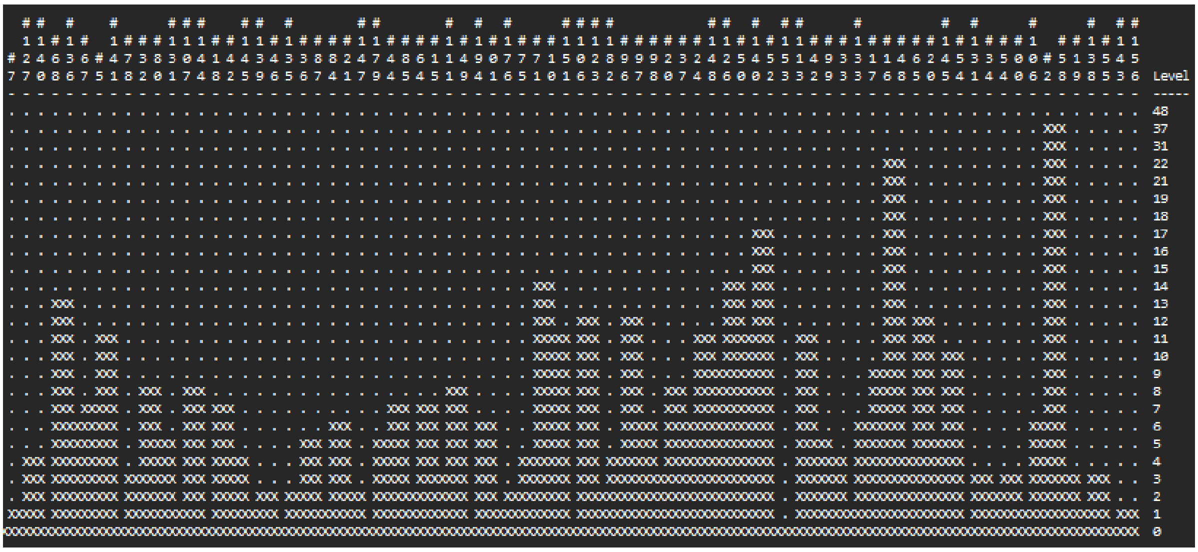

Figure 4.7.2 – Icicle Plot (II Half). Source: adapted from UCINET.

As we can see, the clustering activity starts at the top of the graph and then continues till the bottom where all the documents of our sample are grouped into one single cluster. The column on the far left and right of our graph labeled as *Level,* refers to the degree of similarity among items belonging to the same cluster; while the number of rows indicates the number of partitions made by UCINET (24 in total). In particular, we can see that articles #28 and #27 are grouped together in the top row, followed by articles #2 and #58 in the second row in accordance with the first dendrogram output. Although the icicle plot is a valuable way to visually identify the clusters, their size, and the relationships within papers, it shows once again the limits of the HCA. Specifically, this output can become extremely difficult to read when it contains a significant amount of articles. In fact, as in the case of the dendrogram illustrated in Figure 4.6, these analyses are useful only with data that is hierarchical and that can be sensibly clustered (*Icicle Plots*, n.d.; Murtagh, 2004). However, as highlighted during the direct citation analysis, the Blockchain and Operations Management research field is currently fragmented without the possibility of clearly identifying few central authors. Thus, given that the articles analyzed do not lend themselves to being clustered easily, it becomes extremely difficult to find well-defined clusters. Therefore, it has been deemed critical for the identification of the right number of clusters, to go beyond these graphic representations (dendrogram and icicle plot) by performing other two analyses, namely the ETA correlation and the Principal Component Analysis (PCA).

In this regard, although, as we have previously highlighted, the Hierarchical Clustering Analysis does not provide a pre-defined stopping rule to univocally define the exact number of clusters, UCINET provides us with an additional output titled “Measures of Cluster Adequacy”. Among these metrics, the ETA correlation ratio is reported, which aims to identify the adequacy of cluster partitions. Specifically, this index looks at the correlation between an ideal matrix and our input matrix. In this regard, the ideal matrix assigns values equal to 1 when both the documents in a pair belong to the same cluster, otherwise a value equal to 0 is assigned. The result of the comparison between these two matrices gives us the ETA correlation, where the highest this correlation the greatest the similarity between papers and the better their partition into clusters. In this regard, the UCINET output has been adapted and displayed in Table 4.11.

ETA	CL 1	CL 2	CL 3	CL 4	CL 5	CL 6	CL 7	CL 8
	0.185	0.231	0.256	0.263	0.270	0.274	0.284	0.288
ETA	CL 9	CL 10	CL 11	CL 12	CL 13	CL 14	CL 15	CL 16
	0.292	0.294	0.300	0.304	0.309	0.331	0.345	0.369
ETA	CL 17	CL 18	CL 19	CL 20	CL 21	CL 22	CL 23	CL24
	0.369	0.369	0.382	0.381	0.381	0.380	0.359	0.324

Table 4.11 – ETA correlation. Source: adapted from UCINET.

In our case, the highest ETA correlation belongs to partition CL 19, implying that we can identify 4 main clusters in our study period. This drastically different result confirms once again the limits of the Hierarchical Clustering Analysis performed before (dendrogram and icicle plot) in finding the right number of subgroups given the fragmentation of the studied literature and the tendency of these analyses of breaking larger clusters into smaller ones. This valuable insight given by the ETA correlation will be taken as a point of reference for the following clustering analysis: the PCA.

4.5.2 Principal Component Analysis (PCA)

The third step of our Bibliographic Coupling Analysis consisted in the Principal Component Analysis, which has been once again performed using the raw data matrix illustrated in Appendix B as input for UCINET. As discussed in the previous chapter, PCA requires researchers to choose in advance the number of factors (i.e., components) to retain (Conway & Huffcutt, 2003; Zupic & Čater, 2015), that is to decide the stopping rule when extracting factors. In this thesis, the Kaiser's rule has been deployed, thereby retaining only the factors with eigenvalues equal to or higher than 1. This choice has been aligned with the deployment of the Varimax rotation as the selected method to detect each component. By following this process, we have been able to reduce the number of articles inside the analyzed sample from 156 to 79, thereby retaining only those publications that have been deemed relevant for the research field. The output of the analysis is reported in Table 4.12. As we can see, the number of clusters that have been identified is four, which is equal to the outcome the ETA correlation has provided us, thereby indicating a good harmony between the last indication of the Hierarchical Clustering Analysis and the PCA.

1	2	3	4
Paper #8	Paper #1	Paper #21	Paper #5
Paper #12	Paper #9	Paper #35	Paper #34
Paper #16	Paper #18	**Paper #61**	Paper #54
Paper #17	**Paper #20**	Paper #69	Paper #65
Paper #33	Paper #23	Paper #72	**Paper #67**
Paper #36	**Paper #26**	Paper #95	Paper #68
Paper #40	Paper #37	**Paper #102**	**Paper #79**
Paper #45	Paper #43	Paper #108	Paper #98
Paper #51	Paper #60	Paper #113	**Paper #100**
Paper #56	Paper #64	Paper #115	Paper #111
Paper #66	Paper #88		Paper #121
Paper #71	**Paper #96**		Paper #141
Paper #75	**Paper #106**		Paper #152
Paper #76	Paper #120		**Paper #156**
Paper #77	**Paper #123**		
Paper #80	**Paper #124**		
Paper #84	Paper #125		
Paper #85	Paper #128		
Paper #92	Paper #133		
Paper #94	Paper #139		
Paper #107			
Paper #110			
Paper #112			
Paper #118			
Paper #126			

Paper #129	
Paper #130	
Paper #131	
Paper #135	
Paper #138	
Paper #139	
Paper #145	
Paper #149	
Paper #151	
Paper #154	

Table 4.12 – Principal Component Analysis. Source: adapted from UCINET.

In Table 4.12 the output of the software has been reorganized to better visualize the four factors we have retained. Specifically, we have kept only the publications that exhibited a loading higher than |0.4|. As previously addressed, this decision has been made to retain only the highly influential and pivotal articles in our analysis, thereby reducing the size of the analyzed sample. In the cases in which a paper exhibited a loading equal to or higher than |0.4| in more than one factor, we have decided to place this article into the component that displayed the highest weight. At the same time, the publications with a loading equal to or higher than |0.7| have been deemed as the articles that make the greatest contribution to the component. Thus, we have marked these critical papers in bold.

As we can see from Table 4.12, the majority of the articles retained have been grouped into the first two principal components. Specifically, out of 79 publications, 35 are grouped in the first factor (PC1) which contains 44% of the whole sample, immediately followed by the second factor (PC2) which contains 25% of the articles. In the following sections, we will firstly perform the co-word analysis to better identify and label the thematic areas inside the literature and then, we will describe the content of each one of the recognized clusters.

4.6 Co-word Analysis

As discussed in the previous chapter the co-word analysis is pivotal to understanding the cognitive structure of the research field (Boyack & Klavans, 2010; Zupic & Čater, 2015). Thus, researchers should use this tool to actively explore and label the content of the thematic clusters derived from the bibliographic coupling, and specifically, from the Principal Component Analysis.

This analysis has been performed utilizing two main software; VOSviewer to gain a first general overview of the network, and R Studio to dive deeper into the thematic clusters this analysis can identify. Figure 4.8 and Figure 4.9 show the first output extracted from both R Studio and VOSviewer respectively.

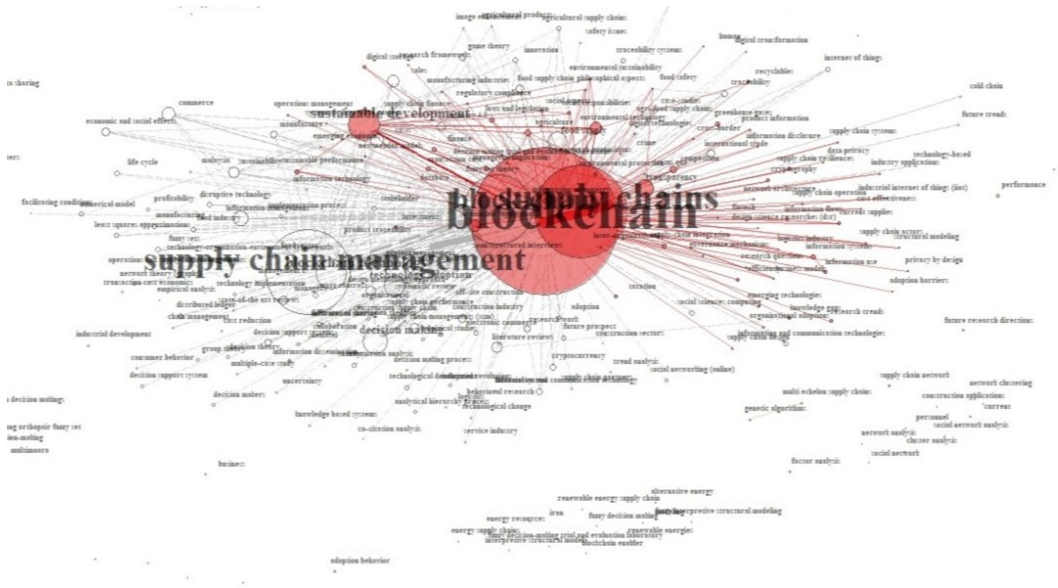

Figure 4.8 – Keyword co-occurrence analysis. Source: R Studio.

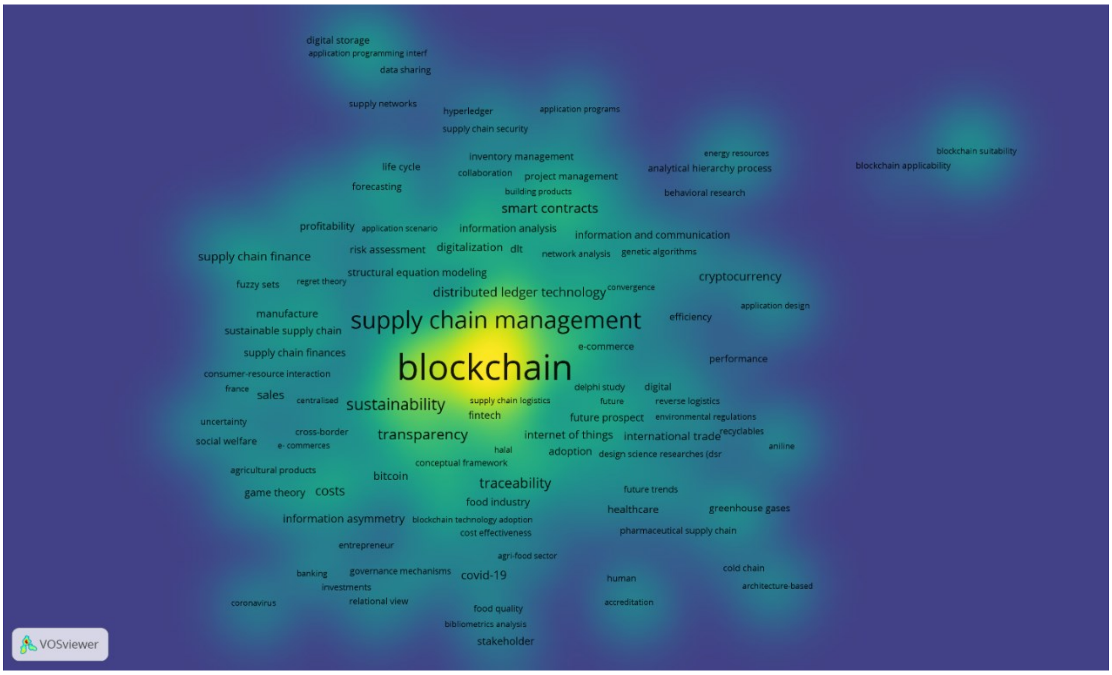

Figure 4.9 – Keyword co-occurrence analysis. Source: VOSviewer.

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Figure 4.8 has been plotted by using the R Studio's function described in the previous chapter. In this case, each node in the network represents a keyword, and the size of the node indicates the occurrence of the keyword (i.e., the number of times the keyword occurs) where the bigger the node, the greater the occurrence of the keyword, while the link between nodes refers to the co-occurrence between keywords (i.e., keywords that occur together). In this way, the nodes and links can be used to explain the topics covered by the articles analyzed as well as the relationships among them. On the other hand, Figure 4.9 has been directly extracted from VOSviewer. In this case, the co-occurrence term map visualization has been depicted, thereby assigning a higher visual heat degree to the keywords that have been used more frequently. At a first glance, we can easily see from both Figures that "Blockchain" and "Supply Chain Management" have been the most utilized concepts. This finding is supported by Table 4.13, which illustrates the most used keywords and their relative frequency.

Keywords	***Frequency – N. Of Articles***
BLOCKCHAIN	105
SUPPLY CHAIN MANAGEMENT	71
SUSTAINABLE DEVELOPMENT	19
TECHNOLOGY ADOPTION	19
DECISION MAKING	17
FOOD SUPPLY	15
TRANSPARENCY	12

Table 4.13 – Keywords Frequency. Source: personal elaboration.

The keywords listed in Table 4.13 highlight the importance of several topics, such as Supply Chain Management, Technology Adoption, Sustainability, and Food Supply Chain. However, although this preliminary analysis is useful to have a general overview of these most critical areas, it does not properly display the thematic clusters belonging to our sample. For this reason, we have performed additional coding computations in R Studio to extract further information. Specifically, as described in the previous chapter, with the function *conceptualStructure* we have been able to extract the Topic Dendrogram illustrated in Figure 4.10 (with a first general overview which has been cut in two halves in correspondence of the black line to allow the reader to better see the keywords listed). On this point, similarly to the case of the BC Hierarchical Clustering Analysis, all the keywords analyzed has been listed at the bottom of the Co-Word dendrogram. These keywords are then progressively aggregated together depending on their connections and frequency with which researchers have used them together. On the left of Figure 4.10, the height measure has been reported to highlight the degree of similarity between keywords and clusters. Indeed, the shorter the length of the segment that links together two or more items, the more alike these units.

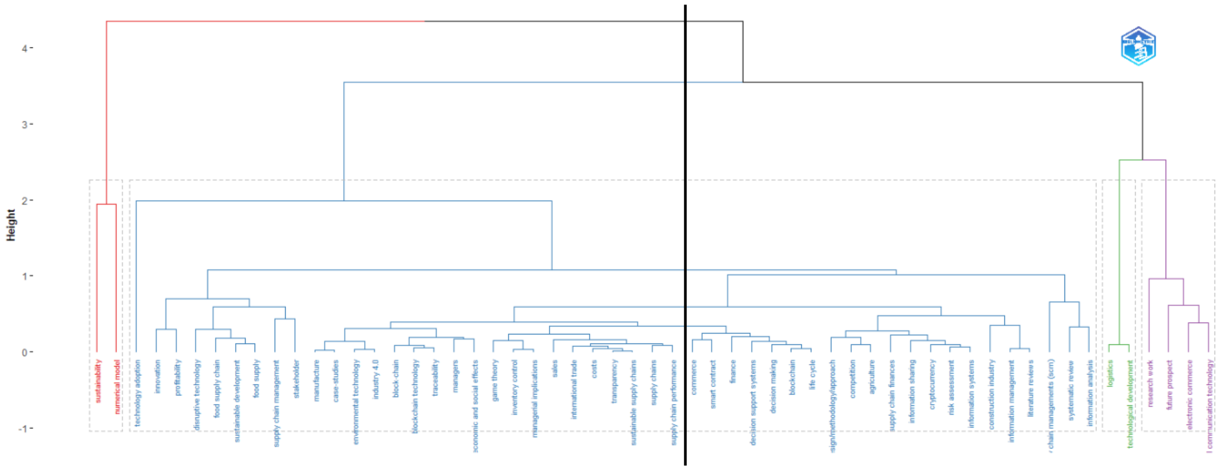

Figure 4.10 – Topic Dendrogram General Overview. Source: R Studio.

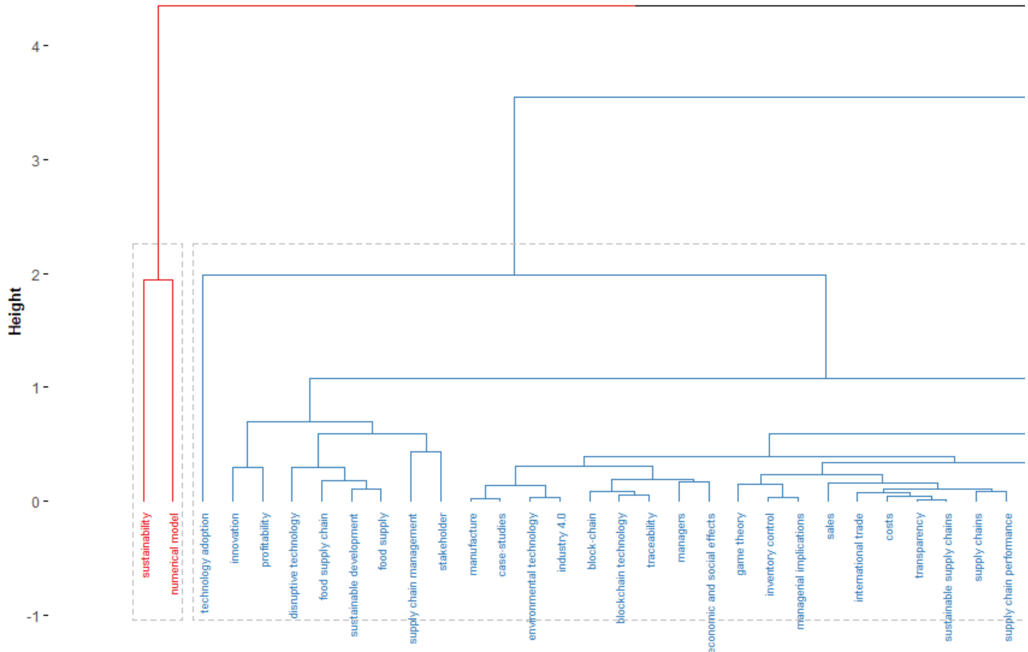

Figure 4.10.1 – Topic Dendrogram (I Half). Source: R Studio.

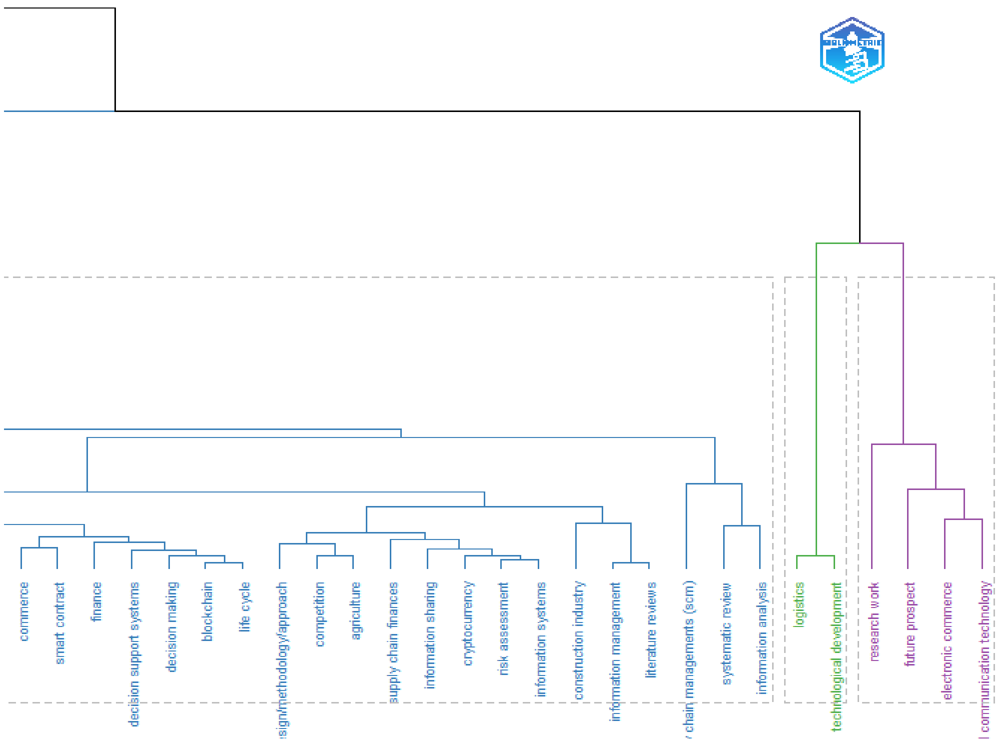

Figure 4.10.2 – Topic Dendrogram (II Half). Source: R Studio.

As we can easily see from Figure 4.10, this grouping process has led once again to the creation of four different clusters that have been distinguished by using different colors. As we have discussed in the previous chapter, the general Hierarchical Clustering Analysis allows the user to arbitrarily determine the final number of clusters; indeed, we have given as input to the software the number 4 as the number of clusters we wanted to identify. This decision has been made in accordance with the subgroups identified during the PCA and the ETA outcome of the Hierarchical Clustering Analysis. In this way, R Studio has provided us with the dendrogram already cut in the most suitable point to achieve the preselected clusters' number. To do so, the software has used the K-means clustering method described in the previous chapter. Table 4.14 reports the result of the co-word analysis, highlighting the most important keywords for each one of the four thematic clusters.

# Cluster	***Most Central Keywords***
1	Sustainability
2	Technology adoption, Supply chain, Innovation, Blockchain Technology, Food Supply Chain, Decision making, Industry 4.0, Traceability, Inventory control, Transparency, Smart contract, Supply chain performance, Information sharing
3	Logistics, Technological development
4	Future prospects, Communication technology

Table 4.14 – Keywords thematic clusters. Source: personal elaboration.

The co-word analysis described in Table 4.14, together with Table 4.13, has been used as the starting point to address, label, and describe the four clusters identified during the previous Principal Component Analysis (Table 4.12). By doing so, the following main thematic keywords have been associated to the four clusters: Supply Chain Management, Technology Adoption, Sustainability, and Food Supply Chain. In the following section, each one of these clusters will be thoroughly discussed and analyzed.

4.7 PCA Discussion

4.7.1 First cluster: Blockchain and Supply Chain Management

The first subgroup is the one that contains the largest number of publications, thereby indicating its centrality in the bibliographic coupling network. Researches included in this cluster are mainly focused on the macro theme of *Supply Chain Management,* upon which also the other three clusters discussed in the following sections rely. In this regard, we can generally define a supply chain as a chain composed of independent organizations which are directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Agi & Jha, 2022). To properly implement an effective supply chain, it is pivotal that all the members involved actively cooperate and mutually share information. On this matter, the studies included in this first cluster point out that Blockchain-based supply chains are radically changing the way companies do business by offering decentralized end-to-end processes.

Babich & Hilary (2020), for instance, have tried to fill the knowledge gap in the literature concerning the implications (potentials and possible downsides) of Blockchain applied to Operations Management (OM). Specifically, they have engaged in a thorough evaluation of the effects of this technology on classical OM problems, such as the Bullwhip effect (studying Production, Procurement, and Inventory Management topics), information flows along supply chains, Supply Chain Risk Management, and queueing optimization. As a result of this analysis, the authors have identified five key strengths (i.e., visibility, aggregation, validation, automation, and resiliency), and five corresponding weaknesses (i.e., lack of privacy, lack of standardization, garbage in garbage out, black box effect, and inefficiency) that Blockchain can bring to OM. On this topic, other authors such as Dutta et al. (2020), Hirata et al. (2020), Varriale et al. (2021), Wang et al. (2021), and Xue et al. (2020) have studied the implications of Blockchain Technology in supply chain operations. Dutta et al. (2020), for instance, have highlighted the potential of Blockchain to transform SCM through its feature of transparency, authenticity, trust and security, reduction of cost, disintermediation, efficient operations, and reduced waste. Additionally, they have investigated the potentiality of mitigating the ripple effect in SC by reducing the disruptions' impacts thanks to the Blockchain implementation. Furthermore, they have also analyzed the industrial sectors that can be successfully improved through enhanced visibility and business process management. Hirata et al. (2020), on the other hand, have brought a critical insight into the literature by pointing out the centrality of integrating Blockchain Technology with the Internet of Things (IoT) to further improve the overall SC efficiency. Xue et al. (2020), instead, have conducted a study with the primary goal of addressing the information asymmetry and distortion typical of supply chains. In fact, they have introduced Blockchain Technology into supply chain operation management, reconstructed information-sharing architecture, and provided a new decentralized way to promote collaboration among all nodes. In this way, they have changed the hierarchical relationship between upstream and downstream members, so that the customers are at the center of the whole system, thus reducing the bullwhip effect.

On the other hand, Mahyuni et al. (2020) have deepened the Blockchain implications in SCM. Specifically, they have focused their research on how this technology can improve SC performance in terms of transparency, traceability, sustainability, trust, and cost-efficiency. These insights have been progressively studied by other authors such as Gligor et al. (2022), who have specifically discussed the recent field of supply chain transparency (SCT). In this regard, the authors have eventually found that Blockchain traceability capabilities are fundamental in enhancing the value of SCT thanks to the possibility of verifying the raw material provenance, including and disclosing additional information regarding the product/service, and documenting real-time flow throughout the supply chain. At the same time, Xu et al. (2021) have discussed how the features of Blockchain Technology impact supply chain transparency through the lens of the information security triad (confidentiality, integrity, and availability). Specifically, they have found that whilst integrity and availability usually promote SCT, confidentiality limits the transparency of the supply chain. However, by implementing Blockchain Technology, companies can overcome this tension between transparency and security and simultaneously preserve them.

Other articles addressing possible different Blockchain applications in SCM have been found. Precisely, Batwa & Norrman (2020) have firstly identified and explored the SC drivers for applying Blockchain Technology. On this point, they have highlighted the importance of knowing the specific drivers in each situation, given that different drivers lead to different applications. Their analysis suggests that lack of visibility, control, and trust are the critical SC drivers that need to be identified to foster Blockchain implementation. Furthermore, they have identified and discussed several potential Blockchain applications in SCM, such as SC

Traceability, SC Integration through Smart Contracts, and Supply Chain Finance (SCF) among others. The result of their analysis eventually suggested that traceability and SCF seem the most suitable applications for Blockchain Technology in SCM. Another study conducted by Malik et al. (2021) has analyzed the Blockchain applications in the Industrial Internet of Things (IIoT) and supply chain systems, thus deepening the insight previously brought by Hirata et al. (2020). In this case, the authors have realized that the Blockchain characteristics (such as immutability, decentralization, and data encryption) can be pivotal in solving the shortcomings of IIoT (such as privacy issues) and the current supply chain systems security and integrity problems.

Finally, another research that needs to be mentioned is the one conducted by Roeck et al. (2020). In this study, the authors have deepened the impacts of Blockchain Technology on Supply Chain Management from a transaction cost perspective. In this respect, they have found some positive effects of Distributed Ledger Technology (DLT) solutions that have a cost-reducing or cost-avoidance impact on Supply Chain Transactions. Precisely, thanks to the increase in transparency and trust along the SC, triggered by the Blockchain Technology implementation, it is possible to have a better decision-making process as well as reduce opportunistic behaviors of SC members, thereby decreasing transaction costs. In the same way, the enhanced transparency helps companies to better evaluate and search for transaction partners and foster information symmetry, thus further reducing costs. Finally, the implementation of smart contracts, that allow an automated process monitoring and enforcement, has once again a diminishing effect on transaction costs.

4.7.2 Second cluster: Blockchain Technology Adoption in Supply Chain Management

As we have seen in the first cluster, Blockchain Technology can drastically improve Supply Chain Management by providing a platform for direct integration between supply chain members to transparently exchange credible and temper-proof data (Agi & Jha, 2022). However, to do so, the technology adoption topic needs to be addressed. As a matter of fact, the second subgroup identified in the literature recognizes the importance of Blockchain implementation in the field of SCM. Indeed, it groups together papers that discuss the main success factors as well as barriers that can boost (or hinder) the adoption of this disruptive technology.

Specifically, in the analyzed cluster, four main studies have discussed the main enablers and success factors of Blockchain adoption. Agi & Jha (2022), for instance, have developed a comprehensive framework for Blockchain adoption in SCM by identifying 20 enablers and empirically evaluating their interdependencies and impact on adoption. In this regard, the authors have included enablers from a technological, organizational, supply chain, and external environment perspectives, and they eventually stated that the relative advantage of the technology as well as the external pressure are the most influential factors that impact the adoption of Blockchain in the supply chain. In the same way, Ghode et al. (2020) have identified and ranked the main factors influencing Blockchain adoption in SCM through a literature review and the analysis of experts' opinions. Their thorough analysis has led to the identification of eight influencing factors, that are, in order of importance: inter-organization trust, interoperability, relational governance, data transparency, data immutability, behavioral intention, product type, and social influence. Similarly, Shoaib et al. (2020) and Tran & Nguyen (2020) have identified other categories of success factors that are able to boost Blockchain adoption in the SCM field. Specifically, the former authors have found 48 success factors which have been subsequently mapped into 11 categories and validated by industry practitioners. In this regard, the Accessibility category, which includes traceability, integrity, and trackability, has gained the highest importance. On the other hand, the latter authors have focused their attention on the impacts that the interaction between UTAUT (unified theory of acceptance and use of technology) and BTRAN (Blockchain transparency) has on Blockchain adoption in SCM, highlighting a positive influence of these factors on the technology implementation. Another study conducted by Falcone et al. (2021) highlighted the importance of studying, together with the Blockchain enablers, the managers' perceptions of and willingness to use this technology for securing a successful implementation. This analysis has identified trustworthiness with regard to competence and distributive justice as the main drivers of managers' willingness to adopt Blockchain.

On the other hand, other authors, such as Bag et al. (2021) and Mathivathanan et al. (2021), have analyzed the potential barriers to the adoption of Blockchain Technology in supply chains that can hinder and impact the businesses decision to establish a Blockchain-enabled supply chain. The first study has specifically focused its attention on examining and prioritizing 15 potential adoption barriers in Green SCM. In this regard, the authors have revealed that the lack of management vision and cultural differences among supply chain partners are the most common general barriers we can find in supply chains; whereas collaborations challenges as well as hesitation and workforce obsolescence are the most influential barriers in the specific case of the Green SCM. In the same way, the second study conducted by Mathivathanan et al. (2021), has analyzed and classified the general adoption barriers based on their strength and dependence. The result of this study highlights that the lack of business awareness and familiarity with Blockchain Technology on what it can deliver for future supply chains are the most critical barriers that hinder Blockchain adoption.

Finally, other two papers belonging to this "technology adoption cluster" have described the adoption of Blockchain in the supply chain with the main goal of combating copycats and deceptive counterfeits (Pun et al., 2021; Shen et al., 2022). Thus, the authors have analyzed the effectiveness of Blockchain as a solution to these types of supply chain challenges as well as the pivotal role that governments should have as decision maker in the technology adoption process.

4.7.3 Third cluster: Blockchain and Sustainability

The third subgroup identified by the PCA groups together articles addressing the impacts Blockchain-enabled supply chains can have on Sustainability. Although this cluster contains a lower number of publications when compared with the other subgroups, the content analyzed is extremely important and popular. Indeed, several authors included in other groups make occasional, but insightful, references to this pivotal topic, such as Bag et al. (2021) when discussing the adoption barriers in Green Supply Chain Management.

The articles included in this cluster focus their attention mainly on the transformation of Circular Economy (CE) practices and business models triggered by Blockchain Technology. In this regard, Khan et al. (2021), by collecting data from 404 enterprises, have discussed the role of Blockchain in CE and its impact on eco-environmental performance which influence organizational performance. In fact, they have found that the tracing and tracking systems allowed by this technology can drastically help companies to monitor the origin, real-time location, and status of any products in the SC network, thereby fostering the reusability, recyclability, and circularity of their supply chains. Additionally, these new CE practices have a positive impact on companies' financial as well as organizational performance. Two of the authors of the article just described (i.e., Syed Abdul Rehman Khan and Zhang Yu) have collaborated with other researchers to dive deeper into the role Blockchain Technology is progressively acquiring in the circular SCM. Indeed, in this other paper, Rehman Khan et al. (2022) have examined the role of this technology in enhancing organizational performance in the context of China-Pakistan-Economic-Corridor (CPEC). Once again, the final result has highlighted the positive impact that visibility, transparency, and smart contracting have on the environmental performance as well as the SCM of the organizations. Linked to this topic, Huang et al. (2022) have discussed the critical Blockchain enablers for Circular Supply Chain Management (CSCM), namely leadership, goal alignment, partnership trust, and stakeholder participation.

Additionally, Parmentola et al. (2022) have engaged in systematic literature review to understand whether Blockchain can affect environmentally sustainable development goals

(SDGs) by, for instance, supporting the implementation of a sustainable supply chain, improving energy efficiency and promoting the creation of secure and reliable smart cities. Their study has eventually revealed that Blockchain can indeed facilitate new means of green production, the storage and analysis of green or low carbon data for timely decision making, as well as, the development of a green supply chain.

4.7.4 Fourth cluster: Blockchain Application in Food Supply Chain (FSC)

As previously discussed, Blockchain with its unique characteristics (such as transparency and traceability) can be the solution to several issues encountered by industries and supply chains. Although different applications have been discussed and studied in the current literature, the adoption of this cutting-edge technology in the Food Supply Chain (FSC) has gained quick popularity. In this regard, the fifth subgroup reflects this trend by including papers specifically dedicated to the implementation of Blockchain in the FSC and the, more general, agri-food industry.

As a matter of fact, food traceability, food safety, food integrity, food quality, and food delivery are becoming determinant factors in the food industry along the whole supply chain, from the farmer to the final customer (M. H. Ali et al., 2021). In fact, as discussed by Guido et al. (2020) in their study, after the recent-years food scandals, customers are becoming more demanding and wary, thereby forcing the food market to segment the customer base in new ways related to price, quality, innovation, area of origin and health content of food. Thus, accordingly to Guido et al. (2020), to achieve this goal and meet the changing demand, the actors operating in the upper hand of the FSC should start implementing well-designed traceability systems taking advantage of the Blockchain Technology. This is a pivotal step in that, the unique strengths of this technology can help the companies to enrich the perceived value of their products as well as the related brand awareness, thanks to the considerable amount of information that can be gathered and transparently shared with the customers (Guido et al., 2020). Other relevant studies, belonging to this cluster, have focused their attention on the positive impacts transparency, traceability, immutability, visibility, integration, disintermediation, and decentralization can bring to the FSC. Specifically, Saurabh & Dey (2021) have focused their attention on the grape wine supply chain and demonstrated that the application of Blockchain in the agri-food industry can actually improve process transparency and efficiency, strengthen trustworthiness, remove unnecessary intermediaries from the supply chain, as well as enhance the customers' confidence for traceable food products (Saurabh & Dey, 2021).

Other authors, such as Dinesh Kumar et al. (2020), Kayikci et al. (2021) and Rana et al. (2021) have decided to focus their studies in additional areas. Specifically, Dinesh Kumar et al. (2020) demonstrated two main hypotheses. Firstly, they discussed how Blockchain can ensure the traceability and reliability of each transaction in the food supply chain, focusing on the possibility that the technology can be used to verify the authenticity of transaction documents. Secondly, they discussed how the technical advantages of Blockchain can bring new regulatory ideas to the government as well as new tools to enterprises to ensure food quality and assure a quick response to changing market conditions. Kayikci et al. (2021), instead, focused their study in the advantages that Blockchain Technology can bring to companies when facing outbreaks. Specifically, they identified some factors (decentralization, consensus mechanisms, and interoperability among others) as pivotal to allow FSCs to be more responsive, flexible, efficient, and collaborative while coping with outbreaks such as the COVID-19. Finally, it is worth mentioning the work of Rana et al. (2021). These authors, together with the aforementioned benefits, highlighted the challenges Blockchain Technology can lead to, such as scalability, privacy leakage, high implementation and infrastructure costs, as well as connectivity problems.

4.8 Limitations

The main goal of this thesis is to provide a representation of the intellectual structure and current state of the literature addressing Blockchain and Operations Management. Although the research field analyzed is relatively new, the number of articles published from 2016 until the first half of 2022 is considerably high. For this reason, we had to restrict the time span of the analysis considering only the publications between 2020 and July 2022 to reduce the set of articles into a manageable size. Although this decision could have led to the exclusion of relevant papers, we have taken as a point of reference an excellent bibliometric literature review published in 2020 by researchers Musigmann, Von der Gracht, and Hartmann that analyzes all the articles published between 2016 and 2020. Additionally, although this article focuses its bibliometric analysis on the specific field of Supply Chain Management and Logistics, we do not believe that critical articles addressing the more general topic of Operation Management have been excluded. Indeed, as explained in section 3.3 only one article published in 2019 addresses the impacts that Blockchain can bring from an accounting transaction execution and tax implication point of view. For these reasons, we believe that such limitations have not hindered the robustness of our analysis.

Nonetheless, the bibliometric literature review presented in this thesis has been carried out by performing several analyses that have intrinsic limitations. In this regard, the direct citation analysis has some structural weak points due to the fact that it relies only on citations indexes. Specifically, by analyzing the citation frequency, it is extremely difficult to distinguish between positive and negative citations (Zupic & Čater, 2015). Indeed, although infrequently, there may be some situations in which a document is cited with the only aim of criticizing its literature contribution. However, this citation is still counted in the frequency computation. Secondly, some authors may try to mislead the citation frequency index by deploying self-citation or team self-citation. The other limitations that can be found in our thesis are related to the Bibliographic Coupling. Indeed, contrary to the direct citation, this analysis does not rely on citation frequencies but only on citing references. Although this can prevent the limits discussed above about citation frequency, it does not allow researchers to filter the set of articles according to the number of citations, thereby impeding the identification of the most influential publications in the research field (Zupic & Čater, 2015).

4.9 Conclusion and direction for future research

In this chapter, we have discussed the main results of the bibliometric literature review on Blockchain and Operations Management. These outcomes have been achieved by deploying a performance analysis as well as direct citation analysis, bibliographic coupling, and co-word analysis of documents published between 2020 and July 2022. Although this research field is extremely recent, we have discovered that numerous authors, coming from different countries, find these topics extremely interesting, thereby strengthening the current positive trend of number of new articles published. In this regard, we have ascertained that the main areas addressed by these scholars relate to the interrelation between Blockchain and Supply Chain Management, the impact of this technology on sustainability matters, the positive and negative factors that influence the technology adoption in SCM, and the specific application of Blockchain in the Food Supply Chain.

Furthermore, the analysis presented in these chapters has provided directions for future research. On this matter, we have highlighted the fact that the adoption of Blockchain Technology in several Supply Chains is at a nascent stage; thus, more research studies on Blockchain implementation are necessary to extend the knowledge base. In fact, the current studies that analyze the application of this cutting-edge technology on SC (such as food, hospital, and tourism among others) are disperse and uncorrelated, thereby making more difficult the generalization of their findings. Therefore, new studies on these same as well as new applications should be carried out to have a better understanding of the general implications, success factors, enablers, and barriers involved in Blockchain adoption in SCM.

As we have pointed out in the previous chapters, the field of Operations Management is extremely wide and goes beyond the already mentioned Supply Chain Management. However, in the current literature it is difficult to find researches and studies that discuss Blockchain implementation taking into consideration the wider area of Operations Management. In fact, among the 156 articles analyzed, only the study performed by Babich & Hilary (2020) "*Distributed ledgers and operations: What operations management researchers should know about blockchain technology*" has explicitly investigated the impacts this Technology may have on several classical OM problems. However, although enlightening, this single article cannot be considered enough to properly understand and analyze all the internal and external implications of deploying BT. Thus, it can be deemed critical for the advancement of the research field, to investigate also the impacts that the adoption of this technology has inside the organization and not only as a mediator between external actors. Additionally, in the current literature, it is not clear how an enterprise should practically approach and transform its operations to implement Blockchain Technology. Indeed, the analyzed literature does not address and define a practical and general roadmap that companies should follow when deploying such technology in their external or internal operations.

In light of the foregoing, in the next chapter, we will try to contribute to filling in some of these knowledge gaps in the existing literature by analyzing an empirical study.

CHAPTER 5 – BLOCKCHAIN IMPLEMENTATION ROADMAP DEFINITION

5.1 Introduction

In this chapter, we use an empirical study to shed light on some of the gaps identified in the current literature. In this regard, our main objective is twofold: firstly, we aim at contributing to the extant literature on addressing the possible impacts the Blockchain implementation may exhibit inside an organization; secondly, we focus on the definition of a comprehensive implementation roadmap that defines the main steps companies should follow to correctly tackle the challenges this transformation journey implies. To do so, we have identified and discussed an emblematic case study from which we have eventually derived and generalized the main steps of the Blockchain implementation roadmap.

5.2 Literature Gaps and Research Question

As previously discussed in Section 4.9, the bibliometric literature review performed in the previous chapters helped us identifying some consistent gaps in the literature. Specifically, despite the large number of articles that have been published during the short time span considered 2020:2022, we have found that the majority of these recent studies mainly focus their attention on the possible benefits and risks of Blockchain implementation in the specific area of Supply Chain Management, thereby concentrating on how this technology can impact the relationship among external actors. On this matter, it has been deemed critical for the advancement of the research field, to describe also the impacts the technology adoption can have inside the organization.

Together with this description, another critical point has been extensively discussed throughout this chapter. Specifically, it has been pointed out that in the current literature it is not clear how an enterprise should practically approach and transform its operations to implement Blockchain Technology. Indeed, the analyzed literature does not address and define a practical and general roadmap that companies should follow when deploying such technology in their external or internal operations. Hence, the present thesis mainly aims to define a comprehensive roadmap that companies willing to implement BT may follow. Specifically, it focuses on the road mapping of the main general steps and initiatives an organization should undertake when starting a Blockchain transformation journey. However, given the high variety of possible different implementation projects with their own specificities, the identified steps and milestones should be seen as the main general activities that can be applied to almost all the projects. To do so, a pivotal research questions has been identified:

RQ: *What are the main steps a company willing to implement the Blockchain Technology should follow? That is, what is the general high-level roadmap a company should follow?*

In light of these gaps in the literature, we designed a qualitative research with the aim of studying a project implemented by a global company leader in the automotive industry. Hence, in this way, we have been able to answer to the research question while, at the same time, providing a thorough description of the main Blockchain implementation internal impacts and benefits.

5.3 Case Study Design and Methodology

To achieve our goal and find the right answers to our research questions, we have adopted a discovery-oriented approach to conduct an in-depth, single case study where the case firm and its Blockchain implementation project have been actively studied. In this regard, as the internal impacts derived from the adoption of this technology and its roadmap are not deeply addressed in the current literature, the single case study has been deemed appropriate to address these complex and little-studied phenomena and advance theoretical understanding. In fact, as stated by Crowe et al. (2011), the case study approach is particularly useful when there is the need to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context. Its major strength is the possibility of tailoring the design and data collection procedures to the research question (Meyer, 2001), thus capturing information on more explanatory *what, how*, and *why* questions (Crowe et al., 2011; Meyer, 2001). Therefore, this approach can help researchers developing or refining theory (Crowe et al., 2011).

According to Stake (1995), there are three main types of case studies that are not mutually exclusive: intrinsic, instrumental, and collective. An intrinsic case study focuses on a unique phenomenon that is different from all others. On the other hand, an instrumental case study uses a specific case to gain a broader appreciation of an issue or phenomenon (Meyer, 2001). Finally, the collective case study selects and simultaneously (or sequentially) studies multiple cases to generate an even broader understanding of a particular issue. Although multiple cases add confidence, and external validity as well as allow the generalizations of findings, we have decided to perform a single case study to gain a deeper understanding on the implementation project at hand. In this regard, we have undertaken an intrinsic case study to investigate the impacts of Blockchain implementation in the Program Management System (PMS) of a leading company. We have categorized it as intrinsic due to the uniqueness of this project with respect to what has already been addressed in the extant literature. However, this case study has been then developed into an instrumental one given that we have tried to understand and map the main general steps a company should undertake when tackling such implementation projects, thereby generating a number of findings that are potentially transferable to other projects.

The involved firm is a European manufacturing company that operates in the global automotive industry. Given the uniqueness and peculiarity of the implemented project, we have not obtained permission to disclose the real name of the company in question. Thus, to guarantee the anonymity and the protection of sensible private information, we will refer to this organization as *Company X*. *Company X* is a global automotive tier-one supplier, specializing in parts manufacturing, vehicle interiors, and the development of mission control technology. It is formed by three main Business Groups (BG); namely, BG 1, BG 2, and BG 3. The first one (BG 1) is focused on the development of technologies for air quality, energy efficiency and thermal management, lightweight, and acoustic performance; the second (BG 2) designs and manufactures seat structures, manual and electrical seat mechanisms, comfort products, and systems, and it also focuses on the complete seat assembling process; the third Business Group (BG 3), instead, focuses on the internal parts of an automobile, such as center console and acoustic modules, door panels, center console, and acoustic modules. In addition to this complex structure, *Company X* boasts 257 production sites worldwide, 39 R&D centers with 213 new programs launched in 2021. In this regard, more than half of its production sites operate on the Just-In-Time (JIT) principle, thus highlighting its attention to waste reduction and efficiency improvement. Its presence is not confined to its national territory; rather, it extends its business to 33 different countries around the world, counting more than 111,000 employees.

5.3.1 Program Management System (PMS)

Before diving into the case study, to better understand *Company X*'s Blockchain implementation, a brief explanation of Program Management System and its differences with respect to Project Management System should be portrayed. In fact, although some of the tools and techniques used may be similar, the two activities and related roles in an organization are radically different.

A program can be defined as a group of projects managed in a coordinated way to obtain benefits not available from managing them individually (Walenta, 2004). That is, the program is the temporary organization that brings correlated and activities and projects together in a coordinated way; focusing both on managing the interfaces between projects as well as on the ongoing activities. Typically, the program lasts longer than the duration of the longest activity or project because it sequences them. That is, the projects contained inside a program do not happen concurrently; rather, one activity follows another. In this regard, part of the value of a program relates to the fact that, thanks to its strategic nature, over time it can be flexible, thereby dropping some projects and initiating others. Hence, the outcomes of a program are usually of strategic importance to the organization, given that they mainly aim at generating value for the company itself. In this regard, Program Management Systems come into play to actively manage, coordinate, and implement the company's programs constituted by related projects, activities, and initiatives, with the final goal of realizing value.

Another way to think about programs and better understand the overall context is to look at an organization as a pyramid with five layers. At the very top of the pyramid, there are the mission and vision of the company, which set out the organization's purpose and aspirations, or even better, the destination the company is seeking to reach. At the next tier of the pyramid, we can find the strategy of the organization, which is a long live process. It sets out the direction of the company to actually reach and pursue the defined mission and vision. Next is the tier of the portfolio which translates the strategy, and gives structure to what the organization is going to do to make the strategy happen. Moreover, the portfolio sets priorities and aligns all the organization's activities in the direction the strategy sets out, thereby delivering value to the company itself. Below the tier of the portfolio, there is the one of programs, which deliver benefits that cumulatively bring value to the organization. Finally, at the bottom, there are the projects, activities, and initiatives that make up the different programs. In this regard, projects can be defined as single, focused pieces of work with a specific scope and defined output. They generally relate to creating, updating, or reviewing a particular document, process, outcome, or another single unit of work and have a set of clearly defined tasks as well as a short or medium-long-term deadline for completion. The corresponding Project Management System can be defined as the process of delivering value that incrementally moves a program forward (Mallek, n.d.); that is, it refers to the process of leading a project performed by a team to achieve certain goals.

Although Project Management Systems are critical to properly define the standards, get the right skills and key stakeholders onboard, divide the ownership of the work and outline the expected deliverables, it is through programs that the company coordinates the different projects. On this matter, we can define seven main internal concerns related to Program Management Systems (PMS). The first of them is management itself, which can become extremely difficult given the need of coordinating all the different projects and activities. Secondly, it is necessary to maintain and show corporate organizational leadership across the span of the different projects. Thirdly, the organization needs to make sure that each program delivers the expected benefits which contribute to the value of the overall portfolio that the company has created. Another important concern is the definition of the approach applied to the programs. In fact, it is pivotal to reach the right balance between certainty, confidence, and control on the one hand, and flexibility, adaptability, and agility on the other hand. Indeed, programs can and should change as the environment changes, by including new projects and eliminating old ones depending on the portfolio's need to be adjusted. Next, it is critical to understand and define the allocation of resources inside a program among different projects, as well as identify the capabilities that their individual projects and initiatives need. Finally, another fundamental aspect of PMS is communication. Indeed, whilst each project communicates with its stakeholders, the program needs to communicate to the organization the changes undertaken and how those changes are going to be coordinate. Hence, although a lot of these concerns are similar to the equivalent concerns within project management, they have a different perspective. In fact, Program Management is all about coordinating a number of related projects and initiatives to make sure that they deliver the benefits promised.

Despite the possible adoption of agile tools and frameworks, finding the right trade-off among all these internal PMS concerns is extremely challenging. On this point, as in the case of *Company X*, Blockchain Technology may provide the solution to organizations willing to efficiently and transparently manage its portfolio of programs without losing control and flexibility on the several projects and activities.

5.4 Case Study Discussion

As highlighted before, half of the production plants of *Company X* operate on the Just-In-Time (JIT) principle. This willingness to smoot every single aspect of its internal and external operations as well as to adopt agile tolls and frameworks has distinguished the company over the recent years. However, although these tools may bring considerable effectiveness and efficiency to the organization, they are not free from drawbacks.

5.4.1 PMS and Potential Blockchain Implementation Gains

As previously discussed, inside an organization, Program Management Systems have several concerns and trade-offs to maintain. However, with the increase in the number of programs, projects, activities, and initiatives that need to be managed all together, it can become challenging maintaining flexibility, control, agility, certainty, good communication and smooth flow of information all at once. In the specific case of *Company X*, its internal Program Management System has been considered as the pivotal tool to properly manage a complex portfolio of more than 600 programs across the three Business Groups; where each one of these programs has its own complexity and peculiarity. This high-complexity environment has led to the development of a robust but heavy and rigid PMS, which has been followed by a core team of up to nine members among which we can find the Program manager, Program Controlling, Costing, Program Sales Leader, Program Buyer, Tool & Equipment Program Buyer, Program Quality Leader, Program Plant Team Leader, and Production Control & Logistics (PC&L).

In this regard, as stated before, inside each program we can find an aggregation of different interdependent projects, which in turn are made of several activities. At this level of analysis, to actually understand and keep track of what needs to be performed inside each project, the Work Breakdown Structure (WBS) is used. The WBS is the main tool used to describe the scope of the project, as it divides the work necessary for its realization into several levels and smaller portions, where each subsequent level involves a more detailed work definition. In this way, it becomes easier to carry out the scheduling, cost estimation, as well as monitor and control the planned work which is defined in the components of the WBS at a lowest level of the hierarchy - also called Work Package (WP). However, in the case of *Company X*, some WPS reached more than 300 WPs, thereby hindering the overall effectiveness and efficiency of the PMS. Additionally, each one of these WP was usually associated with measurable and controllable KPIs, whose presence allowed the owners to be sure of the actual completion of the singles WP. However, once again, the increased complexity of the programs' portfolio, lead to the definition of standardized and specific KPIs (such as, Time to Pass (TTP) for operation performance and Operating Income for financial performance) that limited the flexibility and agility of the PMS itself. Moreover, this structured PMS was spread across five gates with the aim of providing communication opportunities as the activities moved through completion as well as evaluating the possibility of deploy process change management. However, this gate structure contributed to the rigidity of the system itself.

In light of these PMS' drawbacks, *Company X* decided to investigate the possibility of using Blockchain Technology to manage its portfolio of programs. As highlighted in the previous chapters, Blockchain applications are already ongoing in areas such as supply chain, quality or controlling; however, given that Blockchain is a Distributed Ledger Technology (DLT) for securely transmitting any type of information without the control of any central authority, it can bring numerous valuable internal advantages also to a company's Program Management in terms of information sharing, execution control, and reporting automation, among other things. Indeed, as summarized in Table 5.1, Blockchain Technology can offer specific features that are extremely relevant for *Company X*'s programs and that can lead to significant internal efficiency gains.

Blockchain features	***Applications to Company X programs***	***Efficiency***	***Other Internal Gains***
Holistic view and Transparency	Shared & real-time status of activities/deliverables across the ecosystem and between functions.	● ● ●	• Better anticipation & risk mitigation • Less idle time
Smart Contracts to trigger actions	Automatically updated status based on approved deliverables (e.g., status/milestones based on expected deliverables).	● ● ●	• Better cash collection • Less idle time
Immutability and Inalterability	Greater accountability of stakeholders/functions and access to information and commitments.	● ●	• Improved claim management • Analytics-driven insight (e.g.. supplier performance)
Dynamic and personalized access right management	Control what is shared between OEM, *Company X*, other Tier 1 and Tier 2 suppliers depending on program context, nature of the relationship.	● ●	• Total control on who gets to see what

Table 5.1 – Blockchain internal benefits for Company X. Source: personal elaboration.

Hence, in light of these critical benefits, *Company X* decided to implement Blockchain to achieve efficiency gains all along program development. Although *Company X* is the main actor involved and the pioneer of this technology transformation in its ecosystem, it is pivotal to highlight the inevitable impacts this implementation has on the whole ecosystem in which the organization still operates. Indeed, an internal change implies external impacts and vice versa. Thus, it is necessary to take into consideration also the effects Blockchain has on *Company X*'s Tier 1 and Tier 2 suppliers as well as on its Original Equipment Manufacturer (OEM). In this regard, *Company X*'s Blockchain implementation project has the main goal of transforming the existing PMS vertical approach, where the Program Manager has always been the "focal point" for every interaction among actors, into a Blockchain-driven approach, where information is transparently shared across the entire ecosystem. Figure 5.1 illustrates *Company X* ambition.

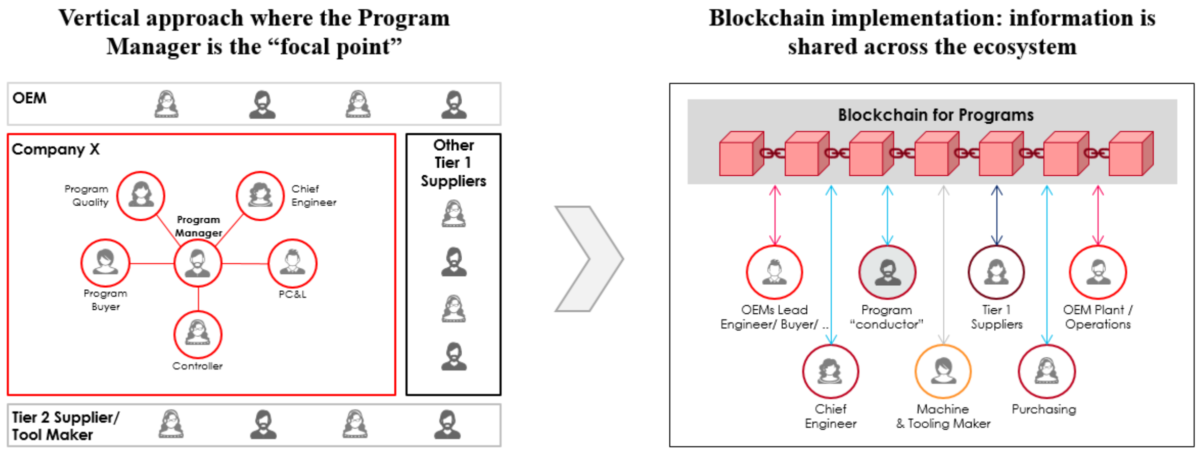

Figure 5.1 – Shift from Vertical Approach to Shared Ecosystem. Source: private documents' personal elaboration.

With the current vertical approach, Program Managers cover a central role in their organization. In fact, they need to perform several activities at once, such as delivering artifacts, engaging with strategic decisions, managing different stakeholders, and mitigating risks across the programs (Mallek, n.d.). Despite existing agile frameworks justify the centrality of this role, it is crystal clear that companies have an extremely high dependency on it, thereby hindering its flexibility. This inevitably leads to numerous non-value added activities, such as coordination and reporting, that need to be performed by Program Managers themselves to guarantee a smooth and regular information flow. Additionally, this smoothness of processes and information may be hindered by some actors that withheld some critical information, thus leading to the creation of critical bottlenecks. Among the several possible causes of these issues, the lack of transparency has a pivotal role. Indeed, bottlenecks, misunderstandings, and costly errors may be carried out, thereby lowering the overall efficiency of the program itself. Hence, with Blockchain Technology implementation, accountability, transparency, and efficiency gains could be easily reached. Indeed, the accountability of every single activity goes in the hands of the task owner, thus increasing transparency and trust among the actors involved. In this regard, Blockchain can drastically restore the transparency and trust by allowing the direct access to certified and real-time information as well as the elimination of non-value added activities performed by Program Managers. Moreover, the traceability of digital and physical assets can allow to be more right-first-time and reduce once again costly errors.

In practice, on a high-level overview, Blockchain can be considered and positioned as a ledger federating all activities and information from tools and processes of all parties involved. In other words, Blockchain can become the "shared memory" of transactions between the different actors involved in each program, with also the possibility of defining channels of confidentiality thanks to which not all the information is available and visible to all actors but only to the necessary ones, thereby protecting private information.

5.4.2 Blockchain Implementation Approach

In light of the Blockchain implementation benefits and internal impacts described in the previous sections, it is now pivotal to describe the approach adopted by *Company X* to transform these gains into reality. Specifically, the first critical step has been the involvement of an external consulting firm (i.e., Accenture). This decision has been made to increase the possibility of succeeding in the Blockchain implementation journey, by benefiting from Accenture's technological knowledge in the field of Blockchain.

The second phase has been the definition of the methodology that needed to be used to actually implement the BT. That is, the technology as well as *Company X*'s needs have been deeply investigated, so that it has been possible to identify the matching points to transform them into opportunities. Figure 5.2 illustrates the detailed roadmap based on agile methodology that *Company X* has followed. Currently, *Company X* has just finished the first "Discovery and Set Up" phase and it has already approached the second one.

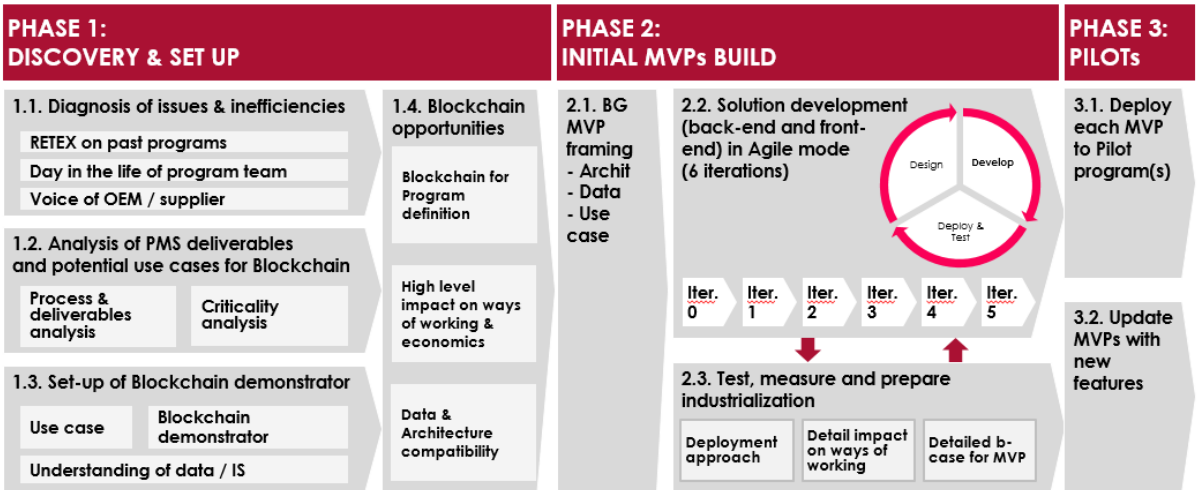

Figure 5.2 – Blockchain implementation Roadmap. Source: private documents' personal elaboration.

The first initial phase has been all about the definition of the current company's status (AS-IS), its issues and drawbacks and the setup of a Blockchain demonstrator right from the beginning. Specifically, the starting point has been the definition of the existing pain points and the scope of the Blockchain implementation. To do so, Accenture and *Company X* organized five working sessions with 20 employees as well as more than 45 interviews. This combination of a top-down approach (through meetings & workshops) and a bottom-up approach (through field interviews) allowed the matching of field needs and top management expectations as well as the appropriation and sponsorship of *Company X* workforce at all levels. On this matter, the interviews have been carried out by involving all the several functions involved in the program management teams, with the main goal of identifying operational pain points and inefficiencies. Once the interviews have been carried out, the highlighted challenges have been reviewed and mapped. Subsequently, *Company X* and Accenture have identified and prioritized the domains for Blockchain implementation that needed to be investigated for the MVPs development. Additionally, a detailed view on the established company's processes has been carried out. Finally, they have investigated the impacts of the solution developed on the ways of working as well as reviewed the related internal economics aspects (e.g., efficiency gains and cost savings) and technical aspects. Once these activities have been performed, the Blockchain demonstrator has been developed and the next steps on MVPs development have been discussed.

Once the first "Discovery and Setup" phase has been completed, the implementation journey entered the second phase "Initial MVPs build". In this step, it is critical to start framing the Minimum Viable Product (MVP) for each Business Group by looking at its architecture, available data, and use cases. In this way, it is possible to define the domain of each MVP depending on the criticalities and inefficiencies of each BG. Afterward, the solution needs to be developed (back-end and front-end) following an agile methodology. On this point, *Company X* will follow the Design-Develop-Deploy & Test cycle, which is a structured progression of work steps from designing to testing a MVP. Although these steps are usually executed in succession, steps can be executed multiple times before a cycle completes; indeed, sometimes the results achieved at one step may lead back to several previous steps. In the case of *Company X*, six iterations will be performed, so that it will be possible to test, measure, and prepare the solution for industrialization.

Finally, the third phase entails the deployment of each MVP to the selected pilot program(s). In fact, the main goal is to initially start with a small program scope related only to some candidate programs and few pilots, which will be then followed by a fast deployment to other new programs until the whole PMS will be involved. Furthermore, together with this fast scalability objective, new valuable features should be constantly added to the existing MVPs.

In the next sections of this thesis we will discuss the achievements of the first phase of the implementation journey and the future steps the company is going to undertake to follow the milestones pointed out in the Roadmap of Figure 5.2.

5.5 Case Study Achievements

5.5.1 Discovery and Potential Implementations for Future MVPs

As highlighted in the roadmap, after having analyzed the inefficiencies related to past programs and existing relationship with OEMs and suppliers, *Company X,* with the help of the consulting firm, has started to fully understand the established PMS as well as assess the Blockchain relevance for particular domains. Specifically, during these preliminary analyses, it has been stated that Blockchain can be used in the overall PMS to share the status of all tasks across parties, to automate certain activities and status changes, as well as save time in coordination, management, and administrative activities. In fact, with the adoption of this cutting-edge technology, it is possible to drastically eliminate and reduce a number of non-value added activities. In light of this, the real benefits Blockchain could bring to different areas inside the overall PMS have been investigated. Indeed, it has been pivotal to firstly look at the potentiality of Blockchain adoption on specific smaller PMS domains before thinking of implementing this technology on a broader scale. In this regard, six main domains have been identified.

The first area relates to the Engineering Change Request (ECR) activity, which refers to a formal request process to make any desired change(s) to a product(s) design. As every request process, different actors are involved in the continuous exchange of information; thus, Blockchain could provide the link between change request backlog, validation, CAD versions, and physical releases, thereby smoothing the flow of information and reducing the number of non-value added activities. In the same way, when looking at *Company X* products, processes, and plants readiness, tooling and equipment activities need to be performed. In this area, Blockchain can bring once again the link between the status of tooling kick-off and test campaigns as well as traceability of raw materials. Another benefit related to products and processes is the usage of Blockchain to keep an updated status of the latest CAD version and latest approvals. Furthermore, in the domain related to manufacturing and Supply Chain, the technology can be used to enhance the traceability of physical assets. Other two areas that can be affected by Blockchain implementation can be the contract management field, where Blockchain can help storing and sharing key parameters of contract across actors, and the so-called PPAP (Production Part Approval Process). On this last domain, Blockchain can help sharing status of the part approval flow across the different actors involved, automate some of the performed tasks, and trigger automatic payments after the PPAP approval.

Despite the importance of all these areas, Accenture and *Company X* have prioritized the first three main domains to be investigated for MVPs development, each of them being led by one of the three Business Groups. By doing so, the following three MVP use cases have been considered: Tooling, Change Request, and PPAP. Starting from the Tooling process, it can be defined as the specific part of PMS that refers to the process of acquiring the manufacturing components and machines needed for production. It covers the specification, ordering, reception, testing, and follow-up of automotive tooling. On this matter, through the interviews held during the first phase of the journey, emerged that there was a lack of traceability and link between tooling engineering levels, tested parts, and test results as well as a manual and inefficient tracking system of the whole Tooling process, form tooling kick-off to the identification of Standard Operating Procedures (SOP). Thus, the use case that has been considered, has the main goal of providing all actors involved (e.g., OEM, tier 2 suppliers, toolmakers, etc.) with a status on all tools, offering traceability of raw materials and parts from material providers to *Company X*, as well as easing test campaigns by sharing test results, engineering levels, tested parts, etc. across all the engaged actors. Indeed, Blockchain implementation in this domain could easily provide transparency and traceability along the different Tooling steps: tooling design, tooling manufacturing, test campaigns at the supplier's site, shipment, and test campaigns on parts manufactured at the *Company X*'s site. In this way, the company can achieve higher efficiency thanks to a lower need of tooling and equipment maintenance and less idle time, as well as cost avoidance thanks to a better spare parts management, which can decrease the level of inventory and increase the cross-site synergies. Moreover, the automation of Purchase Orders, invoices, and payments can provide a better Cash Conversion Cycle (CCC); whilst, the new Tool Tracking system can reduce the time needed to have correct information on tools and equipment status.

The second MVP domain investigated refers to the Change Requests, where Change management activities and processes allow to handle all requests and implementations of engineering changes throughout the program life. During the interviews, it has emerged that there has never been a shared and unquestionable tracking system for ECR proposition, validation, and implementation status. Moreover, it emerged a lack of clear vision on the ECR-related cash balance and payment documents such as Purchase Orders (POs), invoices, and payments. Thus, with Blockchain implementation the company aims at tracing the CR status from validation to implementation (which coincides with the physical release) and from CR backlog to validation. These benefits inevitably lead to a better coordination between Program teams, stakeholders as well as better traceability of CRs through KPIs (e.g., time to validate, volume of work, etc.). Additionally, it can decrease the planning risks, obsolescence (scraps), rework, and the overall lead time thanks to less CR perturbations and higher control. Furthermore, Blockchain can make possible the sharing and streamlining of the validation process of each individual ECR, thereby increasing the tracking efficiency of bottlenecks in the ecosystem.

Finally, the third domain that has been investigated refers to the PPAP (Production Part Approval Process), which is defined as a set of tests and certifications aiming at ensuring that suppliers can meet production requirements in terms of quality and quantity. During the interviews, it emerged once again the lack of transparency on the current status of PPAP as well as PPAP deliverables across the actors involved. Additionally, no systematic and shared tracking system for cash balance and payment triggers (i.e., the realization of pre-determined conditions) has been pointed out. Hence, Blockchain can make the company achieve efficiency gains by automating labor-intensive tasks during the PPAP process and status updates as well as automatically triggering the payments between stakeholders once the PPAP has been approved. Furthermore, Blockchain can provide a dashboard of all PPAP's status to OEM, Suppliers, and *Company X*, thereby enhancing transparency and trust among actors.

In light of the foregoing, the first step will be the deployment of these three MVPs as the starting point in each one of the three domains. By doing so, initially, only a few pilots with several programs (restricted to each area) will be developed. Afterward, the Blockchain implementation will be rapidly extended to new programs always inside the scope of the three selected domains. Eventually, the overall scope will be expanded to the full program scope, thereby implementing the technology to all the six domains that constitute *Company X* PMS.

The first phase of investigation on and set up of the possible domains in which Blockchain can be implemented has immediately shed light on the real benefits this implementation can provide. Indeed, it has been discovered that the technology can bring to the organization substantial internal efficiency gains as well as new ways of working. Tables 5.2 and 5.3 sums up the main direct and indirect benefits the technology can provide to different internal *Company X* roles.

		Roles	***Benefits***
Direct-Team Efficiency	Program Team	Program Manager	Better coordination / sending information across team
		Program Dev. Lead	Less time ensuring synchronization between ECR, CAD versions, etc.
		Program Manuf. Lead	Better anticipation of program launches issues
		Program Quality Lead	Less time providing reports / status to OEM Qualify leads
		Ad. Supplier Quality	Less time seeking information from suppliers on status of parts
		Program Controller	Less time seeking PO / resolving invoicing issues

	Program Buyer	Less time seeking historical data / checking past performance
	Program Sales Lead	Less time seeking PO / resolving invoicing issues / discussing ECR
Other Key Roles	Validation Engineer	Less time linking validation results and associated parts and data
	Tool Tracker	Less time exchanging status info between parties
	Purchasing	Less time seeking historical data & managing POs / invoices, etc.
	Supplier Quality Assurance	Less time coordinating and gathering status / other information

Table 5.2 – Direct Implementation Benefits. Source: private documents' personal elaboration.

	Savings	***Rationale***
Indirect Benefits	Improved efficiency and less FTEs (Full-Time Equivalent)	Reduce idle time and cut non value-added tasks through transparency & automation
	Cost avoidance	Better manage risks, increase right-first-time and avoid rework / scrap through traceability and instant information
	Improved cash management	Recover cash more quickly through traceability and automation

Table 5.3 – Indirect Implementation Benefits. Source: private documents' personal elaboration.

Together with these benefits, the Blockchain implementation in the investigated domains is able to define new ways of working. Specifically, thanks to the increased visibility, transparency, and trust among actors involved, the accountability is shifted to the functions in the ecosystem. Additionally, the Program Manager itself can act more as a strategic pilot, thereby covering a completely new role. Blockchain can shift the traditional gate review approach of the established PMS with less reviews and more risk anticipation as well as define new best practices. All this will lead to a flattered ecosystem with a drastically lower hierarchy among actors involved (e.g., *Company X*, OEMs, Tier 2, etc.), thus making possible to define clearer and healthier rules of the game. Despite the remarkable benefits and new ways of working that Blockchain implementation alone can bring to a company, it still needs the support of other modern digital tools to successfully automate tasks, such as Internet of Things (IoT) among others.

5.5.2 Set Up

After having investigated the best implementation domains and the related benefits, the next practical step has been the Set Up. Specifically, *Company X* has carried out the assessment of several Blockchain vendor characteristics to eventually select the best candidate for its specific use cases. To do so, Accenture and *Company X* defined five critical characteristics that the Blockchain vendor needed to deliver in order to make successful the implementation journey. The first one has been the Permission Layer which is a mandatory feature as it provides flexibility on data visibility and transparency. The second criterion has been the possibility of implementing Smart Contracts. Intuitively, this is a pivotal characteristic in that they are necessary to implement process logic within the solution, thereby allowing the automatic triggering of a contract or activity once specific conditions are met. Then, the Blockchain vendor has been selected also looking at the possibility of having an open source code. In fact, this feature increases the trust among actors and guarantees the continuous evolvement of the Blockchain stack. Furthermore, the consensus mechanism has been another critical factor. Specifically, it has been stated that the Proof of Work consensus mechanism is not adapted for enterprises use cases, thereby leading the choice to those vendors that use different and more appropriate consensus mechanisms. Finally, the last criterion has been the availability of built-in assets such as Bitcoin or Ether. In this regard, these internal assets are not appropriate for enterprise use cases, thus it has been pivotal that no built-in assets were present in the selected vendor. By following this logic, the vendor Hyperledger (Fabric) has been eventually selected as the best candidate for the purpose of *Company X*.

Once this step has been concluded, a Blockchain-based demonstrator has been developed. For this step, the Tooling scope has been selected as the first candidate. This step has been pivotal for the overall Blockchain implementation journey to actually communicate internally and externally with the different actors involved as well as to make them learn how to deal with this technology. Additionally, it has been critical to actually validate and confirm the potential value Blockchain can bring to the actors involved. This demonstrator has been developed on the Tool kick-off scope, and, although it addresses an extremely small scope, it already answers several functional needs. Precisely, it consists in a program dashboard around Tool Kick-off where it is possible to keep track of tools criteria status and change as well as automate the Purchase Orders (from OEM to *Company X*, and from *Company X* to Suppliers). Basically, the demonstrator consists of a "Kanban-like" management tool providing full visibility on the relevant tools at each validation stage. Hence, each player (the OEM, *Company X*, and the tool makers) can work on its own interface and can see the relevant – and filtered – information.

5.5.3 Next Steps on Initial MVPs Building

As previously discussed, the next phase of the Blockchain implementation is about scoping and developing the first MVP. As previously described, MVP stands for Minimum Viable Product, where its final objective is to provide as quickly as possible a usable product to real program (and to OEM/Suppliers as relevant) so that they can use it while continuously improving it. To do so, principle of agility will be used. Particularly, MVPs are planned to be developed with around the three to four weeks of scoping, followed by five iterations of two weeks (the so-called “sprints”); where each sprint delivers a new set of features to the product. In this regard, the key role to drive the MVP journey is the Product Owner, who must represent the voice of the business. In the specific case of *Company X*, there will be one Product Owner for each Business Group, who is expected to lead the related MVP. On this point, when we talk about MVP development we should be aware of the three main steps it involves: Initial Build, Pilot, and Deployment. Specifically, during the first Build phase the Product Owner leads the definition and development of the MVP across the three BGs. In this phase, we have three to four weeks of scoping and the sprint development every two weeks. During the second phase of Pilot, only one program in one Business group will use the MVP in real conditions and will provide valuable feedbacks to the Product Owner, who is still involved to support the program team and drive the evolutions (backlog) of the MVP. Also in this case, there will be sprints development every two weeks. Finally, during the third Deployment phase, the MVP, which will potentially have new features from the backlog, will be deployed to other programs across the three BGs, so that it can be used in real conditions.

5.6 Discussion

Although companies are starting to embrace and recognize the usefulness of the Blockchain implementation inside their operations as well as ecosystem, the journey that needs to be followed is not yet very clear and it is full of possible pitfalls. For this reason, one of the purposes of this paper is to define a possible Blockchain implementation roadmap that can be used as a benchmark for different case studies. To do so, we will now try to identify a comprehensive path that companies willing to implement this cutting-edge technology should follow. Specifically, the proposed roadmap develops the implementation journey on two dimensions: the Process dimension and the Capability dimension. Figure 5.3 illustrates the general roadmap we have derived from *Company X*’s case study.

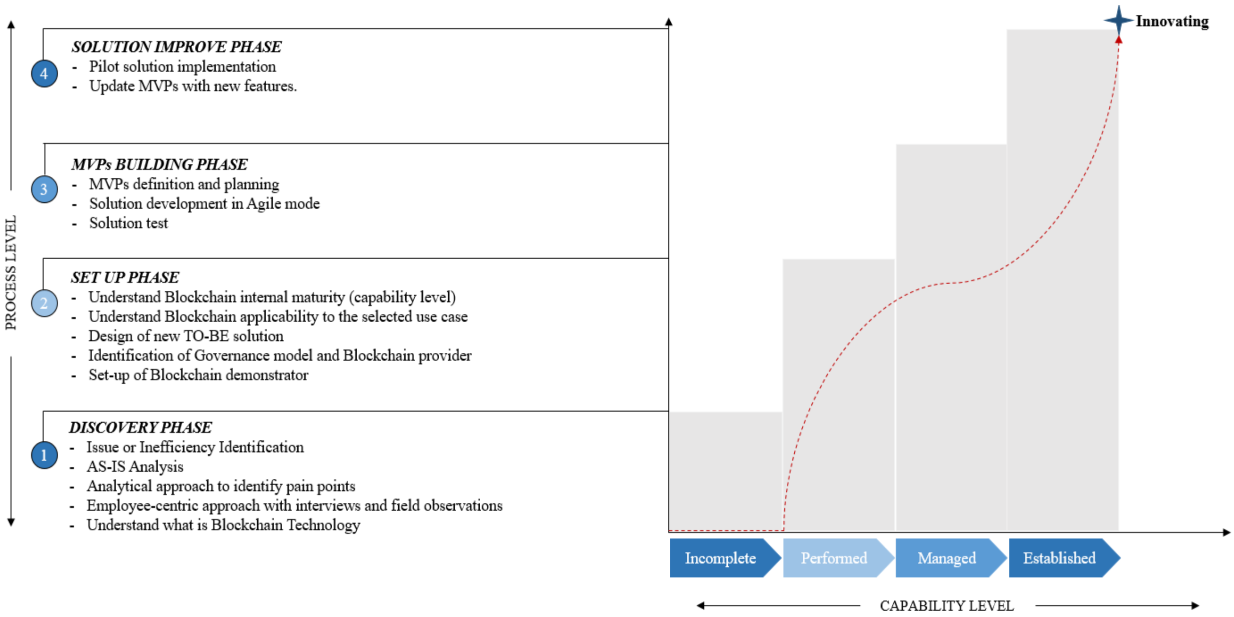

Figure 5.3 – General Blockchain Implementation Roadmap. Source: personal elaboration.

As we can see, the Process dimension is divided into four categories, where each one of them represents a process group, which is a set of different processes and activities that fall into the same category. In this regard, the Discovery process phase includes all the activities that are performed to make sure that the company firstly understand the technology and the company's needs. Indeed, the first step in all implementation journeys is the inefficiency identification and definition. This can be done by performing an AS-IS analysis of the current process status of the company, where it is possible to get to the heart of the issue, understand the root cause, learn how this inefficiency affects the company and all its stakeholders, and develop an effective solution. On this point, to better perform this diagnosis of issues and inefficiencies, it is worth emphasizing the pivotal role an external consulting firm can play. In fact, the decision of involving a consulting company throughout the implementation journey is deemed essential to making sure that a third-party point of view is taken into consideration while approaching the implementation project. In today's fast-paced and developing economic environment, this decision can give the possibility to organizations to create better value, explore new opportunities, and move faster. All this is possible thanks to the fact that these outside companies can often see issues and inefficiencies that stakeholders and those too involved in the organization cannot provide. Additionally, as in the case of *Company X*, although organizations are motivated to explore new opportunities, they often struggle with a lack of technical expertise and implementation knowledge. Hence, to successfully perform this first phase of issues and inefficiencies identification, it is essential to adopt an analytical approach to identify possible use case candidates based on pain points emerged during employees interviews and field observations.

Once this AS-IS analysis has been performed and the inefficiency has been identified, the company can get into the next Set Up process phase that relates to the designing of the new TO-BE solution for the issue selected. To do so, it is first critical to understand the level of Blockchain Technology knowledge inside the organization as well as assess whether the selected issue is a potential use case for the Blockchain Technology implementation. In this regard, like most technology decisions, the choice between a Blockchain and a regular database comes down to a series of trade-offs and it is mainly led by what the company needs to do with such technology. Specifically, if the main goal is to store and follow internal data, a local database is the best choice; while, if other parties need to get access to or fill information, then a shared database managed by a leader or a centralized database managed by a trusted intermediary may be the best solution. On the other hand, Blockchain comes into play when there is no trustworthy intermediary and the database needs to be written by all the parties involved and be relied upon everyone. In this way, no one has full access to all information stored in the database which relies upon any node, and the addition or deletion of any node do not impact the integrity of the database itself. With that being said, we can deduce that Blockchain should only be considered for the types of process that present certain characteristics, such as multiple validation and control points, multiple actors that need to be coordinated, need for a high-level of data quality, as well as auditability where it is necessary to have immutable data storage with transparency on the identity of each change. In light of the foregoing, Figure 5.4 illustrates the practical decision flow that should be followed to define a valid use case for Blockchain.

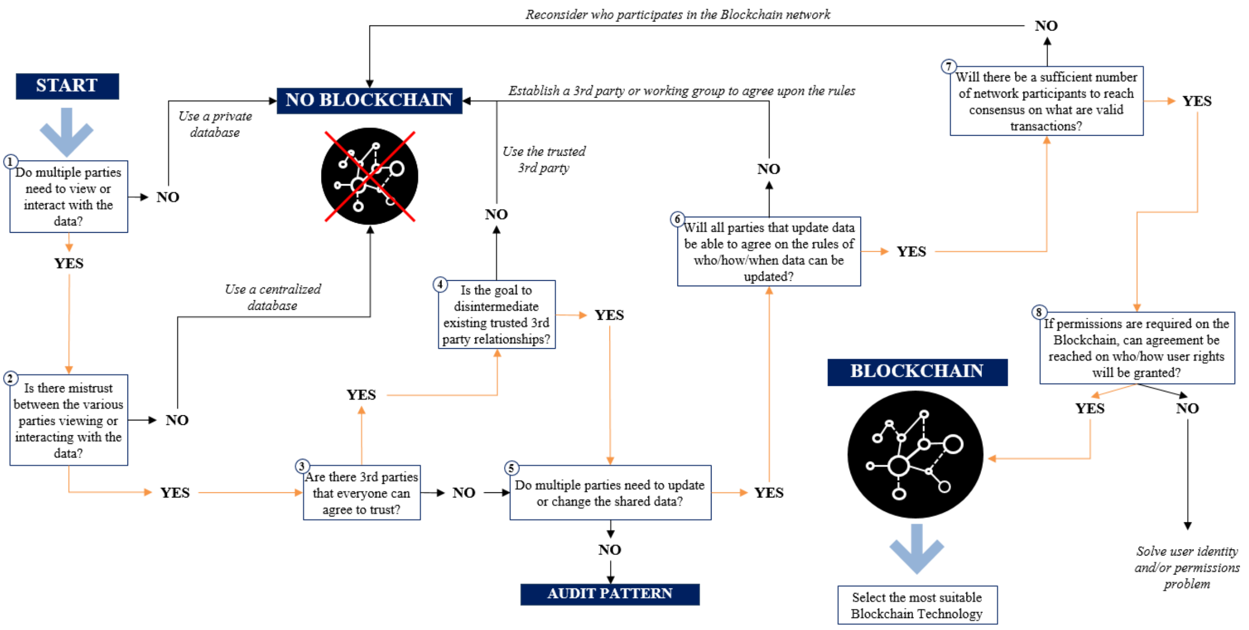

Figure 5.4 – Blockchain Applicability decision flow. Source: personal elaboration.

Once the use case identified has been deemed appropriate for Blockchain implementation, other two activities need to be performed: decide which governance model to apply and select the most valuable Blockchain Technology vendor. For what concerns the former choice, as we have already discussed in Section 1.3, currently there are three main governance models that can be followed to implement Blockchain; specifically, owned (also called private), consortium, and public. In the first case, the Blockchain is set up by the leader of the ecosystem which will then integrate the other members, thereby allowing the owner of the Blockchain to exercise its governance. An example of this Blockchain implementation is given by Walmart that has established its own network and then integrated its suppliers and customers. On the other hand, in a public Blockchain implementation there is no governance, thereby entailing an IT Architecture that is self-functioning. In this case, the drawbacks might be a lower control on stakeholders' integration and a lack of key functionalities, such as confidentiality channels, and a low performance of transactions. In between, we can find the consortium that can be defined as an association of companies, governments, organizations, or individuals that come together to pool resources for a common goal related to Blockchain Technology. In this case, the Blockchain is set up by several stakeholders of an ecosystem with a shared vision (or use case). In this way, the governance is shared among members and its purposes are multiple: define a vision or use case to serve, establish the process, functionalities, standards, confidentiality rules and channels, as well as the architecture of the Blockchain and enforce the usage within its members, distribute the cost of developing and running the Blockchain (e.g., cloud services) and operating the consortium (e.g., communication), advocate the use of the consortium Blockchain in the broader ecosystem to gain more members and drive the ecosystem itself. In this regard, new members can be authorized to access the network and the consortium can decide to join forces with other Blockchain consortia.

Once the most appropriate governance model has been selected, the company should identify the right Blockchain Technology to use. This decision mainly depends on the main features the implemented Blockchain needs to exhibit to properly provide a solution to the company's issue. Figure 5.5 shows a possible decision-making flow, where the choice of a potential vendor depends on what the company is looking for.

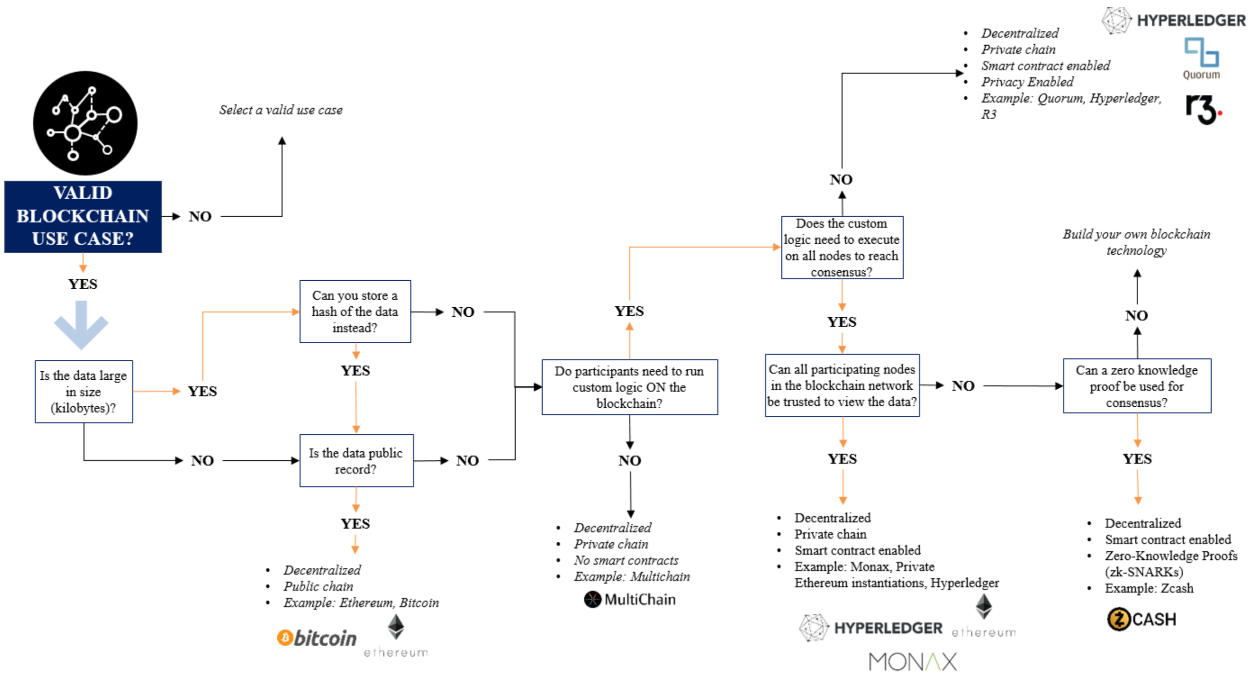

Figure 5.5 – How to select the right Blockchain provider. Source: personal elaboration.

Once also the decision of the most suitable Blockchain type has been performed, the company should start the actual technology set up. On this matter, it is worth highlighting the importance of building and setting up Blockchain demonstrators right from the start to make sure that all the stakeholders involved gradually understand how the new processes work. Generally speaking, when we talk about Blockchain set up, we can say that this technology becomes the shared memory of transactions between the different actors involved in the ecosystem. This is possible because all the stakeholders will be connected to the same Blockchain which is hosted by the leader or partners on cloud or on premise (depending on the governance model selected). Thus, the Blockchain will be connected to the IT of each actor through an integration layer constituted by the Application Programming Interface (API), which is a software interface that allows two applications to interact with each other without any user intervention. In simple terms, API means a software code that can be accessed and executed. In this way, through this API Manager, the System of Record (SOR) of an organization where valuable data are stored, will update the Blockchain and, at the same time, the Blockchain will update each SOR with the new shared transactions. Figure 5.6 shows a general Blockchain set up into a company's IT landscape.

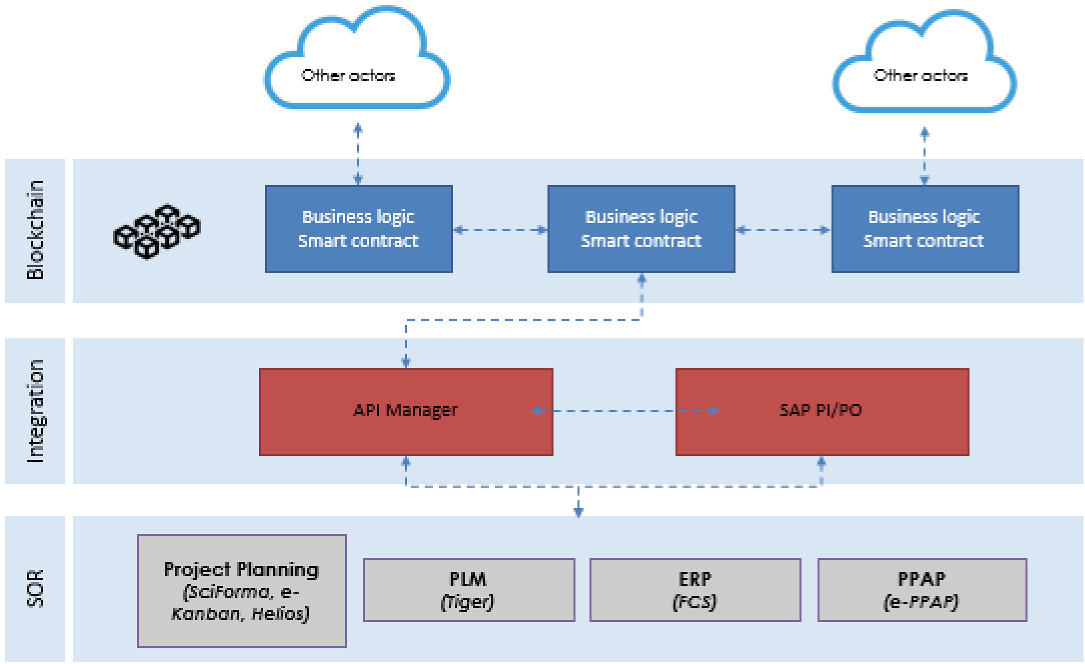

Figure 5.6 – Blockchain Set Up. Source: personal elaboration

Once the Set Up phase has been concluded, the company can proceed with the third step of the implementation roadmap, which refers to the MVPs Building process phase. As already discussed in the previous sections, it is pivotal for an organization that is willing to change its processes, to dedicate time to the understanding and identification of the best Minimum Viable Product (MVP) candidates. In this way, following the agile frameworks described in the previous sections, the company can provide as quickly as possible a usable product (and initial solution) to the issue firstly identified, so that it can be used and gradually improved.

Finally, the fourth step refers to the Solution Improve process phase where all or some part of the solution that the company wants to implement is piloted. This step is pivotal especially when the scope of the change that the Blockchain implementation entails is large. Indeed, this change could cause far-reaching unintended consequences, thereby making the implementation a costly process that is difficult to reverse. The key steps involved in conducting a pilot are strong leadership from top management, select a steering committee/pilot team, conduct briefings with the pilot team, pilot planning for issueless execution, sell to employees affected under pilot, employee training for pilot execution, pilot implementation on the shop-floor, debriefing after pilot implementation and extend to other areas, if required (*Six Sigma Institute*).

Going back now to Figure 5.3, on the horizontal axes the second pivotal dimension of the implementation roadmap has been illustrated: the Capability dimension, which includes five levels from Incomplete to Innovating. In this way, it has been provided a roadmap with a staged approach that relies upon a sequence of capability levels, from the basic necessities to the continuous adaptation for Blockchain Technology. In this regard, it is worth highlighting that each level builds on the previous one, thereby allowing us to understand the company's maturity along the five levels. Specifically, the first one, Incomplete, refers to the situation in which the company has not yet started the process transformation using Blockchain, thus no technical capability is questioned, involved or developed (as we can see from the flat dashed red line in Figure 5.3). Once the issue has been selected and it has been deemed appropriate for a Blockchain use case, the second capability level, Preformed, is engaged. In this step, the company starts questioning and investigating its internal Blockchain knowledge and related skills to start properly developing the vision of the Blockchain transformation and the roadmap for the transition strategy. Furthermore, during this phase, the workforce skill necessities are determined, and the corresponding training starts to be acquired and defined in the company, thereby gradually increasing the internal technical capability level. Once the second Set Up phase has been completed and the company enters the third step of MVPs building, the third capability level Managed is engaged. In this case, the capabilities that have been built during the previous phases are critical to practically start managing the Blockchain transformation process given that potential physical items begins to be created. In this way, additional capabilities are created thanks to the possibility of consistently performing and developing the new processes. With the start of the fourth process step, the fourth capability level, Established, comes into play. At this level, the Blockchain transformation starts being established robustly, given that key processes start being well defined and the fundamentals on which they rely start being standardized. This can give to the company the needed capabilities and skills to introduce new features and improve even further the solution implemented. Finally, once this status has been completely achieved, the company can access the last capability level: Innovating. At this level, the company uses the skills and knowledge built during the implementation journey to continuously enlarge the project scope, improve its processes by using Blockchain, establish a new organization culture that strives for innovation, as well as increase transparency and coordination among all the actors involved. This is possible thanks to the continuous development of new and deeper knowledge on the real potential and impacts of Blockchain as well as to the standardization of established knowledge, thereby enabling a higher operational visibility with automated and seamless information exchange among the network. Hence, at this stage the concepts of continuous improvement and innovation become a core competence of the company and an essential element of its organizational culture.

As we can see, the first four capability levels are precisely matched with the four process steps, thus capturing the fact that during the Blockchain implementation journey each activity related to the company's processes has an intangible impact on the culture, knowledge, skills, and overall structure of the company itself. This impact will inevitably develop new capabilities and will gradually change the mindset of the organization, thereby leading the company towards the next operational step. Thus, there is a sort of growing spiral bidirectional relationship between the two dimensions, that can be described as follows: when an operational step is successfully performed, it helps the organization develop new knowledge, standards, best practices, and capabilities that allow the company to achieve a specific capability level. In turn, this new capability level allows the company to perform the next operational stage and so on. Therefore, by leveraging and capitalizing on the continuously evolving culture and mindset, the company can push even further the transformation process along the Blockchain implementation path.

5.7 Conclusion and Limitations

The present empirical study has several limitations. The first one is the fact that the findings discussed in this thesis do not permit substantial generalization. Indeed, although the general roadmap developed can be seen as a trustworthy benchmark that companies willing to implement Blockchain can follow, it is not free from drawbacks. Generally speaking, every implementation journey has its specificities, challenges, and goals, that are not taken into consideration in our roadmap. Indeed, only the more general and common milestones have been addressed, thereby leaving out possible pivotal aspects that can be deemed essential to the successful implementation of Blockchain in certain situations and conditions. In this regard, while focusing on one single case study assists theory development and gives the possibility of dive deeper into the topic at hand, it would be useful to merge all these possible specificities to develop a more structured and comprehensive roadmap.

Additionally, as a growing number of incumbent firms embark on Blockchain implementation paths, comparisons across cases in terms of Blockchain perception and roadmap definition and implementation could give precious and additional insights into the theory developed in this thesis. In fact, it could be pivotal to collect data from additional case studies over an extended period of time to gather different point of views and implementation approaches, so that it can be possible to track the roadmap evolution as well as the different milestones reached during the Blockchain implementation journey.

Another limitation, that can be seen as an input for further future researches, refers to the fact that the Blockchain implementation journey addressed in this thesis is mainly focused only on the Program Progress Tracking part of the PMS. Despite the precious insights that we have derived from this area, it is worth highlighting the potential of studying how Blockchain could also benefit the internal and external company's operations when used to digitalize a larger set of PMS capabilities. Some examples can be Planning Management, Finance Management (such as automated reporting, forecasting, real-time cash balance status, or predictive product costing), and many others.

CONCLUSIONS

The present thesis aimed at describing the current state of the literature concerning Blockchain Technology and Operations Management and trying to contribute to the less studied topics by focusing on Blockchain implementation.

Given the increasing popularity of this research field that is confirmed by the large number of articles published from 2016 until now, we have started our research activity by identifying 2020 as the starting point of our literature review, so that all the relevant documents from that specific remarkable date until the present year have been collected. In this regard, to properly identify the directions for future research, we have extensively addressed the different ways in which authors have analyzed Blockchain Technology in the Operations Management field. To do so, bibliometric techniques have been used, which allowed us to identify the critical subfields that together constitute the analyzed literature. Among the several tools available to researchers, we have deemed appropriate for the objectives of this thesis to deploy and perform the direct citation analysis, bibliographic coupling analysis, and co-word analysis. Hence, similarity among papers has been identified by addressing citation counts. In fact, by deploying bibliographic coupling, which assumes that the more the references of two documents overlap, the grater their content similarity, we have been able to distinguish the main studied subfield. On this matter, other two pivotal techniques have been executed: Hierarchical Clustering Analysis and Principal Component Analysis. Subsequently, the achieved results have been addressed and compared by means of personal assessment and co-word analysis. As a result of this process, four main subfields have been detected; namely, (1) Blockchain and Supply Chain Management, (2) Blockchain Technology Adoption in Supply Chain Management, (3) Blockchain and Sustainability, and (4) Blockchain Application in Food Supply Chain (FSC). In this regard, the first subgroup is focused on the macro theme of Supply Chain Management and is the one that contains the largest number of publications, thereby indicating its centrality in the bibliographic coupling network. The other three clusters, which build on the first subfield, address the BT with a different focus: the main success factors and barriers of the technology adoption, the impacts on sustainability, and the adoption in the specific case of Food Supply Chain.

Although many studies and researches have been conducted to discover the real potentials and implications of Blockchain Technology in the business world, some issues remain unsolved, thereby indicating directions for future research. Specifically, it has been difficult to find researches and studies that extensively discuss both the internal and external implications of deploying Blockchain Technology. For this reason, it has been deemed critical for the advancement of the research field, to shed light also on the impacts the adoption of this technology can exhibit inside the organization and not only as a mediator between external actors. Additionally, we have not found in the current literature articles and studies that address the pivotal topic of how an enterprise should practically approach and transform its operations to implement Blockchain Technology. Indeed, it has not been possible to find a practical and general roadmap that companies should follow when deploying such technology in their operations. Hence, with the purpose of contributing to the literature on such themes we have discussed a case study involving a global automotive tier-one supplier, called *Company X*, that implemented the Blockchain Technology in its Program Management System.

Our findings outlined many positive internal impacts that can be derived from the Blockchain implementation. Specifically, the implementation of this technology on the PMS has the potential of drastically redefining the internal role of the Program Manager as well as ensuring to the company enhanced accountability, transparency, and efficiency gains. These results suggest that Blockchain can radically redefine the ways in which a company works and does business in its ecosystem.

The second contribution of this thesis concerns the development of a general Blockchain implementation roadmap that can be followed by those companies willing to adopt this cutting-edge technology. This outcome has been the result of a thorough analysis of the implementation approach adopted by *Company X*. Specifically, the proposed roadmap develops the implementation journey on two dimensions that have been deemed pivotal for the successful achievement of a company's objectives; namely, the Process dimension and the Capability dimension. On this matter, the roadmap takes into consideration both the activities the company needs to implement in a staged manner (Process dimension) and the related capabilities to successfully transform its business, strategy, mindset, and culture (Capability dimension).

Limitations of this thesis might provide directions for future research. Specifically, during the bibliometric literature review we have been forced to introduce some restrictive parameters to reduce the number of articles to a manageable size. However, other publications dated before 2020 might have included critical contributions that could have been pivotal for our analysis. Furthermore, more research studies on Blockchain implementation are necessary to extend the knowledge base. In fact, the current studies that analyze the application of this cutting-edge technology are disperse and uncorrelated, thereby making more difficult the generalization of their findings. Therefore, new studies on these same as well as new applications should be carried out to have a better understanding of the general implications, success factors, enablers, and barriers involved in Blockchain adoption. Additionally, new studies should be carried out to gather more data on different point of views and implementation approaches, so that it can be possible to develop an even more general implementation roadmap that contains different milestones.

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APPENDIX

APPENDIX A

#	Author	Title	Date
1	Agi, M.A.N.; Jha, A.K.	Blockchain technology in the supply chain: An integrated theoretical perspective of organizational adoption	2022
2	Ahluwalia, S.; Mahto, R.V.; Guerrero, M.	Blockchain technology and startup financing: A transaction cost economics perspective	2020
3	Ahmad, R.W.; Hasan, H.; Jayaraman, R.; Salah, K.; Omar, M.	Blockchain applications and architectures for port operations and logistics management	2021
4	Akyuz, G.A.; Gursoy, G.	Transformation of Supply Chain Activities in Blockchain Environment	2020
5	Ali, M.H.; Chung, L.; Kumar, A.; Zailani, S.; Tan, K.H.	A sustainable Blockchain framework for the halal food supply chain: Lessons from Malaysia	2021
6	Alkhudary, R.; Brusset, X.; Fenies, P.	Blockchain in general management and economics: a systematic literature review	2020
7	Alles, M.; Gray, G.L.	"The first mile problem": Deriving an endogenous demand for auditing in blockchain-based business processes	2020
8	Babich, V.; Hilary, G.	Distributed ledgers and operations: What operations management researchers should know about blockchain technology	2020
9	Bag, S.; Viktorovich, D.A.; Sahu, A.K.; Sahu, A.K.	Barriers to adoption of blockchain technology in green supply chain management	2021
10	Bagloee, S.A.; Heshmati, M.; Dia, H.; Ghaderi, H.; Pettit, C.; Asadi, M.	Blockchain: The operating system of smart cities	2021
11	Baharmand, H.; Maghsoudi, A.; Coppi, G.	Exploring the application of blockchain to humanitarian supply chains: insights from Humanitarian Supply Blockchain pilot project	2021
12	Bai, C.; Sarkis, J.	A supply chain transparency and sustainability technology appraisal model for blockchain technology	2020
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14	Bal, M.; Pawlicka, K.	Supply chain finance and challenges of modern supply chains	2021
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16	Batwa, A.; Norrman, A.	A framework for exploring blockchain technology in supply chain management	2020
17	Batwa, A.; Norrman, A.	Blockchain technology and trust in supply chain management: A literature review and research agenda	2021
18	Benzidia, S.; Makaoui, N.; Subramanian, N.	Impact of ambidexterity of blockchain technology and social factors on new product development: A supply chain and Industry 4.0 perspective	2021

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22	Chand Bhatt, P.; Kumar, V.; Lu, T.-C.; Daim, T.	Technology convergence assessment: Case of blockchain within the IR 4.0 platform	2021
23	Chang, J.A.; Katehakis, M.N.; Shi, J.J.; Yan, Z.	Blockchain-empowered Newsvendor optimization	2021
24	Cheung, K.-F.; Bell, M.G.H.; Bhattacharjya, J.	Cybersecurity in logistics and supply chain management: An overview and future research directions	2021
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41	Epiphaniou, G.; Pillai, P.; Bottarelli, M.; Al-Khateeb, H.; Hammoudesh, M.; Maple, C.	Electronic Regulation of Data Sharing and Processing Using Smart Ledger Technologies for Supply-Chain Security	2020
42	Erol, I.; Ar, I.M.; Ozdemir, A.I.; Peker, I.; Asgary, A.; Medeni, I.T.; Medeni, T.	Assessing the feasibility of blockchain technology in industries: evidence from Turkey	2021
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45	Filimonau, V.; Naumova, E.	The blockchain technology and the scope of its application in hospitality operations	2020
46	Friedman, N.; Ormiston, J.	Blockchain as a sustainability-oriented innovation?: Opportunities for and resistance to Blockchain technology as a driver of sustainability in global food supply chains	2022
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59	Hosseini Bamakan, S.M.; Ghasemzadeh Moghaddam, S.; Dehghan Manshadi, S.	Blockchain-enabled pharmaceutical cold chain: Applications, key challenges, and future trends	2021
60	Hrouga, M.; Sbihi, A.; Chavallard, M.	The potentials of combining Blockchain technology and Internet of Things for digital reverse supply chain: A case study	2022
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70	Kimani, D.; Adams, K.; Attah-Boakye, R.; Ullah, S.; Frecknall-Hughes, J.; Kim, J.	Blockchain, business and the fourth industrial revolution: Whence, whither, wherefore and how?	2020
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72	Kouhizadeh, M.; Saberi, S.; Sarkis, J.	Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers	2021
73	Kumar, A.	Improvement of public distribution system efficiency applying blockchain technology during pandemic outbreak (COVID-19)	2021
74	Kumar, A.; Liu, R.; Shan, Z.	Is Blockchain a Silver Bullet for Supply Chain Management? Technical Challenges and Research Opportunities	2020
75	Kurpjuweit, S.; Schmidt, C.G.; Klöckner, M.; Wagner, S.M.	Blockchain in Additive Manufacturing and its Impact on Supply Chains	2021

76	Lambourdiere, E.; Corbin, E.	Blockchain and maritime supply-chain performance: dynamic capabilities perspective	2020
77	Li, G.; Xue, J.; Li, N.; Ivanov, D.	Blockchain-supported business model design, supply chain resilience, and firm performance	2022
78	Liu, L.; Zhang, J.Z.; He, W.; Li, W.	Mitigating information asymmetry in inventory pledge financing through the Internet of things and blockchain	2021
79	Liu, W.; Shao, X.-F.; Wu, C.-H.; Qiao, P.	A systematic literature review on applications of information and communication technologies and blockchain technologies for precision agriculture development	2021
80	Liu, Z.; Li, Z.	A blockchain-based framework of cross-border e-commerce supply chain	2020
81	Lohmer, J.; Bugert, N.; Lasch, R.	Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study	2020
82	Luo, S.; Choi, T.-M.	E-commerce supply chains with considerations of cyber-security: Should governments play a role?	2022
83	Mageto, J.; Luke, R.	Skills frameworks: A focus on supply chains	2020
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90	Mishra, H.; Maheshwari, P.	Blockchain in Indian Public Distribution System: a conceptual framework to prevent leakage of the supplies and its enablers and disablers	2021
91	Mittal, A.; Gupta, M.P.; Chaturvedi, M.; Chansarkar, S.R.; Gupta, S.	Cybersecurity Enhancement through Blockchain Training (CEBT) – A serious game approach	2021
92	Mubarik, M.; Rasi, R.Z.R.M.; Mubarak, M.F.	Fostering supply chain integration through blockchain technology: A study of malaysian manufacturing sector	2020
93	Musigmann, B.; Von Der Gracht, H.; Hartmann, E.	Blockchain Technology in Logistics and Supply Chain Management - A Bibliometric Literature Review from 2016 to January 2020	2020

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95	Nandi, S.; Sarkis, J.; Hervani, A.; Helms, M.	Do blockchain and circular economy practices improve post COVID-19 supply chains? A resource-based and resource dependence perspective	2021
96	Niu, B.; Dong, J.; Liu, Y.	Incentive alignment for blockchain adoption in medicine supply chains	2021
97	Niu, B.; Mu, Z.; Cao, B.; Gao, J.	Should multinational firms implement blockchain to provide quality verification?	2021
98	Niu, B.; Shen, Z.; Xie, F.	The value of blockchain and agricultural supply chain parties' participation confronting random bacteria pollution	2021
99	Orji, I.J.; Kusi-Sarpong, S.; Huang, S.; Vazquez-Brust, D.	Evaluating the factors that influence blockchain adoption in the freight logistics industry	2020
100	Pandey, V.; Pant, M.; Snasel, V.	Blockchain technology in food supply chains: Review and bibliometric analysis	2022
101	Papathanasiou, A.; Cole, R.; Murray, P.	The (non-)application of blockchain technology in the Greek shipping industry	2020
102	Parmentola, A.; Petrillo, A.; Tutore, I.; De Felice, F.	Is blockchain able to enhance environmental sustainability? A systematic review and research agenda from the perspective of Sustainable Development Goals (SDGs)	2022
103	Paul, T.; Islam, N.; Mondal, S.; Rakshit, S.	RFID-integrated blockchain-driven circular supply chain management: A system architecture for B2B tea industry	2022
104	Paul, T.; Mondal, S.; Islam, N.; Rakshit, S.	The impact of blockchain technology on the tea supply chain and its sustainable performance	2021
105	Pournader, M.; Shi, Y.; Seuring, S.; Koh, S.C.L.	Blockchain applications in supply chains, transport and logistics: a systematic review of the literature	2020
106	Pun, H.; Swaminathan, J.M.; Hou, P.	Blockchain Adoption for Combating Deceptive Counterfeits	2021
107	Qian, X.; Papadonikolaki, E.	Shifting trust in construction supply chains through blockchain technology	2021
108	Quayson, M.; Bai, C.; Sarkis, J.	Technology for Social Good Foundations: A Perspective from the Smallholder Farmer in Sustainable Supply Chains	2021
109	Queiroz, M.M.; Fosso Wamba, S.; De Bourmont, M.; Telles, R.	Blockchain adoption in operations and supply chain management: empirical evidence from an emerging economy	2021
110	Queiroz, M.M.; Telles, R.; Bonilla, S.H.	Blockchain and supply chain management integration: a systematic review of the literature	2020
111	Rana, R.L.; Tricase, C.; De Cesare, L.	Blockchain technology for a sustainable agri-food supply chain	2021
112	Rashideh, W.	Blockchain technology framework: Current and future perspectives for the tourism industry	2020
113	Rehman Khan, S.A.; Yu, Z.; Sarwat, S.; Godil, D.I.; Amin, S.; Shujaat, S.	The role of block chain technology in circular economy practices to improve organisational performance	2022

114	Rejeb, A.; Keogh, J.G.; Simske, S.J.; Stafford, T.; Treiblmaier, H.	Potentials of blockchain technologies for supply chain collaboration: a conceptual framework	2021
115	Rejeb, A.; Rejeb, K.	Blockchain and supply chain sustainability	2020
116	Rijanto, A.	Business financing and blockchain technology adoption in agroindustry	2020
117	Rijanto, A.	Blockchain technology adoption in supply chain finance	2021
118	Roeck, D.; Sternberg, H.; Hofmann, E.	Distributed ledger technology in supply chains: a transaction cost perspective	2020
119	Sahebi, I.G.; Masoomi, B.; Ghorbani, S.	Expert oriented approach for analyzing the blockchain adoption barriers in humanitarian supply chain	2020
120	Sahebi, I.G.; Mosayebi, A.; Masoomi, B.; Marandi, F.	Modeling the enablers for blockchain technology adoption in renewable energy supply chain	2022
121	Saurabh, S.; Dey, K.	Blockchain technology adoption, architecture, and sustainable agri-food supply chains	2021
122	Sheel, A.; Nath, V.	Antecedents of blockchain technology adoption intentions in the supply chain	2020
123	Shen, B.; Dong, C.; Minner, S.	Combating Copycats in the Supply Chain with Permissioned Blockchain Technology	2022
124	Shen, B.; Xu, X.; Yuan, Q.	Selling secondhand products through an online platform with blockchain	2020
125	Shoaib, M.; Lim, M.K.; Wang, C.	An integrated framework to prioritize blockchain-based supply chain success factors	2020
126	Sivula, A.; Shamsuzzoha, A.; Helo, P.	Requirements for blockchain technology in supply chain management: An exploratory case study	2021
127	Smith, S.S.; Castonguay, J.J.	Blockchain and accounting governance: emerging issues and considerations for accounting and assurance professionals	2020
128	Sternberg, H.S.; Hofmann, E.; Roeck, D.	The Struggle is Real: Insights from a Supply Chain Blockchain Case	2021
129	Tan, W.K.A.; Sundarakani, B.	Assessing Blockchain Technology application for freight booking business: a case study from Technology Acceptance Model perspective	2021
130	Tezel, A.; Febrero, P.; Papadonikolaki, E.; Yitmen, I.	Insights into Blockchain Implementation in Construction: Models for Supply Chain Management	2021
131	Tönnissen, S.; Teuteberg, F.	Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies	2020
132	Tozanlı, Ö.; Kongar, E.; Gupta, S.M.	Trade-in-to-upgrade as a marketing strategy in disassembly-to-order systems at the edge of blockchain technology	2020
133	Tran, L.T.T.; Nguyen, P.T.	Co-creating blockchain adoption: theory, practice and impact on usage behavior	2020
134	Treiblmaier, H.; Sillaber, C.	The impact of blockchain on e-commerce: A framework for salient research topics	2021
135	Tsiulin, S.; Reinau, K.H.; Hilmola, O.-P.; Goryaev, N.; Karam, A.	Blockchain-based applications in shipping and port management: a literature review towards defining key conceptual frameworks	2020

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137	Upadhyay, A.; Mukhuty, S.; Kumar, V.; Kazancoglu, Y.	Blockchain technology and the circular economy: Implications for sustainability and social responsibility	2021
138	van Hoek, R.	Developing a framework for considering blockchain pilots in the supply chain – lessons from early industry adopters	2020
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APPENDIX B

ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
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37	1	1	0	0	0	0	1	7	0	8	2	12	0	0	1	0
38	0	0	0	1	1	0	1	0	0	1	2	0	0	0	3	0
39	1	2	0	0	1	2	1	0	0	0	0	0	0	0	0	0
40	3	8	0	3	3	2	1	11	4	14	5	17	1	1	0	0
41	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
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43	2	0	0	0	2	3	0	0	2	0	3	0	0	3	1	0
44	4	2	0	0	3	0	2	1	3	0	5	0	0	6	3	2
45	4	0	0	5	2	2	1	0	4	0	10	0	0	10	4	0
46	2	1	0	4	2	1	0	0	3	0	4	0	2	4	2	0
47	1	0	0	2	0	0	0	0	1	0	3	0	1	2	1	0
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49	4	3	0	4	3	2	1	1	3	0	7	0	0	4	4	1
50	0	1	0	0	2	1	1	0	0	0	0	0	0	1	0	0
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54	0	0	0	2	1	0	0	0	0	0	3	1	0	0	1	0
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56	3	1	0	2	2	0	2	1	3	0	4	1	0	6	3	1
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58	1	2	0	2	1	1	0	0	3	0	2	0	0	1	1	0
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61	1	2	0	1	2	0	2	0	1	3	1	0	0	3	1	0
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64	3	2	0	0	4	4	0	0	4	0	5	2	0	9	4	0
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66	8	6	0	2	4	3	1	0	4	0	7	2	1	9	4	0
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69	4	2	0	3	3	2	0	0	4	1	5	0	2	7	2	1
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74	0	1	0	2	1	0	0	2	1	1	5	1	0	1	1	1
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79	2	3	0	0	1	0	0	0	2	0	4	2	0	3	1	0
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85	4	1	0	2	0	1	1	0	4	0	4	0	0	5	2	0
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91	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
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93	5	1	0	4	1	1	1	0	2	0	8	0	1	5	3	0
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107	2	0	0	8	1	0	0	0	2	0	8	0	0	6	3	0
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109	3	4	0	2	5	7	2	3	2	3	8	3	1	5	3	0
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114	5	5	0	4	3	1	2	0	4	1	3	0	2	6	3	0
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122	2	0	0	2	2	4	1	0	1	0	4	0	0	5	2	0
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125	3	2	0	1	1	2	2	2	1	1	6	0	1	6	3	1
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136	7	4	0	0	0	0	0	0	2	0	4	3	1	5	2	0
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138	5	2	0	3	1	1	2	1	4	0	3	0	1	4	3	1
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142	11	0	0	5	5	2	1	1	2	1	0	4	1	0	0	0
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148	0	1	1	0	1	0	1	0	0	11	2	14	0	0	1	1
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155	1	0	2	0	2	0	1	1	1	0	3	0	0	5	0	1
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