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A Critical Investigation into Identifying Key Focus Areas for the Implementation of Blockchain Technology in the Mining Industry

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ABSTRACT

A critical investigation into identifying key focus areas for the implementation of blockchain applications in the mining industry

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A critical investigation into identifying key focus areas for the implementation of blockchain applications in the mining industry

The value of digital information is ever-increasing as more companies utilize digital technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) to gain deeper insight into their business operations and drive productivity gains. It is therefore important to safeguard and ensure the integrity of digital information exchange. Blockchain technology (BCT) was identified as potentially providing the mining industry with a trusted system for securely exchanging digital value. However, there is little evidence or understanding of how/where BCT can be implemented and what benefits the industry could obtain. This research study provides a fundamental understanding of what the technology is in order to identify the associated capabilities and potential application benefits for the mining industry. From a technology push perspective, blockchain capabilities are used to evaluate how the technology's value drivers map to the mining industries core value chain processes. This was done to identify potential focus areas within the mining enterprise for further research and development of blockchain applications.

It is suggested that blockchain technology has the potential to increase the speed and efficiency of digital transactions, provide greater business transparency and improve trust within mining enterprise processes. This research provides a starting point for decision-makers to assess whether blockchain applications for the mining industry will be worth the investment.

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GLOSSARY

TERM	AGREED DEFINITION
Application developer	Builds applications on top of existing distributed ledger networks.
Application layer	Consists of all applications that are built on existing distributed ledger networks.
ASIC resistant	Application Specific Integrated Circuits (ASIC) are created to serve a specific use case (performing a particular computing task such as Bitcoin mining). ASIC-resistant is the property of a cryptocurrency that is "immune" to ASIC mining.
Automation	The creation and application of technologies to produce and deliver goods and services with minimal human intervention.
Big data	Data that contains greater variety, arriving in increasing volumes and with more velocity. Big data is larger, more complex data sets, especially from new data sources. These data sets are so voluminous that traditional data processing software just cannot manage them. But these massive volumes of data can be used to address business problems you would not have been able to tackle before.
Bitcoin	Bitcoin is a decentralized digital currency that can be transferred on the peer-to-peer Bitcoin network. Bitcoin transactions are verified by network nodes through cryptography and are recorded in a public distributed ledger called a blockchain.
Blockchain	Type of distributed ledger that is composed of a chain of cryptographically linked "blocks" containing batched transactions; generally, it broadcasts all data to all participants in the network.
Cardano	Cardano is a public blockchain platform. It is open-source and decentralized, with consensus achieved using proof of stake. It can facilitate peer-to-peer transactions with its internal cryptocurrency, ADA. Cardano's development began in 2015, led by Ethereum co-founder Charles Hoskinson.
Casper The Friendly Ghost	Casper The Friendly Ghost (CTFG) is a pure BFT PoS algorithm that aims to transform PoW blockchains into a PoS-only blockchain system.
Chain Protocol	The Chain Protocol is a blockchain-as-a-service (BaaS) provider built on the Ethereum blockchain. It is designed to "manage issuance, ownership and control of digital assets." The Chain Protocol helps financial organizations set up their services and processes from the ground up.
Citi	Citi is the leading global bank; it provides consumers, corporations, governments and institutions with a broad range of financial products and services, including consumer banking and credit, corporate and investment banking, securities brokerage, transaction services, and wealth management.
CitiConnect	An Application Programming Interface (API) connectivity platform.
Cryptocurrency	A cryptocurrency is a digital or virtual currency that is secured by cryptography, which makes it nearly impossible to counterfeit or double-spend.
Crypto wallet	A crypto wallet is a device or program that allows you to transfer and store cryptocurrency.
Data	Data is information that has been translated into a form that is efficient for movement or processing. Relative to computers and transmission media, data is information converted into binary digital form. "Raw data" is a term used to describe data in its most basic digital format.
Data diffusion	Refers to how and to whom data is broadcast in a distributed ledger network.
Decentralization	There is no one central owner. Instead, these systems use multiple central owners, each of which usually stores a copy of the resources that users can access.
Delegated Proof of Stake	Delegated proof of stake (DPoS) is a form of consensus algorithm in which reputation scores or other mechanisms are used to select the set of validators.
Digital economy	Digital economy refers to an economy that is based on digital computing technologies, although we increasingly perceive this as conducting business through markets based on the internet and the World Wide

	Web. The digital economy is also referred to as the Internet Economy or Digitized Economy.
Digital transformation	Digital transformation or digitalization is the adoption of digital technology to transform services or businesses through replacing non-digital or manual processes with digital processes, or replacing older digital technology with newer digital technology.
Digitization	The conversion of text, pictures or sound into a digital form that can be processed by a computer.
Distributed database	Type of database where data is stored across multiple computing devices.
Distributed ledger	Type of distributed database that assumes the possible presence of malicious users (nodes).
Ethereum	Ethereum is a decentralized blockchain platform that establishes a peer-to-peer network that securely executes and verifies application code, called “smart contracts”. Smart contracts allow participants to transact with each other without a trusted central authority.
Fungible	Of goods contracted for without an individual specimen being specified; replaceable by another identical item; mutually interchangeable.
Fork	In blockchain, a fork is defined variously as: "what happens when a blockchain diverges into two potential paths forward", "a change in protocol", or a situation that "occurs when two or more blocks have the same block height”.
GitHub	GitHub Inc. is an internet hosting service for software development and version control using Git. It provides the distributed version control of Git plus access control, bug tracking, software feature requests, task management, continuous integration and wikis for every project.
Global	Means that data is broadcast to every network participant.
Hash	A hash is a mathematical function that converts an input of arbitrary length into an encrypted output of a fixed length. Thus, regardless of the original amount of data or the file size involved, its unique hash will always be the same size. Moreover, hashes cannot be used to "reverse-engineer" the input from the hashed output, since hash functions are "one-way" (like a meat grinder; you can't put the ground beef back into a steak). Still, if you use such a function on the same data, its hash will be identical, so you can validate that the data is the same (i.e., unaltered) if you already know its hash.
Hash power	Hash power, or hash rate, are interchangeable terms used to describe the combined computational power of a specific cryptocurrency network or the power of an individual mining rig on that network. Hash rate is a measure of the computational power per second used when mining. More simply, it is the speed of mining. It is measured in units of hash per second, meaning how many calculations per second can be performed. Machines with a high hash power are highly efficient and can process a lot of data in a single second.
Hyperledger Burrow	Hyperledger Burrow is a complete single-binary blockchain distribution focused on simplicity, speed and developer ergonomics.
Incentivised consensus	Algorithms that reward participating nodes for creating and adding a new block in the blockchain.
Infrastructure provider	Develops core protocol(s) and/or builds full distributed ledger networks.
Initial coin offering	An initial coin offering (ICO) is the cryptocurrency industry's equivalent of an initial public offering (IPO). A company seeking to raise money to create a new coin, app or service can launch an ICO to raise funds.
Initial public offering	An initial public offering (IPO) or stock launch is a public offering in which shares in a company are sold to institutional investors and usually also to retail investors. An IPO is typically underwritten by one or more investment banks, which also arrange for the shares to be listed on one or more stock exchanges.
LINQ	LINQ is a platform powered by the Nasdaq Financial Framework. It is a blockchain-enabled technology that initiates various aspects of trading shares through the market.
Medicalchain	Medicalchain uses blockchain technology to securely manage health records for a collaborative, smart approach to healthcare.
“Miners” (crypto)	Nodes that validate new blockchain transactions and record them on the blockchain.

Multi-channel	Data is broadcast only to the counterparties involved in a specific trade ("selective disclosure").
NASDAQ	(Nasdaq: NDAQ) is a leading global provider of trading, clearing, exchange technology, listing, information and public company services.
Network layer	Consists of the actual peer-to-peer (P2P) network built on top of an existing protocol that brings the distributed ledger "to life".
Node	A node is a device or data point in a larger network. In networking a node is either a connection point, a redistribution point, or a communication endpoint. In computer science, nodes are devices or data points on a large network. Devices such a PC, cell phone or printer are considered nodes.
Non-incentivised consensus	Private blockchain systems deploy a type of consensus algorithms that do not rely on any incentive mechanism for the participating nodes to create and add a new block in the blockchain.
Off-chain	Process or transaction that is external to the distributed ledger.
On-chain	Process or transaction that takes place directly on the distributed ledger network.
Operator	Administrates and operates a specific distributed ledger technology (DLT) application or network.
Ouroboros (BFT PoS)	Ouroboros is a probably secure PoS algorithm utilised in the Cardano platform which supports smart-contract and decentralized applications without relying on any PoW consensus algorithm.
Pain points	Pain points are specific problems faced by businesses in respect of their operations, employees and customers. A pain point can be, for example: inefficient exchange of information, fragmented data sources, labour-intensive processing of information, etc.
Permissioned (closed)	Only selected parties can make changes to the distributed ledger.
Permissionless (open)	Anyone can, in theory, participate in the consensus process. (In practice, however, often limited by resource requirements such as owning suitable hardware or cryptocurrency).
Private	Only selected parties are able to access the ledger and see transactions.
Proof of Cooperation	Proof of Cooperation (PoC) is a consensus algorithm introduced by the FairCoin cryptocurrency which does not implement any mining or minting functionality commonly needed for competitive systems.
Proof of Elapsed Time	Proof of Elapsed Time (PoET) is a consensus mechanism used by the Hyperledger Sawtooth. Sawtooth offers a flexible and modular architecture that separates the core system from the application domain, so smart contracts can specify the business rules for applications without needing to know the underlying design of the core system.
Proof of Importance	Proof of Importance (PoI) works to prove the utility of nodes in a cryptocurrency system, so that they can create blocks.
Proof of Research	Proof of Research (PoR) is a hybrid approach that combines PoS with Proof of BOINC. (BOINC stands for Berkeley Open Infrastructure for Network Computing)
Proof of Stake Velocity	Proof of Stake Velocity (PoSV) is used to secure a peer-to-peer network and confirm transactions of Reddcoin, a cryptocurrency created specifically to facilitate social interactions in the digital age.
Proof of Work	Proof of Work is a form of cryptographic proof in which one party proves to others that a certain amount of a specific computational effort has been expended.
Protocol	A standard set of rules that allow electronic devices to communicate with each other. These rules include what type of data may be transmitted, what commands are used to send and receive data, and how data transfers are confirmed. The English language can be seen as a protocol.
Protocol layer	Consists of the core software building blocks that make up a distributed ledger.
Public	Anybody can access the ledger and see transactions.
Public sector institution	Entity from the public sector (e.g., central bank, government agency,

	regulator).
Read access	Refers to who can access a distributed ledger network and see transactions.
Redundant Byzantine Fault Tolerance	Redundant Byzantine fault tolerance (RBFT) is an improvement over the Byzantine fault tolerance (BFT).
SALT Lending (blockchain company)	SALT or Secured Automated Lending Technology provides loans to borrowers by using cryptocurrency as collateral. SALT Lending provides personal and business loans to their members who put up blockchain assets as collateral.
Scalability	The ability of a blockchain network to increase the throughput of data transactions/communications as demand for the network increases. Usually referred to as a capacity measurement (in transactions per second).
Security	Network security consists of the policies, processes and practices adopted to prevent, detect and monitor unauthorized access, misuse, modification, or denial of a computer network and network-accessible resources.
Smart contract	A self-executing software program that automatically performs some function (e.g., makes a payment when the smart contract is triggered by an event).
Smart contract functionality	Refers to the degree of functionality of a distributed ledger framework or network in terms of the complexity of computations it can perform on-chain.
Software services	Companies building and developing the software that powers distributed ledger networks and applications.
Stateful system	A "logic-optimized" system with extensive smart contract functionality at the protocol level ("baked-in").
Stateless system	A "Transaction optimised" system that does not support complex computational logic at its base layer (but may well have smart contract capabilities at higher stack layers).
Technology	Technology is the sum of any techniques, skills, methods, and processes (digital or physical) used in the production of goods or services or in the accomplishment of objectives.
Technology stack	A technology stack is simply a collection of different technologies that work together for some purpose, usually as a foundation for systems such as websites, mobile apps and standalone desktop software (a combination of programming languages, frameworks and tools).
Tendermint	Tendermint showcases how Byzantine fault tolerance (BFT) consensus can be achieved within a PoS setting of blockchain systems. It consists of two major components: a consensus engine known as Tendermint Core, and its underlying application interface, called the Application BlockChain Interface (ABCI).
The Fourth Industrial Revolution (4IR)	The Fourth Industrial Revolution is the current and developing environment in which disruptive technologies and trends such as the Internet of Things (IoT), robotics, virtual reality (VR), artificial intelligence (AI) and blockchain (BC) are changing the way we live and work.
Tokenization	The process of exchanging sensitive data for non-sensitive data called "tokens" that can be used in a database or internal system without bringing the sensitive data into scope. Refers to the process of digitally representing an existing, off-chain asset on a distributed ledger such as a blockchain.
Velocity of money	The velocity of money measures the number of times that the average unit of currency is used to purchase goods and services within a given time period. The concept relates the size of economic activity to a given money supply, and the speed of money exchange is one of the variables that determine inflation.
Write/Commit access	Refers to who is permitted to take part in making changes to a distributed ledger (e.g., who may add blocks to a blockchain).
Yet another Consensus (YAC)	Yet another Consensus (YaC) mechanism used in Iroha (Australian Iroha Systems (Pty) Ltd). Hyperledger Iroha is designed to be simple and easy to incorporate into infrastructural or IoT projects requiring distributed ledger technology.

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ASIC	Application-Specific Integrated Circuit
B2B	Business-to-Business
BC	Blockchain or Block Chain
BCT	Blockchain Technology
BFT	Byzantine Fault Tolerant
CBDC	Central Bank Digital Currency
CTFG	Casper The Friendly Ghost
DAO	Decentralized Autonomous Organization
DApp	Decentralized Application
DLT	Distributed Ledger Technology
DMRE	Department of Mineral Resources and Energy
DPoS	Delegated Proof of Stake
DTI	Digital Transformation Initiative
ERP	Enterprise Resource Planning
ESG	Environment, Social and Government
GDPR	General Data Protection Regulation
GPU	Graphics Processing Unit
H&S	Health and Safety
HSBC	The Hong Kong and Shanghai Banking Corporation
ICO	Initial Coin Offering
IoT	Internet of Things
IPO	Initial Public Offering
KYC	Know Your Customer/Client
NASDAQ	National Association of Securities Dealers Automated Quotations
NFT	Non-Fungible Token
OEM	Original Equipment Manufacturer
P2P	Peer-to-Peer
POC	Proof of Cooperation
PoET	Proof of Elapsed Time
PoI	Proof of Importance
PoR	Proof of Research
PoS	Proof of Stake
PoSV	Proof of Stake Velocity
PoW	Proof of Work
RBFT	Redundant Byzantine Fault Tolerance
SBFT	Simplified Byzantine Fault Tolerance
UNCTAD	United Nations Conference on Trade and Development
VC	Venture Capital
WEF	World Economic Forum
YAC	Yet Another Consensus

CHAPTER 1

MOTIVATION FOR THE STUDY

This chapter recognises four themes driving the digital transformation process in the mining industry and highlights a common feature, that is “Big Data”. Blockchain technology (BCT) is suggested to play an important role in this process because of the technology’s associated characteristics. A high-level overview of the fundamentals of BCT, value-creating layers, consensus mechanisms, industry use cases as well as limitations is given in this section. The chapter concludes with the problem statement, objectives and methodology for the subsequent chapters.

1 INTRODUCTION

The Mineral Resource sector is a constitution of interconnected industries that help satisfy the basic needs of society by providing the necessary resources for technological development. The advancements in technological innovation come about through automation, digitization and electrification, fundamentally changing the way in which mining organizations operate.

As the mining industry progresses through its digital transformation journey, technologies such as autonomous vehicles, automated drilling, drones and smart sensors are reshaping the sector. Over the past decade the risks associated with adopting these technologies have decreased as mining companies are realizing substantial productivity and safety gains (Bliss, 2018).

The World Economic Forum (WEF) predicts that most mining organizations will adopt autonomous mining machines that are able to operate 24 hours a day, 365 days a year. This will enable increased output targets in the extraction phase, resulting in a value addition to the industry of an estimated $47 billion by 2025 (Spelman, et al., 2017).

In 2015 the WEF launched the Digital Transformation Initiative (DTI) project as part of the systems initiative on shaping the future of the digital economy and society. This research highlighted four themes and initiatives that are expected to play a crucial role in the digital transformation of the mining industry (Figure 1). These four themes are summarized in the following points:

- **Automation, robotics and operational hardware** – reducing manual/human-controlled machinery by deploying digitally enabled hardware tools
- **Digitally enabled workforce** – empowering field, remote and centralized workers in real time through connected mobility and the application of virtual/augmented reality
- **Integrated enterprise, platforms and ecosystems** – linking operations, IT layers and devices or systems that are siloed
- **Next-generation analytics and decision support** – leveraging artificial intelligence/algorithms to process big data from multiple sources in order to provide real-time decision support and future projections

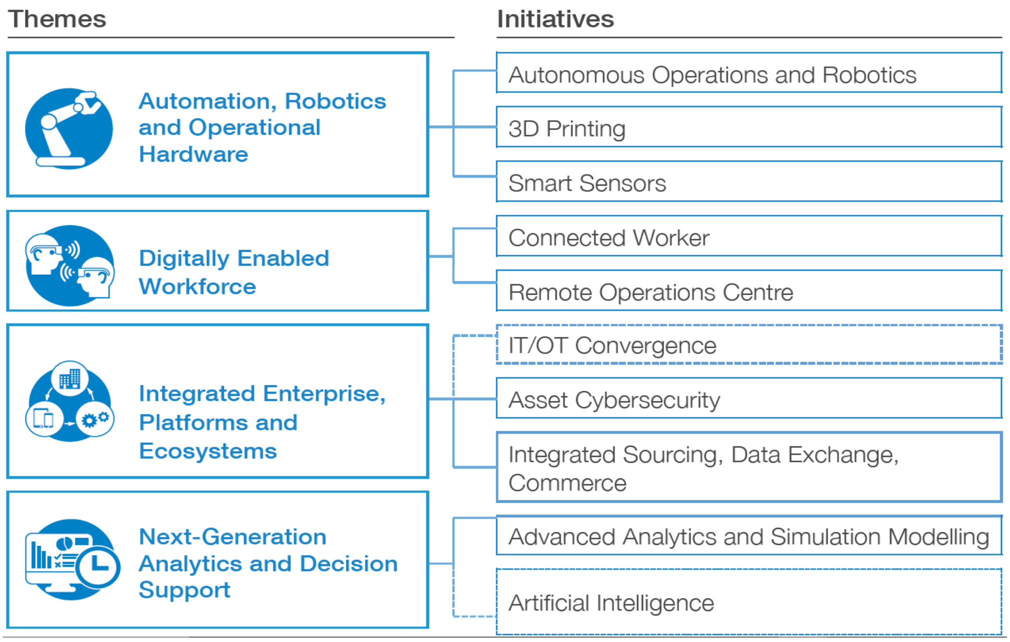


Figure 1: Digital themes and initiatives in the mining industry (Spelman, et al., 2017)

These four themes have a common trait, namely "big data". These technologies produce data, communicate via machine-readable data, or rely on data to operate and perform certain tasks. Hence the availability of data and communication of machine-readable information is imbedded in these four themes.

In 2019 the United Nations Conference on Trade and Development (UNCTAD) published a digital economy report stating that the world is transforming at a rapid pace largely due to the exponential growth in the aggregation of machine-readable information (big data) over the internet. In 1992 the global internet data traffic was 100 gigabytes per day, ten years later it reached 100 gigabytes per second and it was estimated that by 2022 the data traffic would exceed 150 000 gigabytes per second (Figure 2).

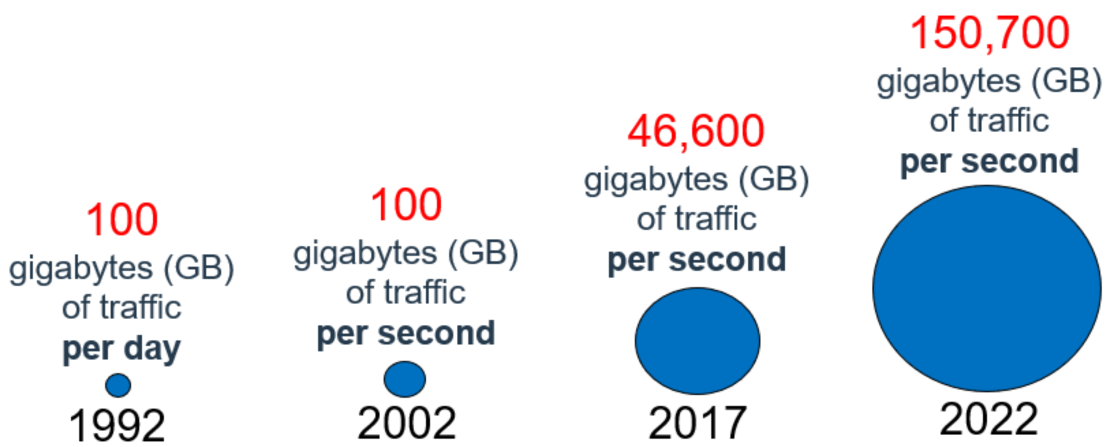


Figure 2: Global internet protocol traffic (Sirimanne, et al., 2019)

This increase in data traffic is driving the expansion of new business models (digital platforms) which utilize digital technologies such as big data analytics, cloud computing and artificial intelligence. The role of big data and technologies is growing as further devices gain access to the internet, more value chains are being digitally connected and the dependence on digital services is set to increase (Sirimanne, et al., 2019).

In 2017 an article was published with the title "The world's most valuable resource is no longer oil, but 'data'" in the journal *The Economist*. The concept behind this article is that, like oil, raw data has little to no value in and of itself; rather, value is created when data is collected accurately, in a timely manner and is connected to other relevant (and processed) data. When refined correctly, data can provide digital intelligence that can become a decision-making tool which allows organizations to be proactive, intentional in their decision-making and to react strategically to market forces. Access to big data and the ability to transform data into digital intelligence forms a crucial part of the competitiveness of mining companies. (Rosebrough, 2020).

The South African mining industry is transitioning from a conventional, deep-level, labour-intensive mining environment to a technologically advanced industry, focusing on mechanized shallower mining environments (Rossouw & Mngadi, 2019). Ultra-deep-level mining, for example, would not be possible without the inclusion of digital technology in the context of all its various applications. This transformation process (i.e., use of digital technologies) comes with many challenges, but one could argue that the success of the transition could be dependent on the availability of data and the capacity to make knowledgeable decisions in future.

Philo and Webber-Youngman (2021) highlighted that as the South African mining industry embarks on the transformation journey, data-fuelled technologies such as Artificial Intelligence (AI), the Internet of Things (IoT) and Blockchain (BC) will play a significant role in the process. Mining organizations are focusing on exploiting digital tools that give better insight into the operational realities of mining operations to drive strategic decision-making.

Philo and Webber-Youngman (2021) developed a technology schematic which suggests **"why"** each tool should be incorporated into the mining industry's operational strategies. This "why" was identified as the value propositions for the application of AI, IoT and BC in the mining industry (Figure 3). Data capturing and communication is the value proposition for IoT. Data capturing and transmission can be achieved through augmenting mining equipment and/or operations with electronic devices that can capture key information and communicate the data with other devices via a network. Artificial Intelligence was identified as a tool for big data management and control due to the technological capabilities of data analytics, robotics and automation. The value proposition for BC technology is a secure system for data exchange between devices and across networks.

The schematic further highlights **"how"** AI, BC and IoT can deliver on each value proposition by leveraging the different technological capabilities of each tool. The **"what"** identifies the potential benefits mining organizations could obtain by implementing these three tools in their business operations. It should be noted that although the schematic identifies individual deliverables for each technology, these tools are mutually inclusive as they all rely on data communication to some extent. Synergies exist between the different technologies that either enable or enhance different applications.

Figure 3: Technology schematic: AI, IoT and BC value propositions (Philo & Webber-Youngman, 2021)

Philo and Webber-Youngman noted that it is important to understand what these technologies are and how they work so that mining organizations can use the right tools for the appropriate application. It was also mentioned that investment in technology such as BC which has to do with safeguarding data could accelerate the move towards automation and the digital mine of the future.

Tapscott and Tapscott (2016) believe that BCT will emerge as the foundational platform in a digitalised economy. He states that this technology will further enable innovations in AI and IoT and increase participation in the global economy.

Tapscott and Tapscott (2017) argues that the internet is entering a second era based on BCT. The past decades brought about the internet of information and now BCT is giving rise to the internet of value. This internet of value is believed to be powered by different BC protocols and applications.

Blockchain emerged in the wake of the 2008 global economic crisis, when a pseudonymous person or persons named Satoshi Nakamoto released a new protocol for “A peer-to-peer electronic cash system” using a cryptocurrency known as Bitcoin. The paper “Bitcoin: A peer-to-peer electronic cash system” proposed a solution to solve the double-spending problem (Tapscott & Tapscott, 2017).

Unlike physical cash, the digital representation is essentially a data file which can be duplicated or falsified. The double-spending problem relates to commerce over the internet whereby the same digital cash (data) is spent more than once. This problem has caused society to rely exclusively on financial institutions which act as trusted third parties to process and validate electronic payments. The paper argues that fraud is inevitable and that third parties cannot be completely trusted to facilitate transactions. Thus, Nakamoto proposed an electronic payment system based on cryptographic proof which allows two parties to transact directly with each other without the need for a trusted third party. A part of the solution involves grouping transactions into blocks and cryptographically linking these blocks together to form a chain – hence the term “block chain” (Nakamoto, 2008).

The interest in this technology has grown significantly, largely due to the price rally in late 2017 which saw the price of Bitcoins increase from $4,200 to $20,000 in less than a three-month period (Figure 4). The significant price increase in a short amount of time drew a lot of attention to the cryptocurrency space.

Figure 4: Bitcoin price chart (trading view)

This attention has amplified the development of BCT across a range of industries, focusing more on the underlying technology. Various parties are investing significant time and capital in understanding how the technology works and what potential value can be unlocked. Blockchain technology is believed to promise increased speed and efficiency in data transaction, redefine business models, provide greater transparency and improve trust across transaction value chains in the digital economy. This is mostly due to the technology's ability to safeguard data, ensure data authenticity and prevent double spending in a decentralized manner (Hileman & Rauchs, 2017).

Blockchain technology is still lacking maturity in terms of scalability, interoperability, integration with legacy systems and lack of BC programming talent (Meijer, 2020). The Hong Kong and Shanghai Banking Corporation (HSBC) published a global survey report in 2017 which highlighted that 80% of the 12 019 participants that have heard of BCT do not understand it (HSBC, 2017).

This technology could play an important role in the future of the South African mining industry and may assist in the industry's digital transformation. However, there is need to comprehend better the capabilities of this technology and to investigate how the industry could potentially benefit from BC through specific applications identified.

1.1 Project Background

From the introduction and the study done by Philo and Webber-Youngman (2021), it is evident that Artificial Intelligence (AI), the Internet of Things (IoT) and Blockchain Technology (BCT) will play an important role in the digital transformation process of the mining industry. The value of digital information is ever-increasing as more companies utilize these digital technologies to gain deeper insight into their operations and drive this transformation process. As AI and IoT typically rely on the exchange and communication of data, it is important to safeguard and ensure the integrity of data exchange within the mining industry. BCT was identified as being potentially able to provide the mining industry with a trusted system for securely exchanging digital value. However, there is still little evidence or understanding of how BCT can be implemented and what benefits the industry could obtain. The project background expands on what BCT is, identifies prominent industry applications and discusses the limitations of the technology.

1.1.1 Blockchain Fundamentals

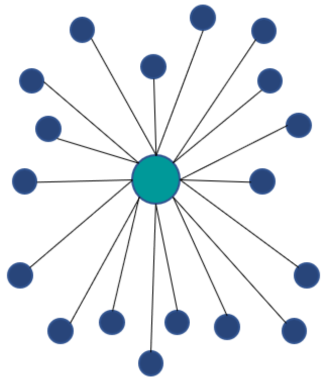
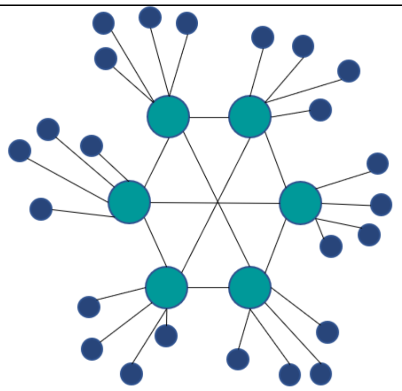
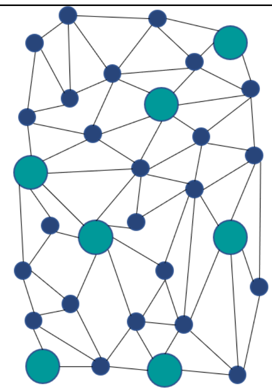
Blockchain technology is fundamentally a new protocol for value transfer via the internet. At the most basic level, a blockchain is a type of database/ledger that is replicated and managed by a cluster of computers (across a peer-to-peer or decentralized network) with no central authority; it enables the distribution of digital information which cannot being copied or forged (Rosic, 2018).

One of blockchain's notable features is the ability to transfer value securely across a decentralized network.

Table 1 illustrates distinctions between three network architectures, namely centralized, decentralized and distributed, while highlighting the positive and negative aspects of each.

Table 1: Centralized vs decentralized vs distributed systems (Touron, 2019)

Centralized System	Decentralized System	Distributed System

Centralized System	Decentralized System	Distributed System
		
Users are connected to a central network owner or "server". The central owner stores data, which other users can access.	There is no one central owner. Instead, these systems use multiple central owners, each of which usually stores a copy of the resources that users can access.	In a distributed system, users have equal access to data, although user privileges can be enabled when needed. The best example of a vast, distributed system is the internet itself.
Positive Aspects: • Simple/Easy deployment • Can be developed quickly • Affordable to maintain • Practical when data needs to be controlled centrally	**Positive Aspects:** • Less likely to fail than a centralized system • Better performance • Allows for a more diverse and more flexible system	**Positive Aspects:** • Fault-tolerant • Transparent and secure • Promotes resource sharing • Extremely scalable
Negative Aspects: • Prone to failures • Higher security and privacy risks for users • Longer access times to data for users who are far from the server	**Negative Aspects:** • Security and privacy risks to users • Higher maintenance costs • Inconsistent performance when not properly optimized	**Negative Aspects:** • More difficult to deploy • Higher maintenance costs

One of the concerns with centralized systems is that they are prone to failures as there is a central point of attack. With decentralized and distributed systems, the ability to manipulate (attack) or gain control over the system is almost impossible. There is also a trust issue regarding centralized systems as power (in terms of data access, storage and usage) is concentrated with a few individuals who have administrative rights to the system. These individuals or actors could abuse their authority and misuse private and/or sensitive information, such as the case with the Facebook and Cambridge Analytica data scandal (Criddle, 2020). With decentralized and distributed systems this power is shared among the network participants and there is no need to trust a centralized entity to act with integrity regarding digital information. This could be useful in the mining industry and could be proved to be such.

The unique characteristics of BCT can be summarized into the following five points (Iansiti & Lakhani, 2017):

1. The technology is **decentralized.** This means that it is a distributed database where each party on the BC network has access to the entire records and its complete history. Every participant can verify the records of transaction partners directly and without a trusted third party/intermediary.
2. The communications/transactions are **peer-to-peer (P2P).** The data commerce occurs directly between peers instead of through a central node. Each node stores and forwards information to all other nodes.
3. The BC database provides **transparency with pseudonymity.** Every transaction and its associated value are visible to anyone with access to the network. Each user, or node, on the blockchain has a unique address that identifies it (30-plus-character alphanumeric identifier). The transitions occur between these addresses, and users can choose to remain anonymous or provide proof of their identity to others.
4. The BC **records are designed to be irreversible.** When transactions are entered into the database and the accounts are updated, the records cannot be simply altered. The BC protocol deploys various computational algorithms and approaches to ensure that the recording on the database is permanent, chronologically ordered, and available to all network participants. All transactions are recorded and cryptographically linked to every transaction that came before them, hence the term "chain".
5. The BC uses **computational logic.** Due to the digital nature of the ledger/database, transactions can be tied to computational logic and in essence programmed, creating smart contracts (a smart contact is a program that automatically executes when nodes reach consensus. The nodes in a BC are configured to trigger when certain conditions have been met, executing certain pre-defined business functions.) Users can set up rules that automatically trigger transactions between nodes.

Blockchain technology is also commonly referred to as Distributed Ledger Technology (DLT). In 2017 a global blockchain benchmark study conducted by the Cambridge Centre for Alternative Finance highlighted commonly used terms that refer to blockchain technology (Figure 5). These terms unfortunately add to the confusion around BCT as they are used interchangeably (Hileman & Rauchs, 2017).

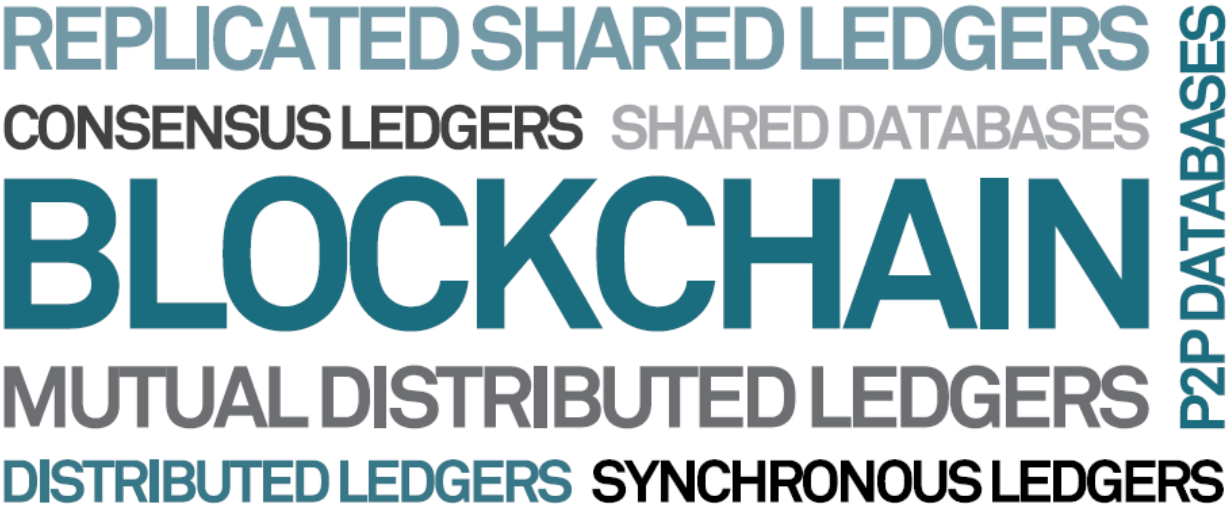


Figure 5: Commonly used terms that refer to blockchain technology (Hileman & Rauchs, 2017)

Originally blockchains were closely based on the Bitcoin architecture, where transactions are bundled up into blocks which are cryptographically linked and which reference preceding blocks (forming a chain of transaction bundles). Different database systems (Figure 6) have been developed which are also referred to as blockchains, but they lack the previously mentioned characteristics of a "traditional" blockchain (Hileman & Rauchs, 2017).

Distributed databases are generally controlled and operated by a single entity that maintains strict control of access to the network. The database is replicated across multiple nodes which collaborate to maintain a consistent view of the database state. This system assumes that all nodes are honest, cooperating freely and sharing data based on mutual trust (Hileman & Rauchs, 2017).

Distributed ledgers are a subset of distributed databases but are designed to be Byzantine fault-tolerant. This means that distributed ledgers assume that not all nodes are honest. Thus they are designed to be able to synchronize and run even if some nodes are acting maliciously. A decentralized database/DLT enables parties who do not fully trust each other to reach consensus about the data status, evolution and authenticity (Hileman & Rauchs, 2017).

Blockchains are a subset of DLT but have additional characteristics. Hileman & Rauchs (2017) state that there is no clear consensus on the definition of a blockchain, but that BC uses a special data structure that cryptographically bundles transactions into blocks, and/or broadcasts the data to all network participants/nodes.

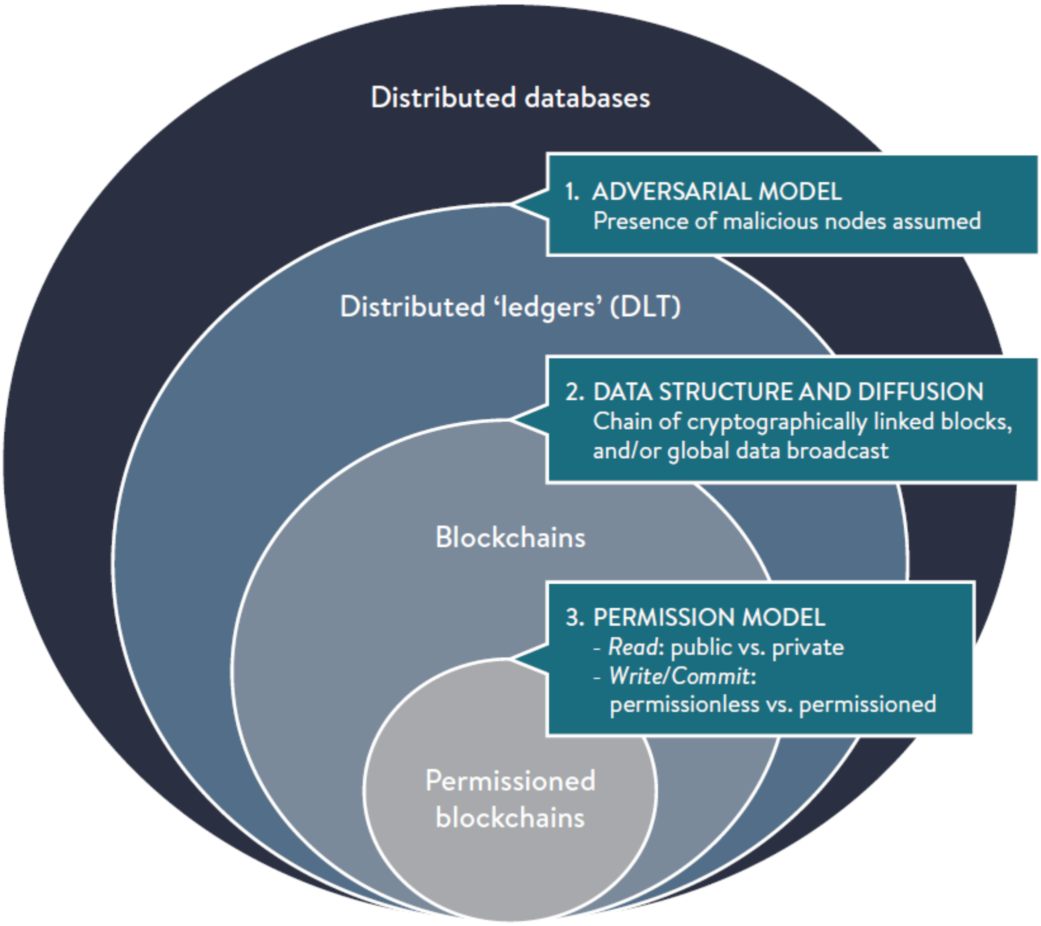


Figure 6: Framework for differentiating blockchain and distributed ledgers (Hileman & Rauchs, 2017)

Blockchains can be further segmented into two types: "open/public" or "closed/private". Closed refers to a private or permissioned (terms used interchangeably) BC where access to the network is restricted to certain participants. When configuring a BC, the following permissions can be designed for:

- "Read" – who can access the ledger and see the transactions
- "Write" – who can generate transactions and send them to the network
- "Commit" – who can update the state of the ledger.

Table 2 differentiates between the four main blockchain network types segmented by their permission models, whereby the term public/private refers to the "Read" capability and the term permissionless/permissioned refers to the "Write" and "Commit" capability (Hileman & Rauchs, 2017). The open or closed BC types illustrate the adaptability of BC applications and can be designed for different use case specifications.

Table 2: Blockchain type segmented by permission model (Hileman & Rauchs, 2017)

			Permissions			Examples
			Read	Write	Commit	
Blockchain Types	Open	Public permissionless	Open to anyone	Anyone	Anyone	Bitcoin and Ethereum
Blockchain Types	Open	Public permissioned	Open to anyone	Authorised participants	All or subset of authorised participants	Sovrin
Blockchain Types	Closed	Consortium	Restricted to an aothorised set of participants	Authorised participants	All or subset of authorised participants	Multiple banks operating a shared ledger
Blockchain Types	Closed	Private permissioned (Enterprise)	Fully private or restricted to a limited set of authorised nodes	Network operator only	Network operator only	International bank ledger shared between parent company and subsidiaries

It is important to understand this as mining organizations that wish to explore BCT do not necessarily need to use open blockchains, but can choose a type that suits their specific needs. Blockchains can be used in situations where mining companies wish to minimize the degree of trust required between industry participants or wish to reduce their dependence on intermediary service providers. A closed BC type could potentially be used at an enterprise level where only certain authorities have access to the network, whereas an open BC type could be used at an operational level where permissions are less sensitive.

In order to comprehend the different BC applications used in industry as a whole it is important to note the different components/layers upon which this technology is built. This will give mining companies an idea of what protocols, networks and applications could be incorporated with their business objectives/strategies.

1.1.2 Blockchain Value-Creating Layers (Technology Stack)

While BC is viewed as a relatively "new" technology, in essence it is more of an innovatively constructed combination of different existing technologies such as P2P networking, cryptographic hash functions, distributed timestamping, digital signatures and Merkle trees (Hileman & Rauchs, 2017). For this reason, technology stacks for BC applications may differ according to specific use cases. For basic comprehension a framework was adapted from Pratt (2016) and Hileman and Rauchs (2017) that will be used to explain the value-creating layers (Figure 7).

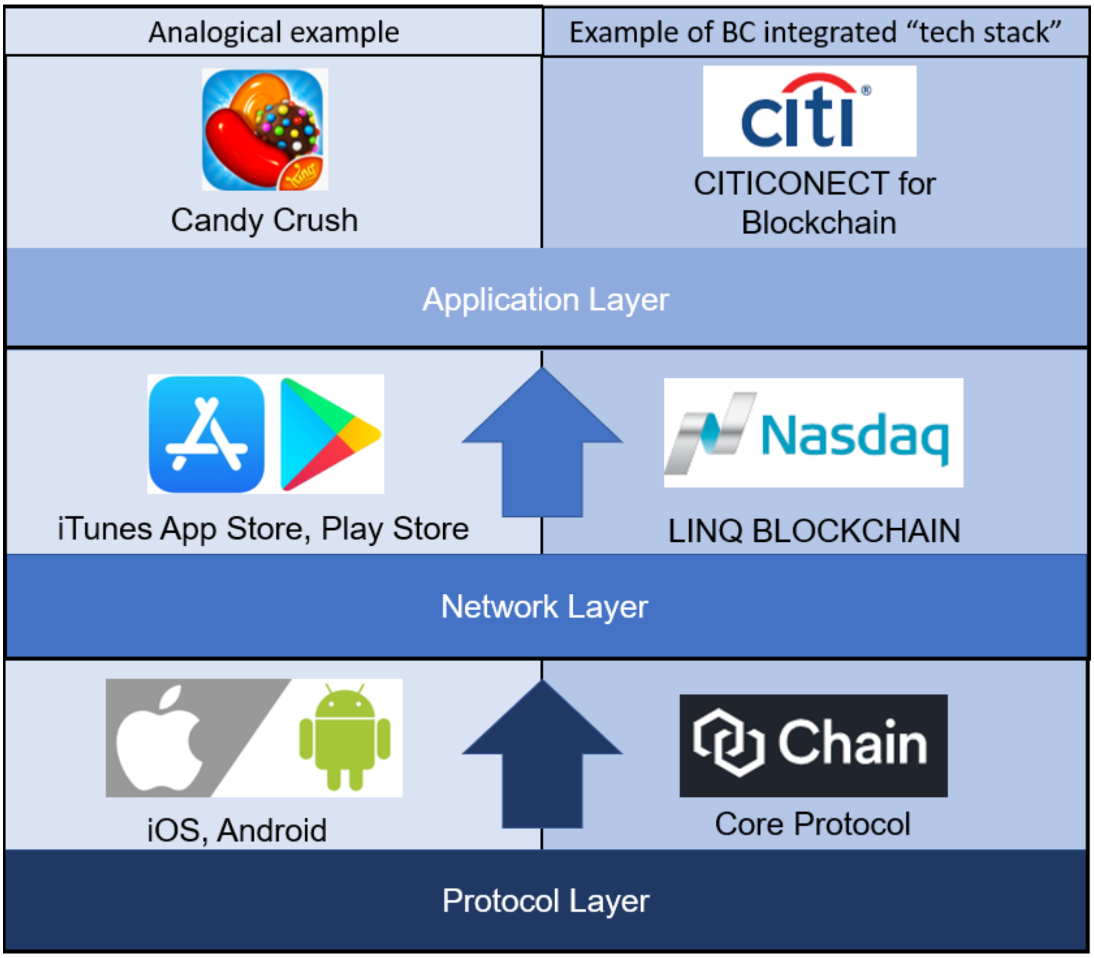


Figure 7: Blockchain system layers
(Adapted from Pratt, 2016 and Hileman and Rauchs, 2017)

The first layer is the **protocol layer**. This includes the core software that constitutes the architecture of a BC system. The protocol layer is the computer code that deals with consensus mechanisms, smart contracts, data structures and functionalities. This layer does not deliver any value without a network, much like iOS and Android, which are operating systems that are difficult to monetize on their own (Platt, 2016). Examples of BC core protocols are Bitcoin, Ethereum and Chain Protocol. The majority of BC protocols/operating systems can be found on GitHub.

The second layer is the **network layer** which brings the BC system to life by connecting participants in a peer-to-peer (P2P) network. As previously mentioned, BC networks can be either "open" or "closed". Bitcoin and Ethereum are examples of open/permissionless network systems that allow any participant to access the network and view information. Network users can create or validate transactions by using the correct/associated protocol. Cryptocurrency exchanges and payment gateways can be grouped into this layer. They assist with network transactions and may act as "gatekeepers" to different BC networks/protocols, much like the iTunes App store or the Google Play store (Platt, 2016). Networks can be enterprise-specific, industry-specific or use case-specific. An example of a running network is the *NASDAQ LINQ BC* network (which enables the issuance of private securities on a BC) built on top of the Chain Core Protocol (Hileman & Rauchs, 2017).

The third layer is the **application layer**. This is where business functions are developed for products and services, and it constitutes the primary user interface for BC systems, much like the game Candy Crush that is played by the end user, who downloaded the application through the iTunes App store on an iOS device. A similar example is CitiConnect by Citi, a product that provides a bank money transfer system that plugs into the NASDAQ LINQ network built on top of the Chain Core Protocol (Hileman & Rauchs, 2017).

Some BC networks, such as Bitcoin, are entirely pre-built three-layer systems and others, like Ethereum, are open to interpretation (Platt, 2016). The framework as illustrated in Figure 7, though rudimentary, provides a basis for further investigation into BCT.

1.1.3 Protocol Layer Algorithms (Consensus Mechanisms)

Most blockchains are maintained by a distributed network of computers (nodes) that need to reach an agreement on the state of the distributed ledger (e.g. number of transactions, transaction value, etc). In a decentralized system this poses a challenge as some nodes are likely to fail or may act maliciously. Thus, consensus algorithms are used as a mechanism to build a Byzantine Fault Tolerant (BFT) blockchain. A BFT system can continue operating despite the presence of malicious actors (Binance Academy, 2018). Figure 8 shows the various consensus mechanisms that are used in different BC applications.

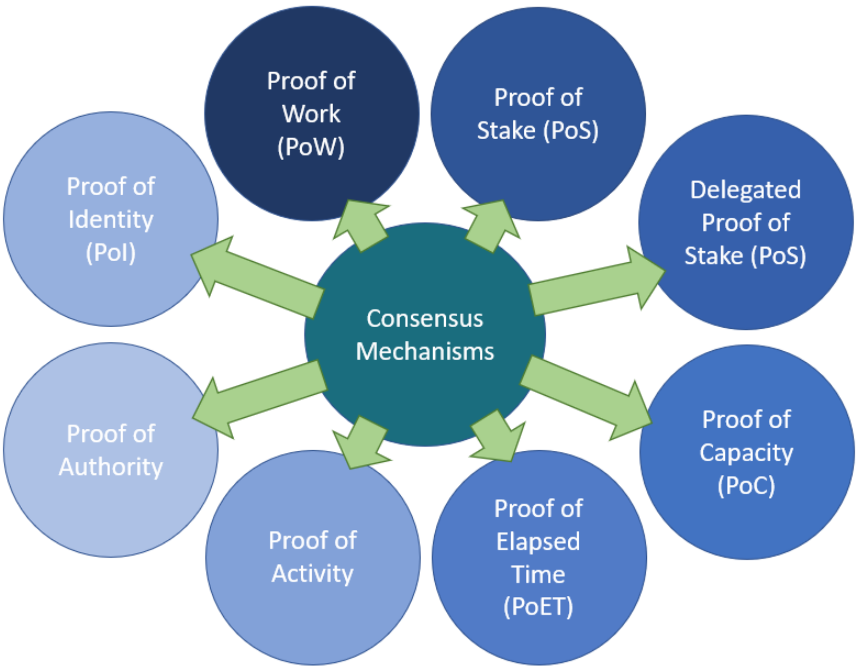


Figure 8: Blockchain consensus algorithms (Anwar, 2018)

On 18 July 2019 a consensus algorithms survey (Figure 9) was conducted on the Top 100 crypto currencies which highlighted that Proof of Work (PoW) is the most widely used (58%) consensus mechanism. Proof of Stake (PoS) and Delegated Proof of Stake (DPoS) were the second most common consensus algorithms used in the crypto space (17% combined).

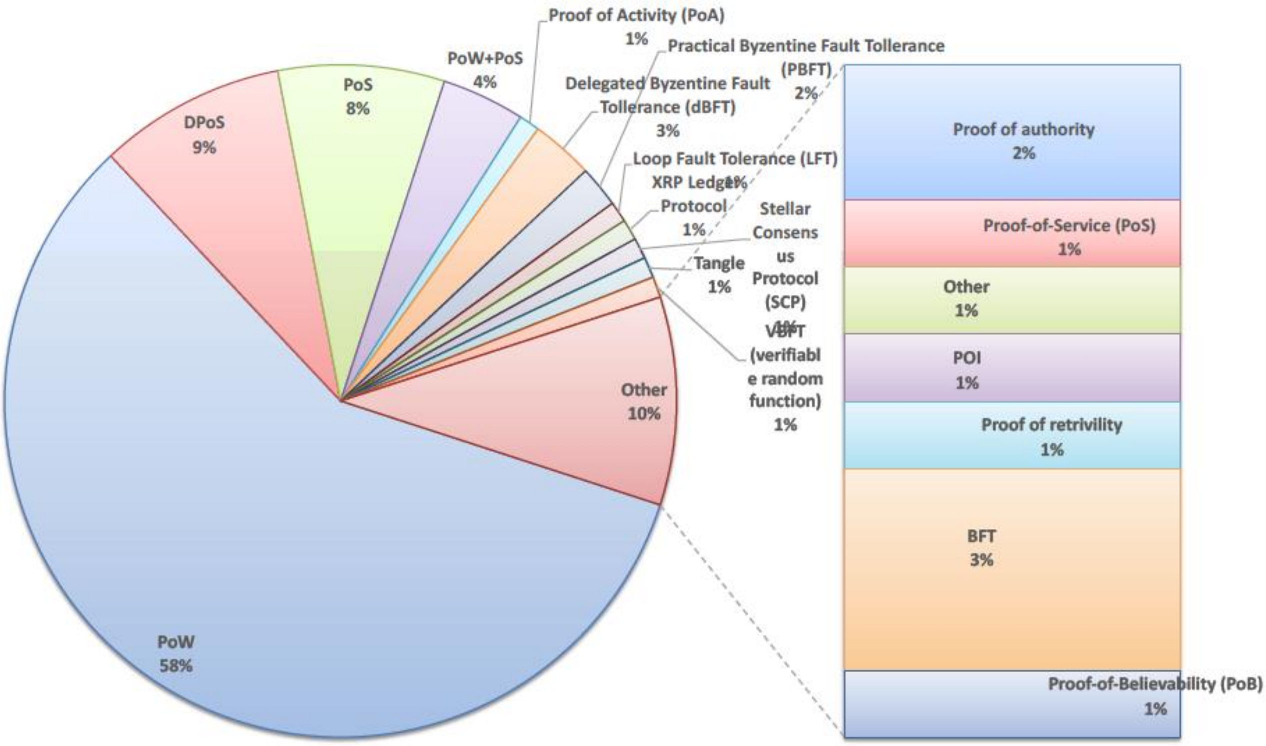


Figure 9: 2019 Results of the survey on consensus algorithms (Ferdous, et al., 2020)

The PoW algorithm is used to achieve consensus for the Bitcoin network and is the most commonly known consensus mechanism applied in the crypto currency space (Ferdous, et al., 2020). The PoW algorithm essentially simulates real-world resource mining in the digital space. This is why the term “miners” is used to refer to Bitcoin mining rigs (Graphic Processing Units and/or Application-Specific Integrated Circuit [GPU/ASIC]) that use computational power to mine/create new Bitcoins via processing and validating blocks on the BC network.

From an Environmental, Social and Governance (ESG) investment perspective, climate change activists are concerned about Bitcoin’s energy consumption and believe that the network is unsustainable (Mora, et al., 2018). Carter (2021) stated that Bitcoin consumed 0.55% (approximately 110 terawatt hours) of global annual energy production in 2021. This energy consumption may be perceived as excessive, but the reality is a little more convoluted. Carter debunks several common misconceptions about Bitcoin's long-term viability by elaborating on the following points:

- **Energy consumed is not equal to carbon emissions:** Energy mix must be understood to evaluate carbon emissions (e.g. one unit of hydro energy will have much less environmental impact than the same unit of coal-powered energy).
- **Bitcoin can use energy that other industries cannot:** Bitcoin mining is geographically independent which allows Bitcoin miners to do mining arbitrage essentially for the cheapest source of electricity, typically, energy sources where supply outweighs demand (e.g. hydro and flared natural gas).
- **Mining Bitcoin uses more energy than using it:** Bitcoin mining will not go on forever as there is a fixed supply. The energy required to validate already-mined (issued) coins is minimal compared to the mining of new coins.

- **Runaway growth is unlikely:** Every year Bitcoin's energy mix becomes less reliant on carbon. Miners are becoming increasingly ESG-focused.

Carter (2021) concludes that it is up to the crypto community to acknowledge and address environmental concerns, work in good faith to reduce Bitcoin's carbon footprint, and ultimately demonstrate that the societal value Bitcoin provides (as a global monetary system) is worth the resources required to maintain it.

The second most common consensus mechanism is PoS which does not rely on excessive computational power to validate transactions and add blocks to the BC. Rather this algorithm requires nodes to stake cryptocurrencies (coins) for the ability to validate transactions. The more coins that a particular node stakes, the higher the probability for that node to validate a block of transactions. These nodes are referred to as validators (similar to miners in a PoW network), which are incentivised to behave honestly or they will lose their stake in the network (Howell, 2021). An overview of the differences between PoW and PoS is presented in Table 3.

Table 3: PoW vs PoS comparison (Howell, 2021)

Criteria	Proof of Work (PoW)	Proof of Stake (PoS)
How information is added to the BC	The validity of transaction blocks is determined by solving cryptographic puzzles. (computational power).	The validity of transaction blocks is determined on the basis of "stake" in the network. (Amount of cryptocurrency staked)
Probability of mining/ validating blocks	The probability of mining (creating new coins/block) depends on the computational work done by the miner (node).	The probability of validation of a new block depends on the number of coins/cryptocurrency a validator (node) holds in the network.
Energy usage	The Proof of Work consensus mechanism is less energy-efficient than PoS. (Miners try to solve an energy-intensive puzzle to get the right to create a new block and add it into the blockchain.)	The Proof of Stake consensus mechanism is highly energy-efficient when compared to PoW. (No competition based on energy consumption for processing a new block).
Security	It is highly secure and has a proven track record. 51% of the network's entire computation power is required to breach the network.	Less secure but there is no financial incentive for validating multiple transaction copies on a blockchain. It is difficult for hackers to own 51% of stake in a blockchain network.
Rewards	Rewards are given to the first miner to successfully solve the cryptographic puzzle for each new block.	Validators do not receive a reward for creating a new block but rather receive fees for processing transactions within each block.
Example projects	Bitcoin	Cardano

From Figure 9 it is clear that there are multiple ways of building a BFT blockchain system. Each of the consensus mechanisms is designed to achieve consensus in different ways. How consensus is achieved can typically influence three main features of a BC, namely security, decentralization and scalability. Vitalic Buterin (co-founder of Ethereum) conceptualized a model (Figure 10) named the "blockchain trilemma", which highlights these features as challenges that programming engineers face when developing a blockchain (CertiK, 2019).

Vitalic states that because of how blockchains are built (programmed), engineers are forced to make trade-offs between decentralization, scalability and security. In theory, blockchains have to sacrifice one aspect in order to achieve a high degree of the other two components. These components are listed thus (Certik, 2019):

1. Decentralization – creating blockchain networks that have no central point of control
2. Scalability/speed – the ability for a blockchain network to handle an exponential number of transactions
3. Security – the ability of a blockchain network to defend itself from malicious attacks, bugs and black swan events

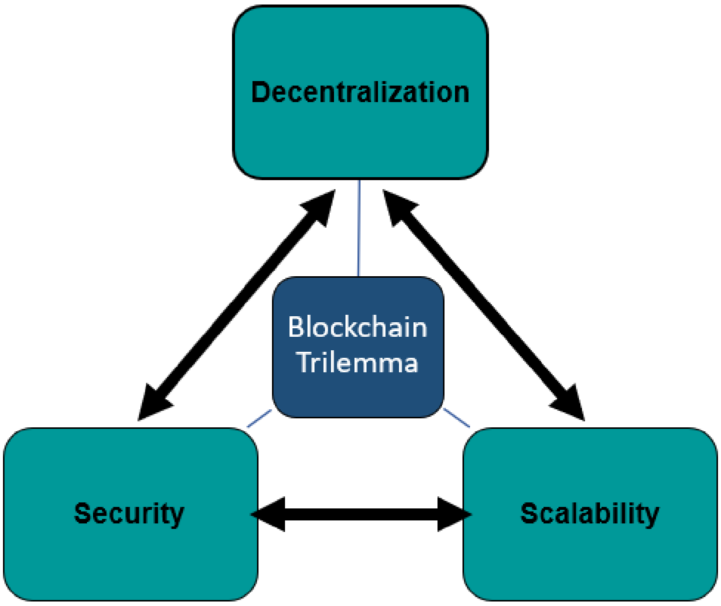


Figure 10: The blockchain trilemma

For the mining industry it is important to make informed decisions when choosing a consensus mechanism as different outcomes are desirable with different applications. When a natural resource mining organization has set an objective, the desired results can be used to work backwards and identify a suitable consensus mechanism that may align with that objective. Figure 11 can be used in the mining industry to determine a suitable consensus algorithm under certain criteria for different scenarios. The decision tree can be leveraged to select a particular consensus mechanism when designing, developing or selecting a blockchain system.

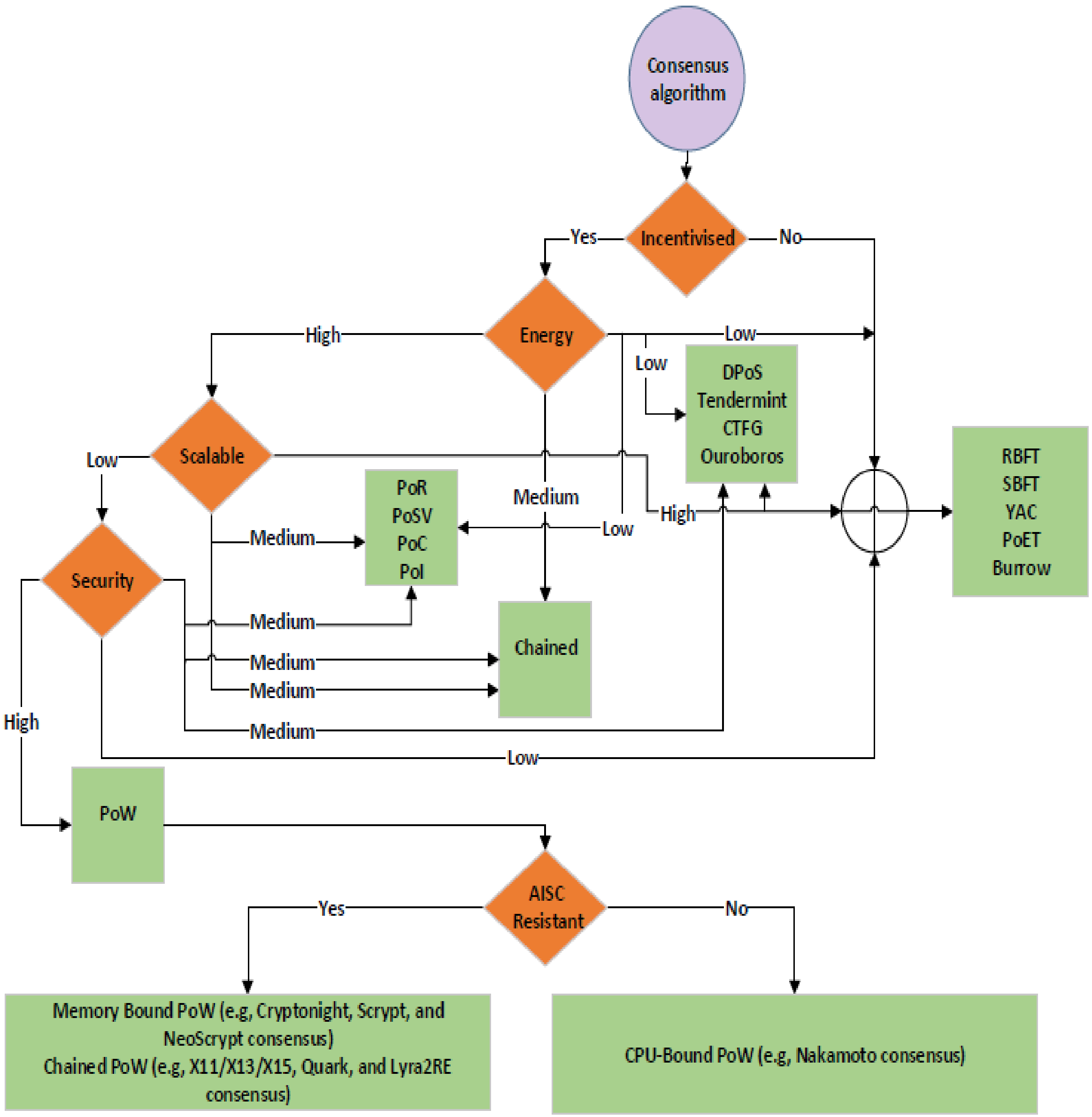


Figure 11: Decision tree to choose appropriate consensus algorithms (Ferdous, et al., 2020)

Term	Elaboration
Incentivised Consensus	These are algorithms that reward participating nodes for creating and adding a new block in the blockchain.
Non-incentivised Consensus	Private blockchain systems deploy a type of consensus algorithms that do not rely on any incentive mechanism for the participating nodes to create and add a new block in the blockchain.
DPoS	Delegated Proof of Stake (or DPoS) is a form of consensus algorithm in which reputation scores or other mechanisms are used to select the set of validators.
Tendermint (BFT PoS)	Tendermint showcases how BFT consensus can be achieved within a PoS setting of blockchain systems. It consists of two major components: a consensus engine known as Tendermint Core and its underlying application interface, called the Application Block Chain Interface (ABCI).
CTFG (BFT PoS)	Casper The Friendly Ghost (CTFG) is a pure BFT PoS algorithm that aims to transform PoW blockchains into a PoS-only blockchain system.
Ouroboros (BFT PoS)	Ouroboros is a probably secure PoS algorithm utilized in the Cardano platform which supports smart-contract and decentralized applications without relying on any PoW consensus algorithm.
PoR	Proof of Research (PoR) is a hybrid approach that combines Proof of Stake with Proof of BOINC. BOINC stands for Berkeley Open Infrastructure for Network Computing.
PoSV	Proof of Stake Velocity (PoSV) is used to secure a peer-to-peer network and confirm transactions of Reddcoin, a cryptocurrency created specifically to facilitate social interactions in the digital age.
PoC	Proof of Cooperation (POC) is a consensus algorithm introduced by the FairCoin cryptocurrency which does not implement any mining or minting functionality commonly needed for competitive systems.
PoI	Proof of Importance (PoI) works to prove the utility of nodes in a cryptocurrency system, so that they can create blocks.
PoW	Proof of Work is a form of cryptographic proof in which one party proves to others that a certain amount of a specific computational effort has been expended.
ASIC Resistant	Application Specific Integrated Circuits (ASIC) are created to serve a specific use case (performing a particular computing task like Bitcoin mining). ASIC-resistant is the property of a cryptocurrency that is “immune” to ASIC mining.
RBFT	Redundant Byzantine Fault Tolerance (RBFT) is an improvement over the Byzantine Fault Tolerance (BFT).
SBFT	This is Simplified Byzantine Fault Tolerance.
YAC	YAC is yet another consensus mechanism used in Iroha. Hyperledger Iroha is designed to be simple and easy to incorporate into infrastructural or IoT projects requiring distributed ledger technology.
PoET	Proof of Elapsed Time (PoET) is a consensus mechanism used by Hyperledger Sawtooth. Sawtooth offers a flexible and modular architecture that separates the core system from the application domain, so smart contracts can specify the business rules for applications without needing to know the underlying design of the core system.
Burrow	Hyperledger Burrow is a complete single-binary blockchain distribution focused on simplicity, speed and developer ergonomics.
Additional source	www.hyperledger.org

1.1.4 Blockchain Use Cases and Capabilities

In a study by Hileman and Rauchs (2017) a list of BC use cases was compiled, segmented into different industries. Figure 12 highlights that 30% of the 132 identified blockchain use cases were in the banking and finance sector. Although the mining sector is not illustrated in this breakdown of BC use cases, it does undoubtedly interact with these industries at some point in a mining organization's life cycle. These use cases are investigated further in the literature review section of this document (Chapter 2) to assess the technology's applicability in the mining industry.

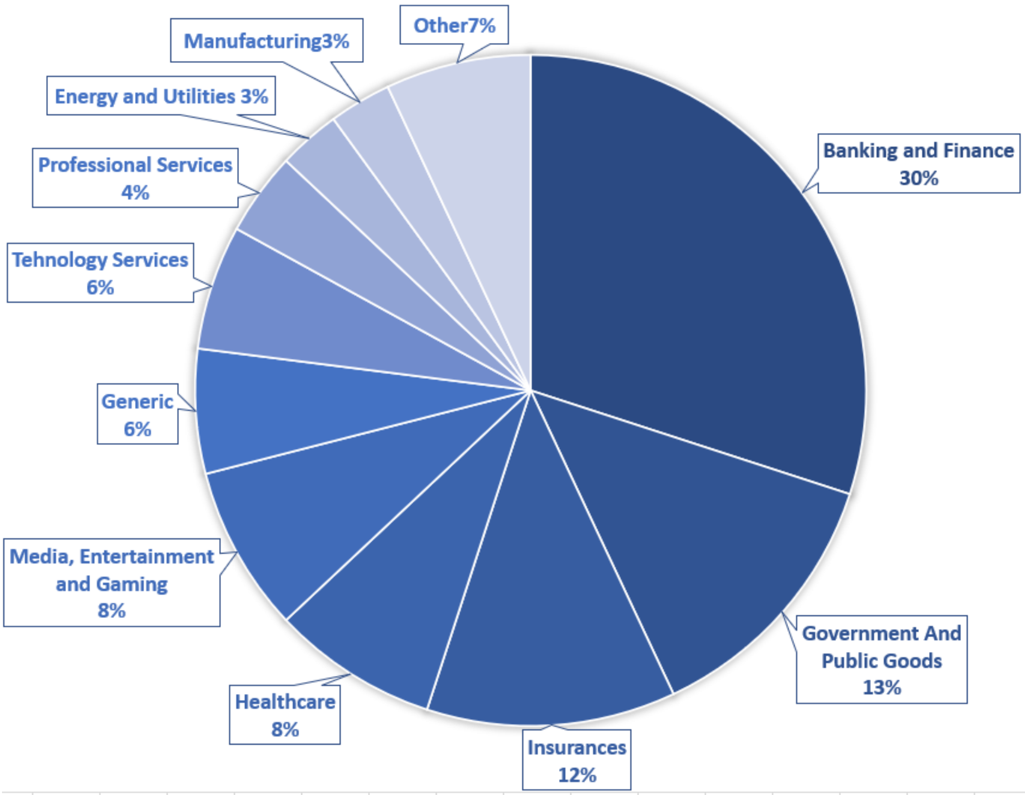


Figure 12: Blockchain use cases segmented by industry (Hileman & Rauchs, 2017)

Compared to existing database systems, blockchain systems are more resilient, better at providing data transparency and have improved automated reconciliation mechanisms. Hileman and Rauchs (2017) concluded with a summary of key advantages associated with using BCT in the various industries. These are as follows:

- The BC system offers improved data availability and dependability, as well as providing system-level security against some forms of cyberattacks.
- Using BCT makes everything represented on the ledger traceable, prohibiting manipulation thanks to the system's open auditability properties.
- Blockchain systems significantly accelerate data processing speed and lower costs throughout the whole operating process by eliminating the traditional reconciliation operations required for "siloed" databases.

When one is looking to develop a blockchain system or simply deciding on what blockchain technology to incorporate into a company's business strategy, it is essential to understand the requirements for enterprise-ready blockchains. Table 4 highlights the capability requirements for an enterprise-ready blockchain.

Table 4: Core Blockchain capabilities (Mueller, 2018)

Capabilities	Considerations	Functions
1. Tokenization	Is it possible to implement the tokenization of physical goods?	**The digitization of real-world assets**
2. Data security	Does the system offer sufficient data security and data privacy aspects?	
3. Decentralized data storage	Does the system support decentralized data storage with sufficient performance?	**The digitization of processes and transactions between independent companies**
4. Smart contracts	Does the system offer smart contracts, i.e. the execution of decentralized applications and/or decentralized autonomous organization (DAO) functionality?	
5. Data immutability	Is the immutability of the data ensured?	**The provision of immutable transaction and asset records**
6. Data permanence	Is the data stored permanently – Are historical records always accessible?	
7. Data transparency	Are all transactions traceable and is the data auditable?	

It can be concluded from the above discussion that data-fuelled technologies such as Artificial Intelligence (AI), Internet of Things (IoT's) and Blockchain (BC) will play an important role in the digital transformation process of the mining industry (Philo & Webber-Youngman, 2021). Blockchain technology is perceived to be a foundational building block of the future digitized economy. To a large extent this technology is still under development and the real benefits of blockchain applications, particularly in the mining resource industry, remain to be confirmed and proved. One of the major challenges for blockchain adoption is the gap between the underlying technology and the understanding of its capabilities. Thus, it is important to research and understand the application of BCT to drive innovation and accelerate digital transformation in the mining industry.

1.2 Problem Statement

From the evidence provided above, digital information will play a crucial role in shaping the future of the mining industry. It is suggested that blockchain technology has the potential to increase the speed and efficiency of data transactions, provide greater transparency within an organization and improve trust within the digital economy. There is therefore a need to better understand the capabilities of the technology to identify key focus areas for the potential implementation of blockchain solutions in the mining industry.

1.3 Research Objectives and Methodology

The research hypothesis for this study is the following: The application of Blockchain technology in the mining industry can add value or additional benefits to core business value chain processes. The following are the main research questions that this research aimed at answering:

1. Why is there a need for implementing blockchain solutions in the mining industry?
2. How could Blockchain technology be used in the mining industry?
3. What are the potential benefits for implementing BC in the mining industry?
4. Where are the potential focus areas for BC applications in mining?

Four themes and initiatives were suggested by the WEF via web and literature search that will likely have an impact on shaping the future economy as well as the mining industry. The following themes: Automation, Robotics and Operational Hardware; Digitally Enabled Workforce; Integrated Enterprise, Platforms and Ecosystems; Next-Generation Analytics and Decision Support all have rely on digital information or “Big data” as a fundamental resource. Blockchain technology was identified as the focus area for further research because of the associated technological features that safeguard and govern digital information as a resource. The literature in this study highlights the applicational benefits of Blockchain technology in various industries and investigates potential focus areas in mining core business value chain processes. This research is relevant to any organizations or individuals who wish to obtain a deeper understanding of Blockchain technology and its application in the mining industry.

The research objectives and methodology are summarised in Table 5. Furthermore a schematic is used to illustrate and explain the methodology approach to this research in Figure 13: Research methodological roadmap. The road map highlights the work done in the literature review, starting with an investigation into BCT use cases in different industries. These use cases are discussed to identify what capabilities of BCT are used and the associated benefits. Mining industry use cases are then researched form a technology push perspective in order to try and find possible focus areas within the mining industries business process for further research. Requirement for BCT applications are investigated to assist with developing a possible use-case. From the literature review, the capabilities and value drivers of BCT are mapped to the mining industries business processes in order to highlight where BCT can be applied.

Table 5: Objectives and methodology

Chapter	Objectives	Methodology
2	**Identify and evaluate blockchain applications in industry.** 2.1 Investigate and compile a list of what value BC provides in different industries. 2.2 Investigate the capabilities and requirements for blockchain technology applications. **Investigate possible application areas where BCT could be used in the mining industry.** 2.3 Summarise the core value chain processes within the mining industry to investigate whether blockchain applications are possible. 2.4 Identify possible guidelines for implementing blockchain solution in the mining industry.	A literature study was conducted on BC applications. This was done to identify why BC technology is used in the related industries and what value the technology delivers. The literature review (Chapter 2) identified factors that should be considered for implementing BC applications (capabilities and requirements). Chapter 2 summarizes and explains the different value chain processes within the mining industry in order understand and assess potential blockchain applications in mining. Frameworks for adopting blockchain in the mining industry at a high level are highlighted.
3	**Results and evaluation of results** 3.1 Tabulate the mining value chain processes and identify potential blockchain applications using the technological capabilities identified. 3.2 Provide reasoning as to the decisions made in 3.1 from information gathered in the literature review by suggesting potential value drivers.	Based on the findings of the literature review industry applications and associated benefits were summarised. A table was created of all the core value chain processes involved in the different mining industry phases and their associated outputs/deliverables. The technological capabilities of blockchain technology were used to justify the potential applications within each mining phase.
4	**Conclusion**	The findings of the main objectives were summarized and the results were presented. The focus was on the technology's enabling capabilities and benefits for the mining industry
5	**Recommendations**	Recommendations were based on the results and evaluation.
6	**Suggestions for further work**	Suggestions were made for further research that can be conducted on multi-criteria decision analysis for incorporating BC technology into mining business strategy. An industry survey can be done for focused business application.

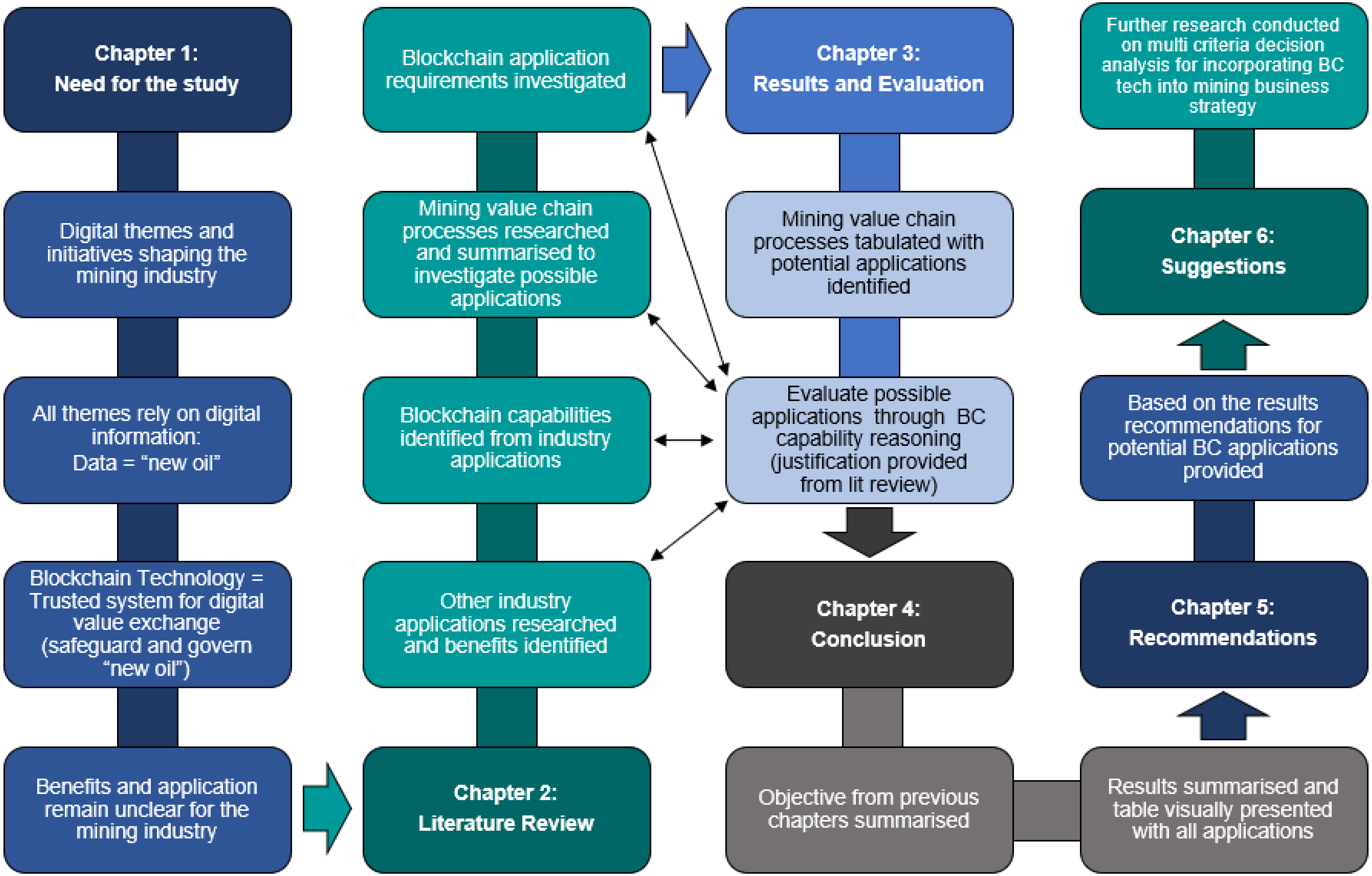


Figure 13: Research methodological roadmap

1.4 Scope of the Research Investigation

As the digital economies of the world evolve, trust and data security will play an important role among all entities/participants in the global economy. Data is seen as the "new oil" of the 21st century and therefore this research aims to understand future trends so that mining companies can position themselves accordingly and not fall behind in the digital economy.

This research focused on blockchain technology to establish context as well as to investigate possible use cases for the mining industry. The focus was on identifying blockchain application areas that could potentially add value to core business processes associated with the different mining phases. The research does *not* focus and/or elaborate on any core applications within the mining industry. Rather, it highlights possible focus areas that mining and related companies can investigate further to potentially develop a business case for use.

The research also did *not* investigate blockchain mining energy consumption technicalities and did *not* focus on one type of blockchain specifically. The aim was to provide a high-level overview of different BC applications used in various industries to identify the technology's capabilities and potential value drivers, and its potential use in the mining industry. No costs associated with BCT implementation (hardware, software, human capital/skills or service providers) are investigated. The focus of the study is therefore a technological push perspective to highlight potential application areas for the mining industry and to encourage further research and innovation in this regard.

CHAPTER 2

LITERATURE REVIEW

The literature study highlights different BC capabilities in different industries by summarizing the technology's use cases. The mining industry's business processes are discussed to lay a foundation for assessing BCT applicability and capabilities in the associated value chain processes. Frameworks are also discussed on how to assess the applicability of BCT for the mining industry.

2 THEORY AND LITERATURE REVIEW

The following section discusses the use cases of BCT in various industries in order identify the technological capabilities and the benefits of application. The mining value chain processes are defined in order to evaluate whether the technological capabilities of blockchain technology could potentially be utilized to drive additional value creation within the mining industry.

2.1 Blockchain Use Cases Globally

Blockchain technology offers an innovative way of recording/storing and transferring important data. Data records are grouped together in blocks that are cryptographically linked, ensuring a transparent, safe and secure data-exchange process. The technology allows all or specific network participants (depending on private or public BC applications) to know who they are doing business with as the data records are decentralized, permanently stored and easily accessible. The data stored on a BC can be tamper proof (changes on a BC need to be authorized by the majority of network participants, i.e. consensus dependent) and/or tamper evident (any suspicious data alteration made will be recorded), preventing unwanted situations for businesses dealing with important digital information (Goyal, 2018).

Goyal (2018) states that in the future, BCT will be used in all industries; it provides four main areas of application: record keeping, digital currencies, smart contracts and securities. Figure 14 attempts to summarize the applications of BCT from a holistic perspective, but some applications are duplicated, especially with regard to securities and digital currencies. The real benefits of applying BCT within different industries are at present still underutilized.

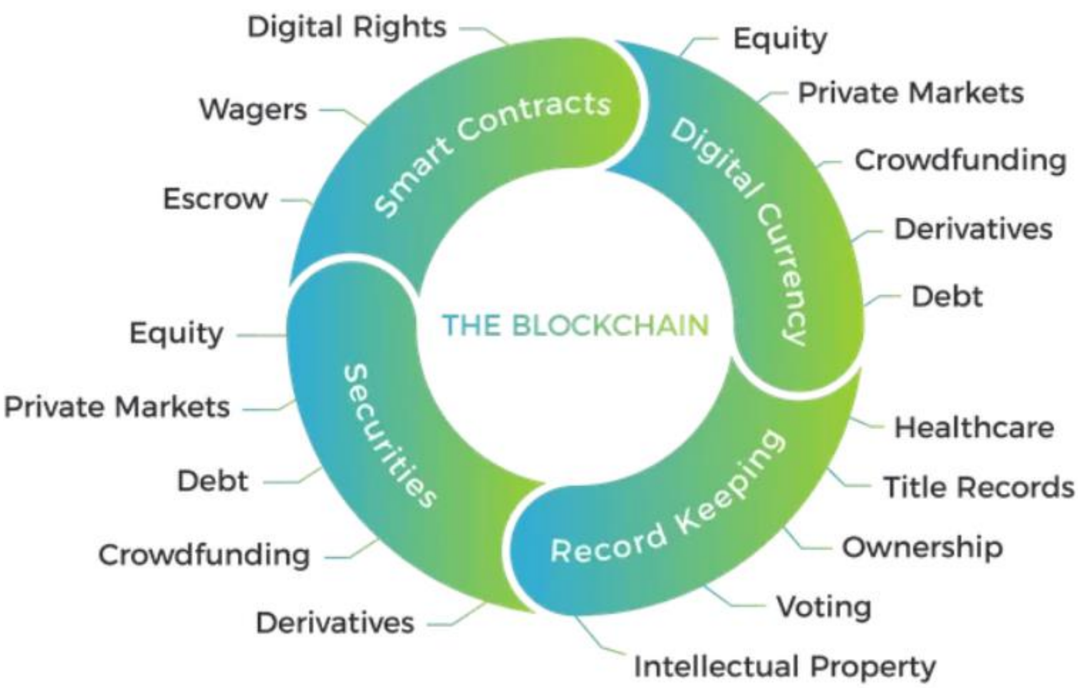


Figure 14 : Blockchain applications (Goyal, 2018)

Hileman and Rauchs (2017) identified 132 potential use cases (payments, identity management, data security, etc.) that have been mentioned in public discussion, reports and press releases. The top five industry segments by BC use cases are: banking, government, insurances, healthcare and media, together constituting more than 80% of the use cases. These industry segments are investigated further to understand what value BCT can provide within each industry and which ones could be useful and applicable to mining.

2.1.1 Banking and Finance

The financial services sector provides financial services to people and corporations. This segment of the economy is made up of a variety of financial firms, including banks, investment houses, lenders, finance companies, real estate brokers and insurance companies. This is probably the most important sector of the economy, leading the world in terms of earnings and equity market capitalization (Catalano & Overcast, 2021).

Consumers or corporations can acquire financial goods using financial services. If a payment system provider receives and distributes money between payers and recipients, for instance, it is providing a financial service. Accounts cleared by cheques, credit and debit cards, electronic fund transfers, and similar methods are included in this sector (Catalano & Overcast, 2021).

The financial services sector is built on the banking industry. While the financial services sector includes investments, insurance, risk redistribution, and other financial activities, it is focused primarily on direct saving and lending transactions (Catalano & Overcast, 2021). To verify and facilitate financial transactions, consumers or corporations have relied on these centralized authorities such as banks and credit card providers. These centralized authorities come with large and actual transaction expenses, and there are fees associated with every transaction. Additionally, fraud, identity theft and the manipulation of centralized authorities are common risks associated in dealing with centralized financial services providers such as banks and credit agencies. Data breaches such as the Equifax hack in 2017 (reported as one of the largest cybercrimes related to identity theft), where the private records of more than 150 million individuals were compromised, support this claim, (Diamandis, 2019).

Issues such as data breaches and the misuse of private and financial information are risks associated with conducting business in the digital age. Individuals or corporations have to place their trust in third party services to facilitate and validate commerce, be it currency, digital, physical products or services. Blockchain technology offers an alternative approach to conventional technologies or business models that place their trust in third-party service providers. Blockchain technology essentially provides trust without the requirement of a reliable third party. This can be trust in a transaction (that the same amount left one account as it entered another, that the sender approved of it, and that the funds used are distinct and were not double-spent); or trust that a conditional contract will be automatically executed (without dispute); or trust that a product originates from the location that a user claims it originates from (Pike & Capobianco, 2020). This "trust" is derived from the technological characteristics and components associated with creating a blockchain, as discussed in the project background in Section 1.1.1 Blockchain Fundamentals.

In 2021 an article on "How blockchain could disrupt banking" suggested that this technology has the potential to disintermediate key services that banks provide. The services mentioned are Payments, Fundraising, Securities, Loans and Credit, Trade Finance and Know your Customer (KYC) and Fraud Prevention (CBinsights.com, 2021). Each of these services is briefly discussed to see how blockchain technology is or can be applied and what value is created/captured via the technology's application. From this its potential application in mining is explored.

2.1.1.1 Payments

If an individual works in the United States and wishes to send a portion of his or her money to a family member in London, he or she may be required to pay a wire transfer fee of $25 flat, plus additional fees totalling 7%. The individual is charged exchange rate fees. In addition, both the sending and receiving banks are charging a fee to facilitate the transaction. It is also possible that the receiving bank only records the transaction a week later (CBinsights.com, 2021).

With a card payment, the transaction must be authorized, cleared and settled by a banking network, as well as a card network such as VISA or Mastercard. Trust is generated by relying on well-established financial institutions that run several checks while the transaction is in progress. The card payment procedure (authorization, clearance and settlement) is shown in Figure 15, Figure 16 and Figure 17.

The objective of the authorization process (Figure 15) is to verify a customer's identity as the owner of the funds they are trying to use, as well as the availability of the funds. The process typically involves the following steps (Wisdomtree.com, 2019):

1. A transaction is initiated when a customer inserts an authorized card into a payment terminal and enters their pin number.
2. The payment details and customer card information are sent to the merchant's bank.
3. The merchant's bank sends the payment details and customer card information to the card network.
4. The card network requests authorization from the customer's bank.
5. The customer's bank checks to see whether the information is correct and that there are available funds, authorizing the request.
6. The card network notifies the merchant's bank that the transaction has been authorized.
7. The merchant's bank notifies the merchant of the authorized transaction.

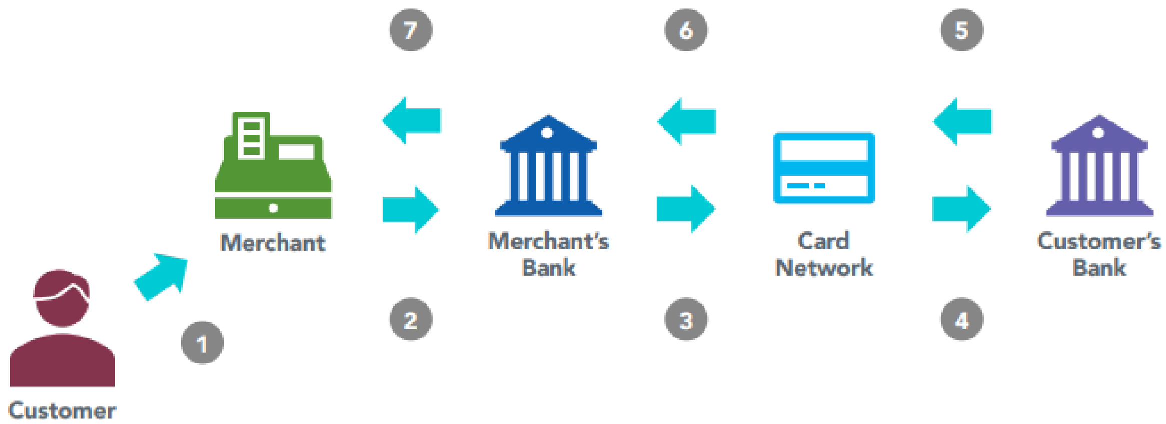


Figure 15: Card payment *authorization* process (Wisdomtree.com, 2019)

Although this entire process takes place in just a few seconds, no funds have actually been transferred. Authorization for the payment transfer has been approved, but the payment clearing and settlement process is still ongoing. Next, the clearing process (Figure 16) is initiated whereby the exchange of transaction-related information is used for the verification of money to be debited from the customer's bank and credited to the merchants' bank. The clearance process is as follows (Wisdomtree.com, 2019):

1. At the end of each business day, all approved transactions are sent by the merchant to the merchant's bank.
2. The merchant's bank transmits the transaction details to the card network.
3. The card network verifies the data, transmits the purchase information to the customer's bank, and then sends the reconciliation data to the banks of both the merchant and the customer.

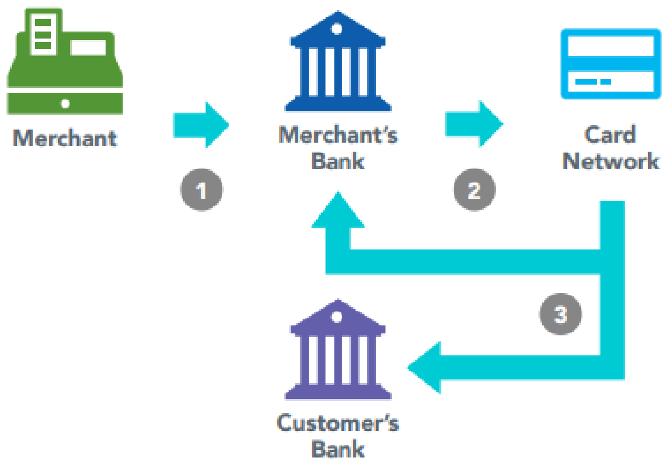


Figure 16: Card payment *clearing* process (Wisdomtree.com, 2019)

Once the clearing process is completed, then the settlement process begins. The settlement process is the actual transfer of funds between the merchant and the customer. This process occurs daily on an aggregated net basis as follows (Figure 17) (Wisdomtree.com, 2019):

1. The card network computes the net settlement position between the merchant's and the customer's banks, sending this information to both banks, as well as to a new party, the settlement bank.
2. The settlement bank pays the merchant's bank.
3. The customer's bank pays the settlement bank.
4. The merchant is then credited.
5. The customer is debited.

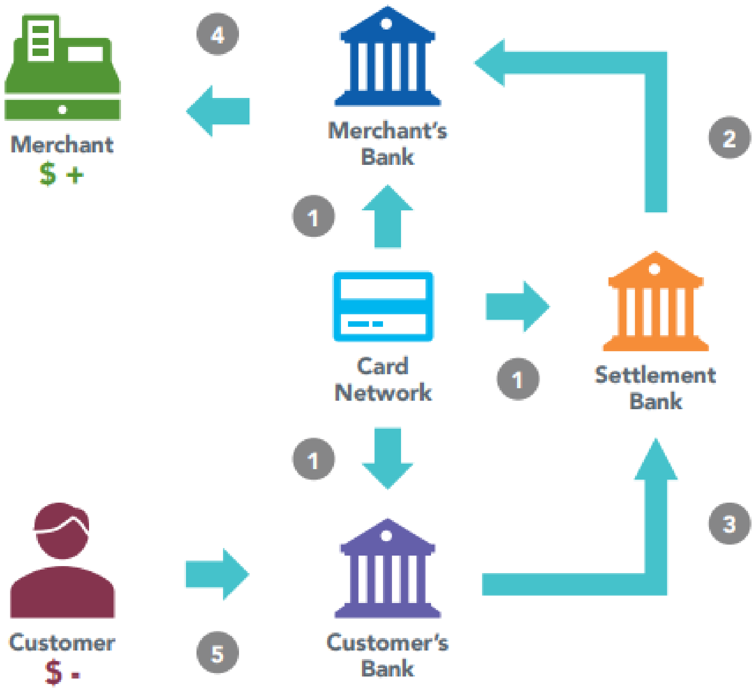


Figure 17: Card payment *settlement* process (Wisdomtree.com, 2019)

The entire payment process discussed from authorization to final settlement is an informationally dense process relying on various counterparties to create, transmit and record digital ledgers accurately. This process requires a certain degree of trust between the process-communicating entities to ensure that all transactional information ledgers are correctly authorized, cleared and settled which, generally takes between 24 to 48 hours (Wisdomtree.com, 2019).

Banks are crucial hubs for value storage and transfer from a macro perspective. Blockchain technology can perform the same role as digitized, secure and tamper-proof ledgers, enhancing accuracy and information-sharing throughout the financial services sector. Blockchain technology enables untrusted parties to agree on the status of a database without the use of a mediator. A use case example is Bitcoin, a desterilized ledger for payments that facilitates faster payments at lower fees than banks charge (CBinsights.com, 2021).

The Bitcoin network payment process

The payment process through the Bitcoin network (Figure 18) follows a different path than that previously discussed:

1. Initially, the customer/sender enters the merchant's/recipient's Bitcoin address and the amount of Bitcoin to send using a digital wallet interface. (Merchants can scan the item of interest, generating a QR code that the customer can scan with their digital wallet on their mobile device, automatically filling in the associated payment amount and address.).
2. The customer's wallet sends this information to the Bitcoin network, using his or her "private key" to sign/authorise the transaction digitally. (The digital signature could possibly be compared to the customer entering a PIN code or signing a receipt in a card transaction in order to prove ownership of the funds.)

3. The transaction information is received and propagated via nodes across the entire Bitcoin network (All notes can independently verify whether the funds are available and have not been previously sent – steps 1,2 and 3 are similar to the authorization step in card payments.)
4. Bitcoin “miners” gather the network transactions and try solve a challenging computational problem. When this problem is solved, the miner notifies the network participants (nodes and other miners) that the problem is solved.
5. All other nodes on the Bitcoin network can easily verify whether the miner’ is telling the truth, in which case a new block of transactional data is added to the blockchain. This step is where Bitcoin ownership changes between the respective customer and merchant (similar to the settlement phase in a card transaction.)
6. When the block (containing the transactional information) is added to the blockchain and registered in the distributed ledger, payment is confirmed in the merchant’s wallet.
7. The merchant is now the new owner of the Bitcoins.

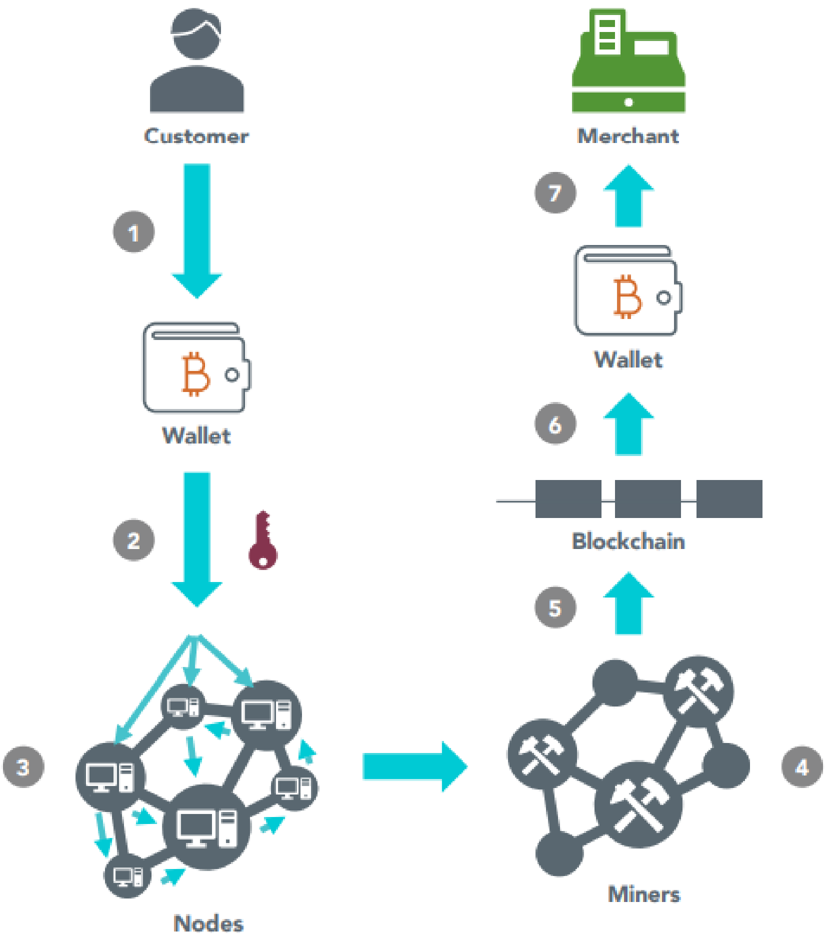


Figure 18: Bitcoin transaction process (Wisdomtree.com, 2019)

The completion time for this entire process is on average 10 minutes but can vary up to 1 hour depending on the network activity and fees (Wisdomtree.com, 2019). When compared to the 24-hour settlement time of traditional card networks, this is a significant reduction in time to complete the same process of exchanging ownership titles.

Significance of available information

The use of blockchain technology as a payment system reduces the number of intermediaries required with exchanging ownership titles regarding Bitcoins. Sending Bitcoins only requires two intermediaries, namely a wallet and the Bitcoin network, as opposed to three different banks (customer, merchant and settlement bank) and a card network. Nodes and “miners” are sub-parts of the Bitcoin network; removal or addition of these entities will not affect the system’s purpose. Having fewer intermediaries involved reduces the communication exchanges and eliminates potential errors among participating entities.

The significant time reduction in settling payments also improves time efficiency. All completed and pending transactions can be viewed simultaneously by multiple or specific entities (depending on open or private BC applications). This may increase the velocity of money, potentially enabling faster service/resource delivery. For example, if an underground mine’s production is put on hold due to a lack of support units (no stock/oversight), then by using a blockchain payment network, support units can be ordered and payment settled within 10 minutes to one hour. The supplier could then immediately initiate the delivery process, no purchase order or excessive paper work is needed, reducing the mine’s downtime.

The adoption of blockchain technology by mining organizations could potentially reduce the number of intermediaries and improve time efficiencies within the payment structure of their business operations. Cost reduction in terms of payment processing, settlement and reconciliation costs could improve the company’s bottom line.

2.1.1.2 Securities exchange and settlement

Stocks, bonds, mutual funds and other forms of financial assets are all referred to as securities. The term "security" refers to a fungible, negotiable financial instrument that holds some type of monetary value. Securities can represent ownership in a corporation in the form of stock, a creditor relationship with a governmental body or a corporation represented by owning that entity's bond; or rights to ownership as represented by an option (Kenton, 2022). Securities are not physical objects but are rather represented as a digital financial claim that can be bought, sold or exchanged in securities exchange markets.

When buying and selling such financial assets, the important task of tracking who owns what is accomplished through a complex chain of brokers, exchanges, central securities depositories, clearing houses and custodians. These different parties are built around an outdated system of paper ownership that is not only slow, but also inaccurate and prone to deception. Each party involved in this process of transferring ownership has their own version of the truth in a separate ledger which adds to the complexity of this operation. Securities trades take one to three days to settle because all the intermediaries’ books need to be updated and reconciled daily. Due to the large number of parties involved, transactions often need to be manually verified, resulting in each party charging a fee (CBinsights.com, 2021).

By building a decentralized database of distinct digital assets, BCT holds the potential to completely transform the financial markets. Blockchain technology can be used to create cryptographic tokens representing a physical or digital asset, which rights can be transferred via a distributed ledger. Even though Bitcoin and Ethereum have only used digital assets to achieve this, new blockchain start-ups are exploring ways to tokenize physical assets such as gold, stocks and real estate. Additionally, tokenized securities can act as programmable shares through smart contracts, allowing for the automatic payment of dividends or share buy-backs (CBinsights.com, 2021).

Securities are held by financial institutions which provide for the safekeeping of such assets using Central Securities Depositories (CSDs). A CSD is a financial market infrastructure that facilitates the processing of securities transactions. The CSD is a ledger system which allows financial institutions to maintain legal records of securities and other assets in digitized form. Their core services typically include notary and central account maintenance services, as well as clearing/settlement services (Symons, 2017).

Symons et al. (2017) discussed the application of BCT in a report titled "Blockchain settlement regulation, innovation and application". The authors investigated the regulatory and legal aspects related to the use of BCT in post-trade settlement of securities. They suggested that the use of BCT in a central securities depository should not require any specific regulation in this field as the application of BCT will only enhance the functionality of CSDs. The benefits of using BCT in this case are highlighted and summarised in this report (Symons et al., 2017):

1. **Reduced settlement latency:** The use of BCT would enable parties in a multi-tier securities custody model to effectively collaborate to maintain the same underlying data set. Information and accounts are often siloed between different cross-border banks or custodians. Using BCT, information only needs to be recorded in a database maintained and accessed in a single distributed ledger, rather than in each separate database layer in the holding chain. BCT will reduce the time required to align data prior to settlement.

2. **Reduced operational and custody risk:** Investors are exposed to errors in the reconciliation of securities throughout the custody chain and are at risk if one of the custodians in the chain fails to execute on a transaction. The BCT model could materially reduce the magnitude of these risks by obviating the need for reconciliation and by removing database redundancies.

3. **Increased transparency to issuers, end investors and regulators:** Investors and other intermediaries typically have access only to the account kept by the intermediary closest to them in the chain. The application of BCT could potentially merge siloes of information along the custody chain into a single master record. The master record could be made fully transparent to the issuer and the CSD, and either fully or partially transparent to relevant regulators and intermediaries in the chain of custody.

4. **Reduced intermediation of recordkeeping** – Using BCT, trading, clearing and settlement would become a single real-time process for updating a single ledger which does not involve multiple entities (assuming intermediaries in the chain of custody are mere record keepers).

Furthermore, Natrajan and Nuthi (2022) estimate that moving securities on blockchains could save $17B to $24B per year in global trade processing costs.

Significance of available information

Mining companies have several financial assets to manage within their organization. The buying and selling of securities enable mining organizations to adjust to different economic environments and align their operations with their strategic efforts/plans. They rely on intermediaries to facilitate the transfer of securities in order to reach their strategic goals.

By creating digital tokens of these financial assets on a blockchain, the buying and selling of securities could be done with fewer intermediaries, reducing the settlement latency and associated fees. The use of BCT within the transfer and settlement process of securities will reduce the associated operational and custody risk, while increasing the transparency of the mining organization's core assets to investors.

The use of smart contracts could also enable automatic dividend payments to all shareholders. These smart contracts could be programmed to execute automatically when certain conditions are met. These conditions can be discussed and managed by the company's board of directors. Efficiency gains could be realised by using BCT where there are high volumes of administration involved or there are different stakeholders operating in silos (i.e. centralized systems that make data transparency and collaboration challenging).

2.1.1.3 Fundraising

Fundraising is the process of soliciting and accumulating funds voluntarily contributed by people, businesses, non-profit organizations or governmental bodies. There are multiple sources/methods of acquiring funds: capital markets (traditional equity), private equity, debt financing, government programmes and crowd funding (Newagemetals.com, 2019). In contrast to these methods, initial coin offerings (ICOs), supported by open-source blockchains such as Ethereum and Bitcoin, are a popular way for businesses to raise capital (CBinsights.com, 2021).

An ICO is a method of raising funds for a project by selling blockchain-based digital assets (cryptocurrency coins or tokens). Table 6 distinguishes between crypto coins and tokens. Like an initial public offering (IPO), investors can participate in the ICO to receive new cryptocurrency tokens issued by the company. This token may have utility related to a product or service or may represent a share in the company or project (Frankenfield, 2022).

Table 6: Difference between crypto tokens and coins (Tarasov, 2022) and (Feign, 2022)

Token	Coin
Built on existing BC network (e.g. Ethereum) using smart contracts.	A crypto coin is a form of digital currency that is native to its own BC.
Tokens are a recorded in a register. The record describes the essence of the property that is "represented" in the token.	Coins are mined through PoW or earned through PoS mechanisms.
Tokens in different blockchain networks have various technical standards and are not fungible.	They are used as a means of exchange and store of value.
Represents an asset or offers holders certain platform-specific features or functionalities such as utility, security and governance.	Examples of crypto currency coins are Bitcoin (BTC), Ether (ETH), and Cardano (ADA).
Used for different purposes such as Decentralised applications (DApps), or for creating Decentralised Autonomous Organizations (DAOs).	
Different types of crypto tokens are Security tokens, Nonfungible tokens (NFTs), and Utility tokens.	

Thurman (2021) highlights these advantages of using ICOs for raising capital:

- **Reduced time to gain access to capital:** Only 100 lines of code are needed to create an Ethereum-based token for an ICO. These tokens can be created and distributed in a very short period when compared with other means of financing such as initial public offerings (IPOs).
- **Liquidity:** Tokens can be sold into a global market that operates 24/7.
- **No gatekeepers:** ICOs can raise capital directly from anyone with a crypto wallet and internet connection from anywhere in the world.
- **Ownership:** Tokens do not grant ownership rights to token holders unless this is explicitly programmed into the smart contract.
- **Community:** ICOs attract early investors/adopters that resonate with the project.
- **Minimal bureaucracy:** Depending on the project tokens' regulatory status, disclosure requirements and paperwork can be minimal.

An alternative way of gaining funds is through loans. The use of BCT as an alternative source for finance has enabled peer-to-peer (P2P) lending which offers a cheaper, more efficient, more inclusive, and more secure way of making personal loans to a global range of people (Saiedi, et al., 2022).

P2P lending brings a wide range of lenders and borrowers together on a decentralized BCT-based platform which uses cryptocurrencies. Users or companies can gain access to cash via a loan, without the need for banks or other financial institutions. The most popular alternative finance model in Europe in 2017 was P2P lending to consumers. This model generated €1.392 billion in volume; it did not take into account business to business (B2B) which had a 13.8% market share in 2017 (Saiedi, et al., 2022).

SALT Lending is one company that uses BCT to make cash loans. The SALT Lending platform allows users to borrow money using various cryptocurrencies (Bitcoin, Ether, etc.) as collateral. Loans are accepted based on the value of the collateral rather than on the borrower's credit score. In order to gain access to SALT's platform, the user must first purchase SALT (the platform's cryptocurrency) to gain membership, and can then utilize the platform's functions (Owen, 2016).

Significance of available information

ICOs are a different source for financing projects. The main benefits of using BCT for funding projects is the ability to tokenize physical assets or create digital assets that can be programmed to various degrees of functionality. These tokens can be bought or sold with cryptocurrency (coins) on a global market, operating 24/7, by anyone with a crypto wallet and internet connection. Junior mining companies typically identify, explore and develop a mineral deposit in order to prove the economic viability of extracting that deposit. The ICO tokenized funding model based on the intrinsic value of the ore deposit or its production can be used to raise capital for further exploration in the junior mining space.

Smaller mining companies or start-ups can also use P2P or B2B loans to gain access to capital for project development. These BCT-based platforms, such as SALT Lending, provide entrepreneurs with an easier way of funding their goals. Capital can be sourced from various geographical regions using cryptocurrencies and be put straight to work. Mining businesses can also provide loans to local community members using BCT platforms, which will encourage community upliftment and local entrepreneurialism.

2.1.1.4 Customer KYC process and fraud prevention

The Know Your Customer/Client (KYC) is a process of validating the identity and other credentials of financial services users. This process is intended to help prevent money laundering and the financing terrorist activities (Davies, 2021).

The KYC is a labour-intensive process, which involves verifying photo IDs, paper documentation, including address proofs and fingerprints, and can take banks up to three months to complete. Some clients may sever ties with the banks if the KYC procedure takes too long. A Thomson Reuters survey found that 12% of businesses claimed they had switched banks as a result of delays in the KYC procedure. The survey also mentioned that banks spend up to $500 million annually on client due diligence and KYC compliance (CFI, 2021).

Blockchain technology can assist in lowering the human labour and expense associated with KYC compliance. Due to the decentralized nature of the platform, all institutions that need KYC would be able to access consumer information that is recorded on a blockchain. According to Goldman Sachs, using blockchain for KYC will allow banks to save up to $160 million annually by reducing their required manual labour by 10% (CFI, 2021).

Blockchain technology provides a unhackable digital process of sharing user information on a permissioned network which will reduce the time and effort required in the initial phases of KYC. In consequence, this reduces the cost of regulatory and compliance while also speeding up customer onboarding (Chirag, 2022a).

Distributed data collection is enabled by using BCT. KYC user data can be updated in real time, available on a decentralized network that can be accessed by authorized parties. Additionally, the system provides effective data security because unwanted access to the data is prevented as users can only access the data based on the permissions granted (Chirag, 2022a).

According to BNY Mellon Treasury Services, one of the main reasons for concern for the banking industry is the rise of fraud and cyberattacks. The cause is that banks have shifted to consolidating all consumer data into centralized ledger systems, making that information highly vulnerable to an intrusion. Blockchain technology assists in preventing a hacker from gaining access to all of that consumer information by decentralizing the storage of data (CFI, 2021).

An example of improved KYC through BC application is Bloom, a credit scoring platform. Customers can construct blockchain-based profiles using the mobile application. Bloom's identity monitoring program continuously searches the internet and the dark web for any potential data leaks. OnRamp is part of Bloom’s recent KYC and anti-money-laundering compliance solution, which includes ID verification along with screening for sanctions and politically exposed persons. Users can connect to and verify their bank account details using this platform (Schram, 2021).

Another company offering blockchain KYC solutions is Quadrata. Users can save verifiable compliance and KYC identity information using the Passport on a non-transferable, non-fungible token (NFT). The passport is a privacy-preserving, sybil-resistant technology that brings identity, compliance and reputation to DApps built on public blockchains. Access to KYC information can then be granted by the user via smart contracts to different institutions or applications in order to verify personal information (Cheng, et al., 2022).

Significance of available information

The application of BCT in the KYC process can lower the turnaround/onboarding time of clients with financial institutions as KYC information can be stored on a decentralized database, saving data gathering and processing time. Data quality is also improved as alterations are tracked and monitored in real time via the BC network. Manual labour is reduced using BCT as the process can be automated using smart contracts, eliminating the need for paperwork. Mining organizations have to deal with financial institutions so using BC based KYC processes will enable these benefits within the organization, allowing mining companies to focus on their core business objectives.

2.1.2 Government and Public Goods

The term "Government" refers to a system or institution made up of people who manage a nation or state. The constitution of the nation guides how the government conducts itself. The constitution is a body of fundamental rules and ideas designed to guarantee sound government. These rules or regulations support the government's involvement in all acts pertaining to social law, order, welfare, defence, education and financial policies. This section of the literature review does not discuss specific roles and responsibilities of government, but rather different potential blockchain use cases that may aid certain governments in fulfilling their functions. This is done to highlight the technology's capabilities and identify the associated benefits.

2.1.2.1 Government applications

Globally, governments spend $9.5 trillion on procurement contracts, through complex processes characterized by opacity and a large degree of human discretion. Approximately 10–30% of a public contract's overall value is lost due to corruption, and the money is funds often diverted to the pockets of corrupt government officials and other participants (Lannquist & Raycraft, 2020).

Lannquist and Raycraft (2020) state that the cost to society of public sector corruption and weak accountability is immense. In many parts of the world, public sector corruption is the number one obstacle to social, economic and environmental development. Corruption often revolves around lack of transparency, poor records and poor public accountability. The authors suggest that BCT, when applied sensibly to certain corruption-prone government processes, could make these systems more transparent and accountable, reducing the risk and spread of fraudulent activity.

Public procurement typically involves four stages for large government contracts: planning, bidding, bid evaluation, and then implementing and monitoring the contract (Figure 19). A direct or negotiated purchase agreement may be used to award more modest or complicated contracts. Every stage of every type of public procurement process has its own difficulties and opportunities for corruption, including bribery, improper influence on government judgements, private-sector cooperation, bid rigging, coercion, extortion, and fraudulent bid submissions and evaluations (Lannquist & Raycraft, 2020).

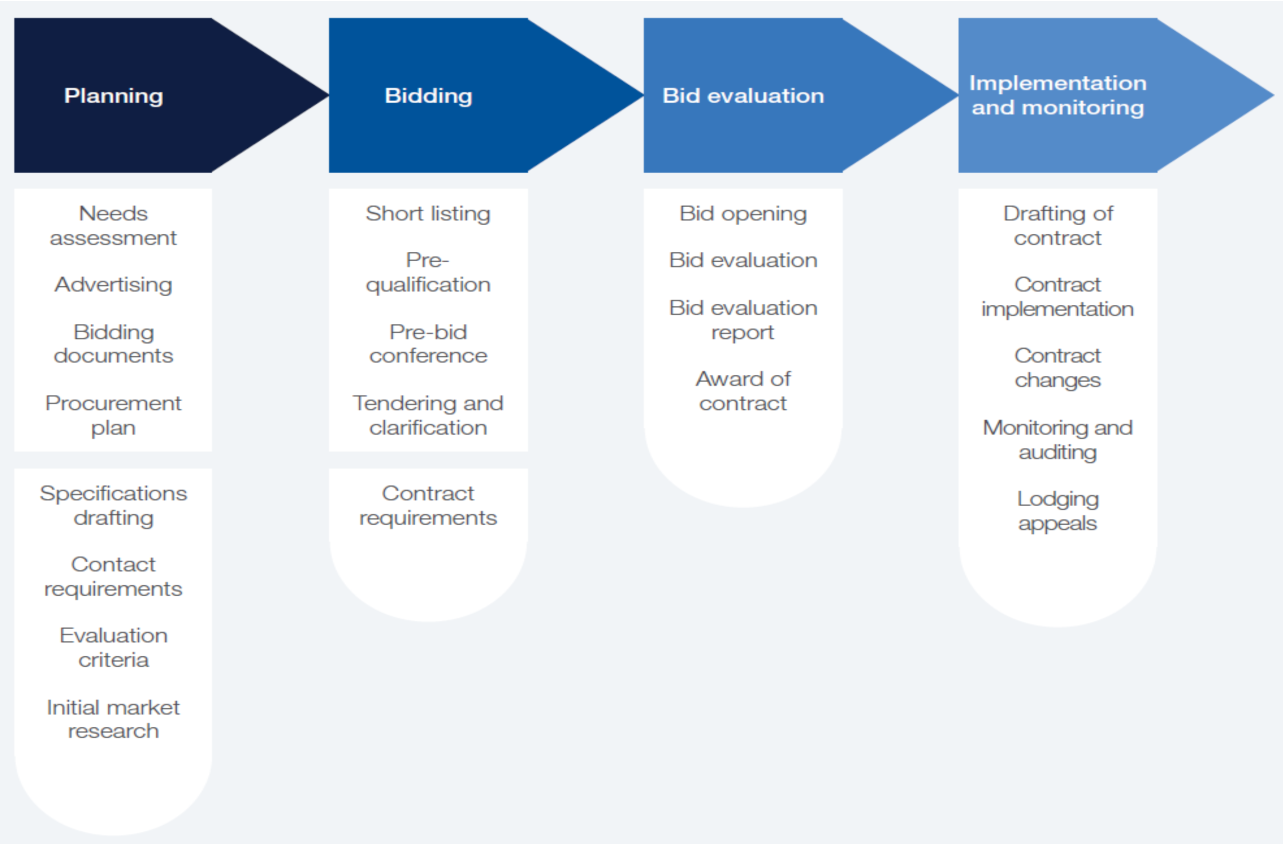


Figure 19: The four key stages of the public procurement process (Lannquist & Raycraft, 2020)

A summary of the challenges with respect to accountability and transparency in public procurement is given in Table 7.

Table 7: Summary of accountability and transparency challenges in public procurement (Lannquist & Raycraft, 2020)

Transparency and access	Competitiveness and integrity	Institutional challenges	Contract pricing
- Delayed or incomplete publication of records - Low procurement process and record access and visibility - Low transparency in payments	- Direct contracting - Bid tailoring - Conflicts of interest and bribery - Prevalence of auctions that favour established and large vendors	- Low investigatory capacity at national monitoring, oversight, and “watchdog” institutions	- Price collusion among vendors - Poorly conducted price “benchmarking” - Vendor underestimation of contract price to win bid

Lannquist & Raycraft (2020), along with other stakeholders, developed a blockchain-based system for the procurement of a public-school meal programme that feeds Columbia’s most vulnerable children. This programme was identified as a historic site for procurement corruption in Columbia. By using cryptography and distributed consensus mechanisms, BCT was able to provide permanent, tamper-proof records, data transparency, and auditability of transactions within the procurement process. Furthermore, the uses of “smart contracts” enables process automation while reducing centralized authority and information ownership within the procurement programme. These mentioned capabilities are believed to make BCT a strong contender likely to limit corruption (Lannquist & Raycraft, 2020).

The team created a Proof of Concept (PoC) blockchain-based e-procurement system, fully public and permissionless on the Ethereum blockchain network, focused on the vendor bidding and bid evaluation process. The report highlighted the applicational advantages in terms of procedural transparency, permanent records and honest disclosure. Lannquist and Raycraft (2020) conclude by stating that blockchain-based e-procurement systems show promise for further development, but that the technology itself fails to mitigate the risk of corruption in certain human activities that may occur outside of electronic procurement systems (Lannquist & Raycraft, 2020).

Ølnes et al. (2017) state that BCT can be used in any transaction or exchange of information in which governments are involved. The underlying fundamental characteristics (see Section 1.1.1) of this technology enable a wide range of applications in processes involving asset registries, inventories and information exchange for tangible (such as real estate) and intangible (such as ideas, votes, patents, reputation, intention, health information) assets. Pilot projects using BCT are being carried out by governments all around the world. These projects include digital identity, the preservation of court judgments, funding for school construction, money tracking, marital status, electronic voting, business licences, passports, criminal histories, and even tax records (Ølnesa, et al., 2017).

By using BCT, organizations will gain access to trustworthy information stored on an immutable ledger. Through collaborative creation, evolution and management of a single unchangeable history of transactions, organizations can subsequently gain the ability to better predict future events. A notable example supporting this statement is the granting of permits to the organizers of large-scale events such as concerts or protests. Such events require the consent of multiple parties (municipality, the police, the fire brigade, and health organizations). This can all be collaboratively managed using BCT to ensure that all parties involved are equipped to handle the large-scale event. The information captured and shared on the BC can be used to assist with future event planning (Ølnesa, et al., 2017).

Another example is the use of BCT in land tenure projects. The application of BC is especially useful when ownership records are not maintained systematically or when the business organization is not trusted. In some countries it is difficult to prove ownership of land. BC can be used to protect property owner rights, resolve disputes, ensure that ownership has been properly transferred, and prevent unauthorized/fraudulent charges (Ølnesa, et al., 2017).

Aburumman et al. (2020) and Calvin et al. (2020) identified the different use cases of BCT in the government services and public sector. These different use cases for government are summarised and discussed in Table 8.

Table 8: Use cases for BCT in government (Aburumman et al. 2020 and Calvin et al. 2020)

Applications for BCT and associated countries	Descriptions
Central Bank Digital Currencies (CBDC): China, United States, Switzerland and various others	More than 100 different countries are investigating the use of CBDC to better manage a country's financial stability. End-to-end transparency and traceability for supervision and control.
Education: Japan, Malta	The use of BCT to create digital certification and the management thereof in government schools.
ID management: Estonia	Personal identities are tokenized, allowing the government to store and manage this data on a BC which can be used for other government processes or transactions. This application allows individuals to access their data and share it with other parties without the need for a third party to verify their identity.

Payments and taxation: United Kingdom, Ukraine, Switzerland	Several countries use BCT to verify transactions and track them in the payment and tax process. These processes conducted via BCT are faster and more transparent than the traditional method which requires a third party to perform verification and tracking operations.
Record store: UAE, Estonia, United States, China, Russia	Each user on the blockchain receives a "diamond copy" of the ledger that contains the information in a block. If the record changes, a new block is added and the revised file is synchronized across the network. This process can be completed in near real-time (depending on the BC architecture). As more and more changes are made, new blocks are added, to form a chain which contains a complete record of all data changes. The "transparent" nature of BCT will benefit government and financial institutions in general by facilitating mandatory regulatory reporting.
Voting systems: Ukraine, Estonia, and Australia	Electronic voting operations can be conducted using BCT. The technology's ability to maintain the confidentiality, transparency and safety of user data enables the application of an easily accessible and more democratic voting process.
Healthcare: United States, Estonia, China, United States, Switzerland, Philippines, Japan, Brazil	Blockchain technology helps in preserving patients' information and health history data, which can be accessed by other health service providers such as doctors, pharmacists, and even insurance companies. Blockchain technology enables governments to track health records, increasing accountability, whereby support and advice can be provided to make better decisions in this area. There is also focus on the supply chain management of goods required or associated with the healthcare industry (medication, syringes, first aid supplies, etc).
Assent management (land registry and transactions): Ghana, Georgia, Sweden, Honduras, Switzerland	Ownership titles can be stored on a decentralized registry with no central authority or third party to verify or validate transactions. The entire process of ownership transfer can be programmed into a BC network using smart contracts whereby users can store the information with digital signatures and timestamps, which can be processed and verified by the BC network itself.

Significance of available information

The literature identifies a wide range of use cases for the government sector, from central bank digital currencies to identity management, data preservation, procurement processes, marital status, electronic voting, business licences, passports, criminal histories, and even tax records. The various use cases indicate that there is significant opportunity for BCT to aid with the different functions and services that government provide. The mining industry can benefit from adopting BCT in the ID management of their employees and service providers, as well as storing digital records.

2.1.2.2 Government applicational benefits

Numerous application benefits associated with BCT in the public sector are listed in Table 9. The value BCT drives within the sector have been categorized in terms of strategic, organizational, economic, informational, and technological. Although an explanation is given for each benefit, many of these categorized drives are not backed up by factual data from actual use cases as a lot of BC projects are still being researched and developed. The design decisions involved in the BC architecture and applicational development process will determine whether the benefits, which are interdependent and stackable, will be realized (Ølnesa, et al., 2017).

Table 9: Potential benefits and promises of BCT (Ølnesa, et al., 2017)

Category	Applicational benefits	Explanation
Strategic	Transparency	Democratizing access to data. Transaction history is always visible, with each node showing a complete overview of the transaction.
	Avoiding fraud and manipulation	Information is stored on multiple distributed ledgers, making it difficult for hacks and unauthorized changes to go unnoticed.
	Reducing corruption	Information storing on a distributed ledger prevents corruption. For example, BC stores land ownership titles with set rules for non-manipulable ownership changes.
Organizational	Increased trust	Process reliability with improved control through immutable record and data validation with multiple nodes.
	Transparency and auditability	Tracking transaction history and creating an audit trail. Access to multiple ledgers for consistency.
	Increased predictive capability	Since historical information can be traced back, the availability of historical information enables improved predictive power.
	Increased control	Adding a transaction requires network consensus, so you have more control.
	Clear ownerships	Governance rules are clearly defined on how information can be changed.
Economical	Reduced costs	It reduces the cost of completing and validating transactions by eliminating the need for human involvement.
	Increased resilience to spam and cyber attacks	Higher levels of resilience and security reduce the cost of countermeasures to prevent attacks.
Informational	Data integrity and higher data quality	The information stored in the system corresponds to what is fundamentally represented due to the need for consensus voting in transactions and the decentralized nature. This will improve the quality of your data.
	Reducing human errors	Automated transactions and controls reduce human errors.
	Access to information	Information is stored in multiple locations, making the information easier and faster to access.
	Privacy	Users can remain anonymous by providing an encryption key. Access can be protected so that other users cannot see other individuals' information.
	Reliability	Data is stored in multiple locations. Consensus mechanisms ensure that information is only changed if all relevant parties agree.
Technological	Resilience	Resilient to malicious behaviour.
	Security	Data manipulations is difficult as this data is encrypted and stored in multiple places. Hacking all these data sources at the same time is less likely.
	Persistency and irreversibility (immutable)	Once data is written to the BC, it is difficult to modify or erase it without notice. Also, the same data is stored in multiple ledgers.
	Reduced energy consumption	Increased efficiency and transaction mechanisms reduce network energy consumption.

Significance of available information

The use cases for BCT in government are vast, ranging from digital identity issuance/management, preservation of legal documents, money tracking, electronic voting, business licences, passports, tax records to any transaction or exchange of digital information where governments are involved.

A pilot project for governments e-procurement systems highlighted that BCT can provide procedural transparency on how the bidding and evaluation process works. By providing permanent records of all bidding and transactional information associated with the procurement process, honest and trustworthy disclosure of information can be achievable. This should result in a better e-procurement system for governments while being less susceptible to corruption. The main value drivers identified are trust and transparency within the public procurement process. It should be noted that while the application of BCT in the e-procurement process can provide an open and trustworthy system, individuals acting in the physical world are still prone to collusion and corruption no matter how well the virtual platform is designed.

The benefits of using BCT in the government sector are hard to categorize and quantify despite the attempts of many researchers. The capabilities of BCT lend themselves to numerous applicational benefits that are sometimes interlinked. For example, the application of BCT can facilitate better control and auditing of digital information, which in turn could lead to increased trust in that system. Trust is not created by the technology itself, but rather through providing a transparent system which anyone can assess or validate.

The application of BCT in the mining industry should be useful in any processes where digital information is stored, altered or exchanged. The value drivers categorized in terms of strategic, organizational, economic, informational and technological are benefits that many mining organizations would like to benefit from in their day-to-day business.

2.1.3 Insurance

Companies that provide risk management through insurance contracts make up the insurance industry. The fundamental idea behind insurance is that one party (the insurer) will make a financial commitment to cover an unwanted future event (e.g. accidental death, asset damage, etc.). The insured party or policyholder pays the insurer a premium in exchange for that security against that potential future adverse event (Beers, 2016). This section identifies the use cases of BCT and the associated benefits in the insurance industry.

Deloitte published an article on their website on the use of BCT for the insurance industry. This article suggested that the application of BCT will create new insurance processes and business models that can address pain point (inefficient exchange of information, fragmented data sources, manual claims review and processing) within the insurance industry (Colaco, et al., 2022).

The researchers at Deloitte specified that the use of BCT in the property and casualty insurance division will benefit the underwriting of contracts and claims processing activities within the industry. The impact BCT will have on the associated proccess within these two activities, as well as the benefits, are summarised in Table 10.

Table 10: Impact of BCT on property and casualty insurance use case (Colaco, et al., 2022)

Property and Casualty insurance underwriting impacts			
Risk assessment	Quoting	Onboarding	BCT benefits
• Enable trusted and verifiable provenance information. • Provide transparency on past/current policy records and claims. • Enable shared interface with other data providers (i.e. property registry, notary service, public records, etc.).	• Improved accuracy of pricing through transparent quantification of risk and disintermediation of intermediaries. • Provide digital smart contracts to capture obligations and terms binding insurer and insure.	• Enable capture of immutable, trusted, and verifiable information based on digital cryptography. • Provide fast, seamless, and transparent experience in binding policy to insurees.	• Efficient exchange of information. • Improved risk profiling. • Automation through smart policy. • Enhance client onboarding.

Property and causialty insurance claims processing impacts			
Claim registration	Claim assessment	Payment and closure	BCT Benefits
• Provide trusted and verified submission of claim data and/or documentation. • Enable automated pre-assessment of the loss coverage against the policy • In the case of smart assets/properties, enable claim to be securely and automatically submitted without human intervention. • Automate process to engage repair and assistance providers in order to reduce response time and ensure use of preferred suppliers.	• Provide access to validated external data through trusted sources (i.e. oracles). • Enable automated determination of loss liability. • Enable automated assessment of loss coverage for syndicates/ reinsurance. • Enable programmable escalation to human decision-making in case of complex risks.	• Provide automatic payment to insurees through smart contracts. • Provide immutable and transparent proof of claim settlement.	• Simplified / automated claim submission. • Reduced fraud loss. • Enhanced customer experience and no manual inspection. • Automated compliance.

Arpan & Navin (2012) found other specific real-time BC applications in their analysis of trade literature for marine and travel insurance. These two examples further demonstrate how the insurance sector is leveraging BCT to attain improvements in operational efficiency.

The Danish marine shipping company Maersk partnered with E&Y and Microsoft to develop a blockchain-based insurance solution for its fleet of ships. These ships transport valuable cargo and are vulnerable to pirate attacks, cargo damage, port delays and storms. The main goals of the BC system were to simplify supply chain auditing, make the entire database impenetrable (limit third-party write access), and enable universal access to the data (read access for data transparency) (Arpan & Navin, 2012).

The French multinational insurance company AXA has used blockchain technology to create a new travel insurance product named "fizzy". This product ensures travellers who were affected by flight delays. There is no need for manual intervention because the process is entirely automated and secure. A smart contract contains the policy details and is integrated with the flight traffic databases. As a result, the compensation process is much more transparent and faster because the traveller will be informed of the smart contract's decision to compensate or not (Arpan & Navin, 2012).

Significance of available information

The value drivers identified from BC applications in the insurance sector are improvements in process audibility, data management, automation, security, information sharing and transparency. Financial insurance products/services play an important role as uncertainty is something the mining industry deals with at every level of a mining venture and can never be eliminated. Insurance is needed to protect the mining industry’s businesses, property, employees, equipment and contractors from numerous potential risks.

The use of a decentralised BC ledger recording digital events and or information (mining industry operational data, assets, operational procedures) shared between authorised parties (mining company and insurance provider) will enable synergies for the insurance underwriting processes. Better risk assessments can be done with trustworthy and transparent data, potentially reducing policy premiums for mining organizations.

Smart contracts will enable a more efficient and less labour-intensive claims process in cases where an unwanted event has occurred (damaged infrastructure or mining equipment, loss of life, etc.). The contract will have access to the shared ledger and when an unwanted event is captured and verified, the claims process is automatically executed. The mining business is then compensated in real time and can focus its attention on remedial actions.

2.1.4 Healthcare

Krawiec et al. (2016) identified that BCT offers a new distributed framework that can amplify and support the integration of healthcare information within the sector. The application of BCT addresses numerous pain points associated with Health Information Exchange (HIE) processes and enables a system that is more efficient, disintermediated and secure. The authors summarized the related pain as well as BC applicational opportunities as in Figure 20.

HIE pain points	Blockchain opportunities
Establishing a trust network depends on the HIE as an intermediary to establish point-to-point sharing and "book-keeping" of what data was exchanged.	**Disintermediation of trust** likely would not require an HIE operator because all participants would have access to the distributed ledger to maintain a secure exchange without complex brokered trust.
Cost per transaction, given low transaction volumes, reduces the business case for central systems or new edge networks for participating groups.	**Reduced transaction costs** due to disintermediation, as well as near-real time processing, would make the system more efficient.
Master Patient Index (MPI) challenges arise from the need to synchronize multiple patient identifiers between systems while securing patient privacy.	**Distributed framework for patient digital identities**, which uses private and public identifiers secured through cryptography, creates a singular, more secure method of protecting patient identity.
Varying data standards reduce interoperability because records are not compatible between systems.	**Shared data** enables near real-time updates across the network to all parties.
Limited access to population health data, as HIE is one of the few sources of integrated records.	**Distributed, secure access** to patient longitudinal health data across the distributed ledger.
Inconsistent rules and permissions inhibit the right health organization from accessing the right patient data at the right time.	**Smart contracts** create a consistent, rule-based method for accessing patient data that can be permissioned to selected health organizations.

Figure 20: HIE-related pain point and BCT opportunities (Krawiec, et al., 2016)

The Organization for Economic Co-operation and Development (OECD) published a report in 2020 which discussed the possible opportunities and challenges of BCT in the healthcare sector. The report highlighted that BCT can play a major role as a supporting technology that will enable transparency and accountability within healthcare data operations (Oderkirk & Slawomirski, 2020). The following are key findings summarized from the report:

- The application of BCT is ideal for transactions with a light digital footprint (in terms of data size) where transparency and immutability are beneficial. For such cases, BCT is particularly useful for: identifying verification of patients and staff; medical and pharmaceutical supply chain management; and managing dynamic patient consent and data-sharing permissions (Oderkirk & Slawomirski, 2020).

- Deployment of BCT in the health sector on a national scale is rare. Published research papers overemphasize the usefulness of BCT and only provide theoretical frameworks, architectures or models for BCT implementation. There is a lack of technical details regarding BCT implementation as there are seldom prototypes or pilot programmes targeting a specific healthcare sector use case to learn from (Oderkirk & Slawomirski, 2020).

Although BCT applications on a national scale are still being investigated, a technology consultancy company, STLPartners, outlined five key use cases for blockchains: in the development of digital health; supply chain transparency; patient-centric electronic health records; smart contracts (Insurance and supply chain settlements); medical staff credential verification; and IoT security for remote monitoring (STLPartners, 2021).

2.1.4.1 Supply chain transparency

Verifying the provenance of medical goods to validate their authenticity is a significant concern for the healthcare sector, as well as many other industries. Customers can have complete visibility and transparency of the products they are buying thanks to the use of a blockchain-based system to trace items from the moment of manufacture and at each stage through the supply chain. *MediLedger* (a BCT application) enables businesses operating in the prescription drug supply chain to confirm the legitimacy of medications, as well as expiration dates and other crucial data (STLPartners, 2021).

The benefits of using BCT for supply chain transparency are (STLPartners, 2021):

- **Improved customer confidence –** By integrating manufacturers, wholesale and distribution partners on a BC network, customers can track the provenance of each package end-to-end.
- **Enhanced compliance** – In order to maintain patient safety, pharmaceutical companies and medical device manufacturers undertake burdensome reporting processes. By combining supply chain data into one system, compliance can be made easier.
- **Supply chain optimization** – When all the data (device manufacturers, pharmaceutical companies, medical institutions) is amalgamated into one BC, businesses use AI to more accurately estimate demand and adjust supply.

Significance of available information

Large mining organizations have complex and sometimes fragmented supply chains which could benefit from adopting BCT. With more focus placed on mining companies to adopt ESG principles, a BC-enabled supply chain tracking network could provide managers with accurate and transparent information relating to the tracking of raw material (mines' production), consumables (operation–specific, e.g. paint, explosives, support units), equipment and other products.

2.1.4.2 Patient-centric electronic health records

Data silos are a problem that affects healthcare systems worldwide, giving patients and their healthcare professionals a partial picture of their medical histories. According to data from Johns Hopkins University published in 2016, medical errors stemming from poorly coordinated care, such as planned actions not executed as intended or omissions from patient records, were the third largest cause of death in the US (STLPartners, 2021).

Developing a blockchain-based medical records system that can be integrated with current healthcare software can serve as a solution to medical errors. Each new item added to the blockchain, such as a doctor's note, a prescription, or a test result, is converted into a distinct hash function (a brief string of letters and numbers). Every hash function is distinct and can only be deciphered with the permission of the owner of the data, in this example, the patient. The patient's personal data does not need to be recorded on the BC, only the medical records. In this scenario, each time a patient record is modified and they agree to disclose a portion of their medical information, a transaction is recorded on the BC. *Medicalchain* is a business collaborating with healthcare providers to build a blockchain-enabled emergency medical response service (STLPartners, 2021).

The benefits of using BCT for emergency medical response service are (STLPartners, 2021).:

- **Better patient and healthcare provider experience** – BCT provides a comprehensive single source of truth of a patient's medical records.
- **Improved patient data transparency and control** – Patients can observe when their medical records are updated and can decide to disclose all or a portion of their medical records to other parties.
- **Process efficiency improvements and reduced costs** – Medical insurers can receive immediate, validated confirmation of healthcare services directly from patients using a BC network, without the time and cost of an intermediary.

Significance of available information

The health and safety (H&S) of employees are important to any organization. Mining companies have dedicated H&S officials at their mining operations that ensure compliance with relevant legislation. The use of BCT to store employees' personal health records will be useful for cases when incidents occur at a mining site. For example, if there is a fall of ground in an underground working section of a mine and a worker is injured, emergency response teams could gain access to that person's medical information on the BC. This information can be used to inform the team on how to treat the injured person and what medication to administer (if necessary). The use of smart contract on the BC can be used to gain permissions to private health-related data that could potentially save the injured person's life. For instance, a smart contract can be programmed to give access permissions to relevant parties in situations where the injured person is unable to give consent.

Mining companies require medical examinations of their employees to ensure that they are fit for duty in a specific working environment. Exit medical examinations are also done when employees leave the company or join other mining operations. By storing this medical information on a BC network, the mining organization can assess the impact of different working environments on people. This information could be useful in cases where potentially fraudulent financial claims are made against the mining organization regarding the health and safety of employees. All H&S-related information can be verified on the BC to see if there is evidence backing the claim. The mine's research and development team could also use this information to improve the H&S within their operations.

2.1.4.3 Smart contracts (insurance and supply chain settlements)

Chronicled and Healthverity are two companies developing smart contract BC solutions for the healthcare industry. Various companies (pharmaceutical firms, wholesalers, insurers, etc.) in the healthcare industry can authenticate their identities as organizations, log contract details, track transactions of goods and services, and track payment settlement details for those goods and services using BCT. Beyond supply chain management, these BCT services also enable insurers and trading partners in the healthcare industry to function under entirely digital and, in some circumstances, automated contract conditions (STLPartners, 2021).

Instead of each participant having their own copy of the contracts, manufacturers, distributors and healthcare organizations can considerably reduce disputes over payment chargeback claims for prescription drugs and other items by using shared digital contracts kept on a BC ledger. Because price structures frequently change, over one million chargeback claims are made amongst these players each year, more than 5% of which are challenged and require time-consuming human resolution, according to Chronicled (STLPartners, 2021).

Significance of available information

As mining companies grow in operational size and capacity, additional service providers are used to assist with driving value creation within their business operations. Telecommunications companies can be used to set up wireless communication for mining equipment, consultancy service providers can assist with improving blasting results, specialist service providers can assist with optimising metallurgical processes, etc. All these service providers will be contracted by the mining company to perform certain task. These contracts can be stored on a BC ledger where all parties can have access to the information. Criteria (such as service delivery receipts, key performance indicators) can be programmed into these contracts so that when service providers complete their contractual obligations, payment for services will be automatically transferred.

For example: A mining company uses a service provider that is contracted to deliver rock bolts on a monthly basis. The service provider first collects the product from the manufacturer and then transports and delivers the product to the mine. The smart contract is programmed to compensate the manufacturer for the product and the service provider for delivery when a digital receipt is scanned and verified on the BC. This process can considerably reduce disputes over payment and services by using shared digital contracts kept on a BC ledger for all parties (mining company, product manufacturer and transportation service provider) to see.

2.1.4.4 Medical staff credential verification

Blockchain technology can be used to track the experience of medical professionals in a manner similar to tracking the provenance of medical goods. Reputable healthcare organizations and institutions can log the credentials of their staff on to a BC ledger, which streamlines the hiring process in the healthcare sector. Such a medical credential verification system was created by US-based *ProCredEx* using the R3 Corda blockchain protocol (STLPartners, 2021).

The benefits of using this BC system for credential verification are (STLPartners, 2021):

- **Efficient and faster process:** Credentialing time and effort for healthcare organizations during the hiring process is reduced.
- **Data monetization:** Medical institutions, insurers and healthcare providers can monetize their existing credentials data on past and existing staff using this BC system.

- **Provides transparency and reassurance for partners:** Organizations sub-contracting *locum tenens* (person who temporarily fulfils the duties of another), or in emerging virtual health delivery models to inform patients on medical staff experience have easy access to such details.

Significance of available information

The application of BCT in staff credential verification within the mining industry is a possible use case. When the mining industry employees move from working at one company to another (e.g. from a diamond to a gold mine), the verification of their work experience is important to ensure that they are competent for their new job. Having a "mining industry experience" BC that captures employee-related milestones, achievements, certifications and work-related competency data will enable efficient employee onboarding processes, and allow mining companies to match the right people to the required job. Employees can give permission as to whether or not companies may view this data and can use this information to negotiate wages.

2.1.4.5 IoT security for remote monitoring

Remote monitoring solutions can be used, where various sensors tracking patients' vital signs are utilized to help give healthcare practitioners better visibility into patients' health. This is a trend in the healthcare sector that would enable more proactive and preventative patient care (STLPartners, 2021).

Security, however, is a significant problem in health IoT, in terms of ensuring both that patient data is private and secure, and that it is not altered to produce false data. It is also crucial that the supporting systems are extremely resilient to Distributed Denial-of-Service (DDoS) or other attacks disrupting service in some situations where a connected device may be relied upon in emergency situations (STLPartners, 2021).

Blockchain technology can improve the security of IoT remote monitoring devices through cryptography and decentralization. Most IoT connections go through a central server; the decentralized structure of blockchains allows IoT devices to interact directly with one another, making DDoS attacks more challenging. Blockchain technology uses a cryptographic hash function to store patients' data (sources data) as a hash (fixed-length alphanumeric variables). This source of data can only be accessed by using a cryptographic key to decode the hash function, ensuring that only permitted parties can gain access to personal data (STLPartners, 2021).

Although this use case is still in the early phases of development, blockchain may improve IoT security in the healthcare industry. Blockchains are worth looking at for digital health companies trying to figure out how to keep remote monitoring equipment secure, but only as a component of a far more comprehensive end-to-end security plan (STLPartners, 2021).

Significance of available information

The BCT use case for improving the security of IoT remote monitoring is an opportunity that the mining industry could benefit from. Mining operations are relying more on remotely operated and fully autonomous heavy machinery and equipment to achieve production targets and provide a safe working environment. The use of BCT can increase the operational security of such equipment and machinery.

2.1.5 Media, Entertainment and Gaming

Blockchain technology can support the media, entertaining and gaming industry by protecting intellectual property (IP), combating misinformation, and opening new avenues for monetization (Fatemi, 2022).

2.1.5.1 Media and entertainment use cases

By using smart contracts for media and entertainment licensing agreements, BCT can register, verify, and govern entertainment content shared between content producers and consumers (Morabito, 2017).

For independent musicians, content creators and artist, blockchain technology can enable new business models that offer the disintermediation of third-party involvement which often charge fees. These third-party costs can be eliminated and transactions can be directly executed between producers and consumers using BCT (Camila & Alberto, 2018).

An article published by ConsenSys.net on the future of BC in media and entertainment stated that unfair profit distribution, privacy breaches and copyright infringement are some of the major problems in this sector. These industry-related pain points can be addressed with the application of BCT in the following areas (ConsenSys.net, 2022):

- **Peer-to-peer sales and content distribution:** A significant percentage of the business administration work pertaining to contracts, licences and payments can be automated by using BC smart contracts. Creators can sell their work directly peer-to-peer as payment is automated and executed at a fraction of the previous cost. Markets for digital content built on the BCT enable direct communication between content creators and consumers without the use of expensive middlemen. Security of content distribution is also improved, protecting content creators' copyright.
- **Streamlining royalty payments:** Artists can upload original works, self-publish, manage distribution and control licence options on a BC-based platform. Royalty payments for digital content can be included in a smart contract that automates payments to the artist whenever it is used.
- **New pricing options for paid content:** Currently, customers pay content aggregators to access advertising and media (e.g. YouTube, Netflix, Hulu). An alternative pay-per-use consumption-based model using BCT presents an opportunity for new pricing options. Blockchain technology is capable of logging elaborate records of media usage data and can enable efficient micropayments for specific content.

Significance of available information

Secure peer-to-peer payments, fair royalty distribution and copyright security are some of the capabilities of BCT. The value that BCT derives within the media and entertainment industry is: automated entertainment licensing agreements and digital rights management; disintermediation of third-party involvement; peer-to-peer content distribution and payments, royalty optimization and new content-specific pricing models.

2.1.5.2 Gaming use cases

The use of BCT in online video gaming offers better control over virtual assets. Gamers can own virtual assets that can be used across different gaming platforms, unlike traditional video games, where players' virtual possessions (such as charter skins, equipment, etc.) are limited to one platform. Blockchain technology allows for the monetization of a game's virtual assets whereby players can sell these assets on one platform and purchase different assets on another gaming platform. These in-game virtual assets are referred to as non-fungible tokens (NFT) which can represent characters, memes, videos and any other digital assets. As a result, players can have more entertaining and flexible gaming experiences (CIOReview, 2019).

Additionally, blockchains can be used to create various incentive systems (such as Play-to-Earn) within the game, between players and game developers. Security measures are also enhanced using BCT by securing the ownership of virtual goods on gaming platforms and preventing any unauthorized transactions, hacking, and theft of virtual items (CIOReview, 2019). The peer-to-peer characteristics of BCT also provide multi-player online games with resilience and real-time cheat prevention (Kalra, et al., 2018).

Gala Games is one example of a blockchain-based Play-to-Earn gaming platform that rewards players' in-game accomplishments with virtual assets. These assets can be traded for cryptocurrencies that can then be used to buy other digital assets for different game titles within the platform (Kraken, 2020). Figure 21 illustrates the benefits of using BCT in the gaming industry.

Figure 21: Blockchain benefits transforming the gaming industry (Chirag, 2022b)

Significance of available information

The benefit of using BCT in the gaming industry is a "game changer", mainly because of BC's capability of securely storing digital assets that can be monetized and exchanged across platforms using cryptocurrencies. Similar BC-based gaming applications could be used by the mining industry to train personnel. Virtual reality and simulation training within the mining industry is already assisting personnel to develop work-related competencies. The application of BCT to gamify training modules with economic incentives could spur competitiveness in competency training programmes. Mine workers could be "paid-to-learn", improving the overall quality of employees and business operations.

2.2 Mining Industry Value Chain Process for Assessing BC Applicability and Potential Use Cases

In order to assess the applicability of blockchain technology in the mining industry, a high-level view is needed to better understand the mining industry processes so that potential areas can be identified where the technology's capabilities could add value. For this purpose, Table 11 was adapted from the Open Group's EM business process model which defines the standard business activities for organizations that operate in the exploration and mining sectors. Descriptions of both the enterprise processes and associated value chain processes are provided in order to map possible blockchain application areas in the industry.

Table 11: Exploration and mining business enterprise processes and value chain process descriptions (adapted from TheOpenGroup, 2013)

Enterprise processes	Description of Enterprise Process	No.	Value chain processes	Description of value chain processes	Value chain process output
Discover	The process by which an exploration target and/or a mineral resource is articulated and defined for acquisition purposes. The process includes: evaluation of grade and tonnes; pre-feasibility phase; examining the production options; and acquisition of the necessary rights. At a strategic level: the exploration strategy and associated activities to find new deposits. At a tactical level: focus on the evaluation of existing mineral deposits. At an operational level: day-to-day enhancement of the level of confidence in the geological model.	1	Prospect/Explore	Exploration aims to locate the presence of economic deposits and establish their nature, extent and grade. Exploration techniques include: geological surveys; geophysical prospecting (may be ground, aerial or both); soil and grab samples; geochemical; boreholes and trial pits; surface or underground headings, drifts or tunnels.	Geological and mineralogical data with spatial attributes.
		2	Assess Mineral Resource	This process focuses on considering the attributes of structure, density, grade; and tonnage.	A geological model used as a basis for mine planning.
		3	Examine Production Options	This process involves the production of a technical mine and beneficiation plan at an appropriate level of confidence. The process is focused on improving levels of confidence, moving from green fields, through brown fields, to an operational/mine site.	Technical mine plan (i.e. volume and product profiles over time).
		4	Develop Business Plan	This process is focused on the analysis (including options) and creation of the financial viability plan associated with the establishment of a particular site in order to be able to make a go/no-go decision.	Documented business case to enable decision-making. Green fields: bankable feasibility study (for investment-related decisions). Brown fields: internal project proposal (for capital cost-related decisions); operational/mine site. Production forecast and budget (for operational costs).
		5	Acquire	This process involves securing all the necessary rights applicable to a particular mine site, including: mineral rights; Environmental Impact Assessment (EIA); approved environmental plan surface rights; access rights; approved social and labour plan; water (riparian) rights.	Secured rights (mineral, surface, access & water), approved social and labour plan and Environmental Impact Assessment (EIA)
Establish	All the activities necessary to create a mining environment (the full infrastructure). At a strategic level: creating the mine; beneficiation plant; environment; supporting facilities & communities; plus financing. At a tactical level: ensuring mid-term	6	Initiate establishment	This process is focused on marshalling all necessary resources required to start the project.	Established project (approved project plan) and marshalled resources
		7	Engineering design	This process aims to produce the necessary alternative designs in order to be in a position to embark on design selection and construction on the site.	Final (approved) engineering design & final mining layout designs, including all mining technical inputs (e.g. ventilation and rock engineering)

Enterprise processes	Description of Enterprise Process	No.	Value chain processes	Description of value chain processes	Value chain process output
	continuity and viability of the mining operation. Typically funded by capital expenditure, e.g. sinking a new shaft, planning and building of extensions to an existing mine. At an operational level: creation of further access to the ore body with all the associated supporting engineering infrastructure. Funded by operational fund (OPEX).	8	Construct	This process develops all the facilities and infrastructure necessary to start the mining operation according to the engineered design.	Constructed facilities and infrastructure, operational mine site, operational beneficiation site
		9	Commission	This process involves ensuring operational readiness by piloting the operational environment, and the handing over of this environment to operations.	Accepted operational environment (mine) as per specification and signed acceptance certificate
Exploit	For a given mine type, rock type, and mining method, this process includes the breaking and removal of "rock". Rock is a generic term to describe all types of mineral resource host material. It also includes the transport of the broken rock and waste from the working place to the plant and/or stockpile.	10	Break rock	For a given mine type, rock type and mining type, this process includes having access to the ore body, mining the ore body, and extending any necessary infrastructure.	Broken rock as per approved plan (e.g. waste or graded ore)
		11	Remove rock	For a given mine type, rock type and mining type, this process includes classifying, moving (transporting) and stockpiling the broken material. Rock can be moved by various means, for example: hopper tramming; hoisting; conveyor belt; hauling and trucking (dump trucks); train/ship/barge; front-end loaders.	Transported rock (e.g. to beneficiation plant or waste dump), stockpiled ore
Beneficiate	This process focuses on the processing of ores for the purpose of: • Regulating the size of a desired product, removing unwanted constituents, and improving the quality, purity or assay grade of a desired product. • Concentration or other preparation	12	Handle material	This process involves the collection of all material required for processing and, if needed, includes the blending of material. It also involves getting the material ready for input to the plant and subsequent treatment. (Blending is about mixing materials from different sources which may have differing grades or compositions.)	Blended material (no reagents), classified material(s),readied for treatment

Enterprise processes	Description of Enterprise Process	No.	Value chain processes	Description of value chain processes	Value chain process output
	of ore for smelting by, e.g. drying, flotation, or magnetic separation and improvement of the grade of ores by milling, flotation, sintering, gravity concentration or other processes.	13	Treat material	This process focuses on liberating the mineral/metal from the ore (including crushing and/or grinding), concentration of the desired material (adding of reagents), separation and removal of waste, and recovery of the desired final material (drying, sizing, etc.). The process also includes all of the associated chemical and metallurgical processes, storage of waste, and discarding of tailings or waste product. Typical processes include: crushing, milling, floatation, magnetic separation, gravimetric separation, leaching, filtration, cementation, calcination, sizing, sorting	Concentrated material(s), classified material(s) (e.g. sized, graded), managed waste (e.g. solid, liquid, solution, suspension or gaseous)
		14	Refine material	The process(es) by which the material is treated further in order to separate the desired material(s) from its unwanted matrix (gangue) material and so generate a purified product. Typical processes include: electrowinning, solvent extraction, ion exchange, dissolution and selective precipitation, osmosis, leaching, gravimetric separation, magnetic separation, adsorption, calcination	Refined product(s), managed waste material(s) (e.g. solid, liquid, solution, suspension, or gaseous)
		15	Handle product	This process includes the classification, blending, packaging and storage of saleable materials, including by-products.	Saleable product(s)
Sell	This process focuses on dealing with customers in order to dispose of the product and attain revenue. It also includes product marketing.	16	Engage customer	This process focuses on the interaction with the customer, including the necessary information to identify and interact with the customer.	Customer relationships
		17	Handle order	This process focuses on obtaining the correct information regarding the specific products and the associated quality and quantities ordered so that the organization is in a position to fulfil the order and analyse trends regarding customer preferences.	Order fulfilment and customer preferences trends analysis.

Enterprise processes	Description of Enterprise Process	No.	Value chain processes	Description of value chain processes	Value chain process output
		18	Ship and distribute	This process executes the shipping and distribution of products ordered to the correct customers.	Product delivery.
		19	Process financial transaction	The financial transaction that occurred as a result of an order being fulfilled needs to be completed in order to recognize the revenue and/or follow up on the debt.	Settled financial transactions.
		20	Support product marketing	Product marketing requires information from customers and orders, as well as input of a strategic nature to ensure that the correct products are marketed to the correct customers in line with the organizational strategy.	Marketing plan
Rehabilitate	This process focuses on returning the mining site to a desired "improved" state concurrently with or after the primary mining and associated activities. Planning for rehabilitation is now a key deliverable of any exploration or mining plan and must generally be approved before any exploration or mining tasks can be undertaken.	21	Initiate rehabilitation	This process is focused on marshalling all necessary resources in order to follow through on previous rehabilitation commitments (e.g. EIA), as well as on decisions regarding the final state of the rehabilitated site.	Final rehabilitation proposal(s), marshalled resources, approvals, objectives, governance models and business case(s)
		22	Design rehabilitation	This process aims to produce the necessary alternative designs, approaches and methods in order to be in a position to embark on returning the site to the desired final state.	Final (approved) rehabilitation design, final site designs, including all sustainable environmental inputs (e.g. water management, vegetation, etc.)
		23	Execute rehabilitation	This process delivers the projects that are focused on returning the site to the desired state. It also includes the ongoing maintenance activities (as required/prescribed) required for minimizing site degradation and ensuring that the site is in an acceptable state (as defined) after the end of mine life.	Rehabilitated site

Significance of available information

Using the mining industry's different value chain process descriptions as well as the associated output, the applicability of BCT can be assessed to identify, if possible, what applications or opportunities exist. These opportunities can be identified from a technology push perspective, using the BC capabilities and industry-related benefits, encouraging further research and development within the mining industry.

2.2.1 Possible BCT Applications for Mining

Cosgrove (2019) believes that blockchain technology is extremely useful and relevant to the mining resource industry because of its ability to provide security, transparency and immutability of digital information in business transactions. He highlights the following six areas in mining where the industry could potentially benefit from BC applications (Cosgrove, 2019):

1. Engineering, construction, and hand-over (This process typically includes the transfer of documentation, equipment, personnel, and other assets from the construction team to the operations team) of the mine site.
2. Compliance and mining lease management
3. Supply chain
4. Mineral provenance
5. New approach to mining
6. Mining equipment original equipment manufacturers (OEM)

2.2.1.1 Engineering, construction, and hand over of the mine site

Engineering, Construction and Handover (ECH) operations involve a lot of project management techniques which generate enormous amounts of complex spatial and engineering data. The process of managing and maintaining the accuracy of this data is a costly affair. Additional costs could be incurred if this data is not accounted for correctly and in time, which can potentially delay business run-rates and an organization's strategic goal. The information traceability aspect of BC could ensure trust and work compliance during the complex process of managing regulations and standards (Cosgrove, 2019).

Significance of available information

This potential application of BCT could benefit the construction and commissioning value chain process within a mining organization. The use of smart contracts could also provide automated hand over processes when engineering projects are completed.

2.2.1.2 Compliance and mining lease management

Blockchain technology can be used to improve the mechanism of custody and control of digital documents (e.g. mining rights and titles) that receive approval from the required relevant entities (Cosgrove, 2019). In South Africa, mining companies, along with the Department of Mineral Resources and Energy (DMRE), need to manage approvals of documentation created in the exploration, resource/reserve estimations, mine design and planning processes. Cosgrove (2019) suggests that the application of BCT could improve the traceability of reserve estimation (for stock exchange reporting) and inventory (enterprise resource planning (ERP) management of resources and reserves).

Blockchains can be used to verify the process/audit of the actions and results utilized to calculate resources and reserves statements. Smart contracts can be set up to manage resource and reserve estimation results, which can be shared with stock exchanges for the release of resource/reserve estimates (Cosgrove, 2019).

Significance of available information

The benefits associated with using BCT for lease management could be realised in the discovery enterprise process. Mining companies need to acquire land and apply for prospecting and mining permits. Storing digital mining rights on a blockchain that is transparent to all relevant parties (mining company, DMRE, investors, etc.) will enable compliance with mining regulations. Mining regulation entities can easily assess whether a certain company has all the legal documentation required before mining activities commence. Once issued on a BC, mining permits cannot be tampered with and can be managed with smart contracts in accordance with regulatory requirements.

2.2.1.3 Supply chain applications

Blockchain technology can be used to assist with supply chain tracking. Materials and equipment used in the mining value chain can be tracked and traced on a BC. Additionally, the mining companies' production can also be tracked, from blocks in the ground to stockpiled material, to concentrate, to the final product (Cosgrove, 2019).

The application of BCT in supply chain tracking will also provide transparency for joint venture partners as most value chains are disorganized with transactions expanding across multiple parties (Cosgrove, 2019).

Significance of available information

BCT for improving supply chain transparency can be applied throughout the mining enterprise processes (from Discovery through to Rehabilitate). This application will however require a multi-disciplinary team of specialists that understand the inner workings of supply chain systems as well as BC developers. Supply chains have various parties involved that offer specific services, materials, parts, and equipment for mining operations. The approach to developing a BC-based supply chain for the mining industry should start within one value chain process, for example site establishment. A blockchain platform could connect all required resource vendors needed to supply materials to the mining sight. This will enable collaboration between the parties involved in the site establishment and the project plan can be approved once all marshalled resources have been verified.

2.2.1.4 Mineral provenance

The unethical sourcing of minerals is an issue for manufacturing enterprises. Businesses such as Apple have made the decision not to utilize minerals from mines operated in conflict zones, using child labour, with underpaid workers and with poor environmental standards (Cosgrove, 2019). Mineral provenance can be traced using BCT to ensure that the resources used in a business's manufacturing processes are sourced ethically. This will also foster investor trust when transparent sourcing of mineral resources is verified on a BC.

Significance of available information

Provenance has to do with tracking an item (matter – anything physical) through its value chain (how that item came to be) so that the item's origin can be verified. An example of this is the purchasing of a diamond ring. Customers might want to know where that diamond came from. By using BCT, that diamond can be traced back to where it was mined. Information pertaining to that diamond (geographical region, mining company, production batch data, cutting and polishing company, inspection and certification, manufacturer, reseller) could be recorded on a BC to prove its origin. This ties in with the tracking and tracing capability of BCT in supply chains. Mineral provenance will support product marketing value chain process.

2.2.1.5 New avenue for mining

The Chief Innovation Officer at Barrick Gold, Michelle Ash, presented a possible use case for BCT which she termed "Green Gold Vault." The green gold vault idea does not require mining or identifying value in the ground but, rather, investors buy digital tokens representing gold in the ground. This gold can be traded on an exchange using digital tokens and might never be mined. Michelle's team regards this BC use case as the "true" original green gold concept of monetizing wealth without even mining (Cosgrove, 2019).

Significance of available information

Creating digital tokens that represent physical assets such as potential gold in the ground that can be traded in new markets offers different avenues of wealth monetization. This BCT application could disrupt the junior mining sector which focuses on the prospect/explore value chain process. The geological and mineralogical data of a deposit can be tokenized with different levels of the confidence associated with it (measured by the amount of accurate and verifiable data). These tokens can then be sold and traded on a BCT platform, providing liquidity in the junior mining sector which will encourage more exploration projects and potential mining activities.

2.2.1.6 Mining equipment OEMs

Mining original equipment manufacturers (OEMs) collaborate in a high-performance environment, sourcing parts from different vendors. In a typical supply chain arrangement, the OEM is the only one that is aware of the various vendors that supply components for its mining machines or equipment. In the case where a mine experiences critical failure situations (e.g. part failure on mining production equipment), the mine will have to source the part from the OEM which sources the part from the relevant vendor (Cosgrove, 2019).

With BCT this process of identifying which parts are sourced for which vendor becomes easier. The mine's maintenance department could submit a request to the OEM to investigate the history of that specific part failure. The BC attached to the relevant part of the OEM contract could give the authorization to view the relevant data on the part. The OEM and vendor can then collaborate to address the failure issue (either by sourcing a different part or through quality improvement) and the mine can be assured of the quality of the parts and equipment used in their mining operations (Cosgrove, 2019).

Significance of available information

This is another BC supply chain use case where OEMs can track and trace where components are sourced from. By connecting mining companies, OEMs and their vendors on a BC platform, real-time information exchanges can be tracked and be visible to all parties. This application would assist in the exploiting enterprise process of the mining industry where equipment and machinery are used for production tasks.

2.3 Blockchain Application Frameworks

There are various BC applications that target specific use cases, while other applications are theoretical, simply highlighting the benefits associated with the technology. This section describes two blockchain frameworks that can be used by the mining industry on its journey to develop specific BCT applications.

2.3.1 Blockchain decision tree framework

In 2018 the World Economic Forum (WEF) published a practical framework for business leaders that can be used to assist executives in understanding whether blockchain is an appropriate and helpful tool for their business needs. The framework consists of a decision tree (Figure 22) that enables a swift initial analysis of whether BC is an appropriate tool that can be used to address a certain business problem. The decision tree consists of a series of questions that help determine whether BCT is the right approach for a particular issue (Mulligan, et al., 2018). These questions from the decision tree are listed and discussed as follows:

1. It is important to understand the business context for blockchain (BC) to be considered a potential solution. The question of whether the business issue requires the removal of middlemen must be considered. For instance, it must be determined if it would be cheaper to deal directly with a supplier or competitor rather than using a clearinghouse.
2. The successful application of blockchain technology (BCT) requires working with assets that are "digital native," meaning assets that can be well represented in digital form. If an asset has a physical representation that can change shape, it can be difficult to manage effectively on the blockchain. An example of this is food tracking and tracing on the blockchain. While tracking and tracing of individual items can be done, BCT has challenges when it comes to the change of shape of that individual item, such as wheat converted to flour and then baked to produce bread.
3. A crucial question to consider is whether a permanent record of the digital asset in question is desired. The blockchain must be the only source of trust in this case. If an object's state has multiple sources of trust, it is effectively not stored on the blockchain. If a permanent record can be created, all parties involved in the state of the digital asset must agree on how it will be handled and managed in new business processes before development occurs. If immutable records are unnecessary or unproductive for the specific application, then BCT may not be the right solution, as it is typical for cases where the ability to delete information from a ledger or database is necessary.
4. It is important to determine if the business application requires millisecond-level data transactional performance. If so, further research is required as there are BC developers working on creating faster applications. As of April 2018, DLT in various formats has a processing time of 2–10 minutes.
5. Storing non-transactional data on the blockchain is currently not recommended (2018). If this is required for the specific use case, using blockchain is not recommended. However, if the trust in question is related to transaction records and not to the underlying data itself, BCT may apply. In any case, no personal information or data that could conflict with local and global data protection regulations such as GDPR should be stored on the blockchain.

6. If the industry has specific requirements for using intermediaries or trusted partners, BC deployment can be complicated, even if other benefits of using the technology are obvious. For use cases where regulation plays a major role, it may be necessary to involve regulators in the project and provide the means to ensure compliance with laws such as antitrust and competition laws. This engagement becomes a key issue that many industry participants need to address. Examples include stringent requirements from multiple regulatory authorities, each requiring insight into different aspects of transactional data. It may be very difficult to provide blockchain for transmitting transaction data to a supervisory authority for legal or other reasons without regulatory involvement.
7. For blockchain to potentially reduce costs and deliver real business value, it is critical that the focus area deals with the management of transactions involving digital assets. If the business problem does not involve the management of contractional relationships or value exchange, other technologies could potentially solve the problem more effectively.
8. It is necessary to determine if the use case requires shared write access, and if some or multiple network participants need to write transactions to the blockchain. If participants do not need access, another technology may provide a better solution.
9. If network participants know and trust each other, the application of BCT might not be necessary. If they do not know or trust each other and/or have conflicting interests, they may have good reasons not to use BC.
10. If there is a need to change the functionality of the BC (e.g. node distribution, permissions, intrusion rules, consensus mechanisms, etc.) without extensive discussion on major open-source BC forums, a private permissioned BC should be chosen.
11. A private permissioned BC is a good choice if transactions need to be kept private. If not, a public permissionless BC can be used.

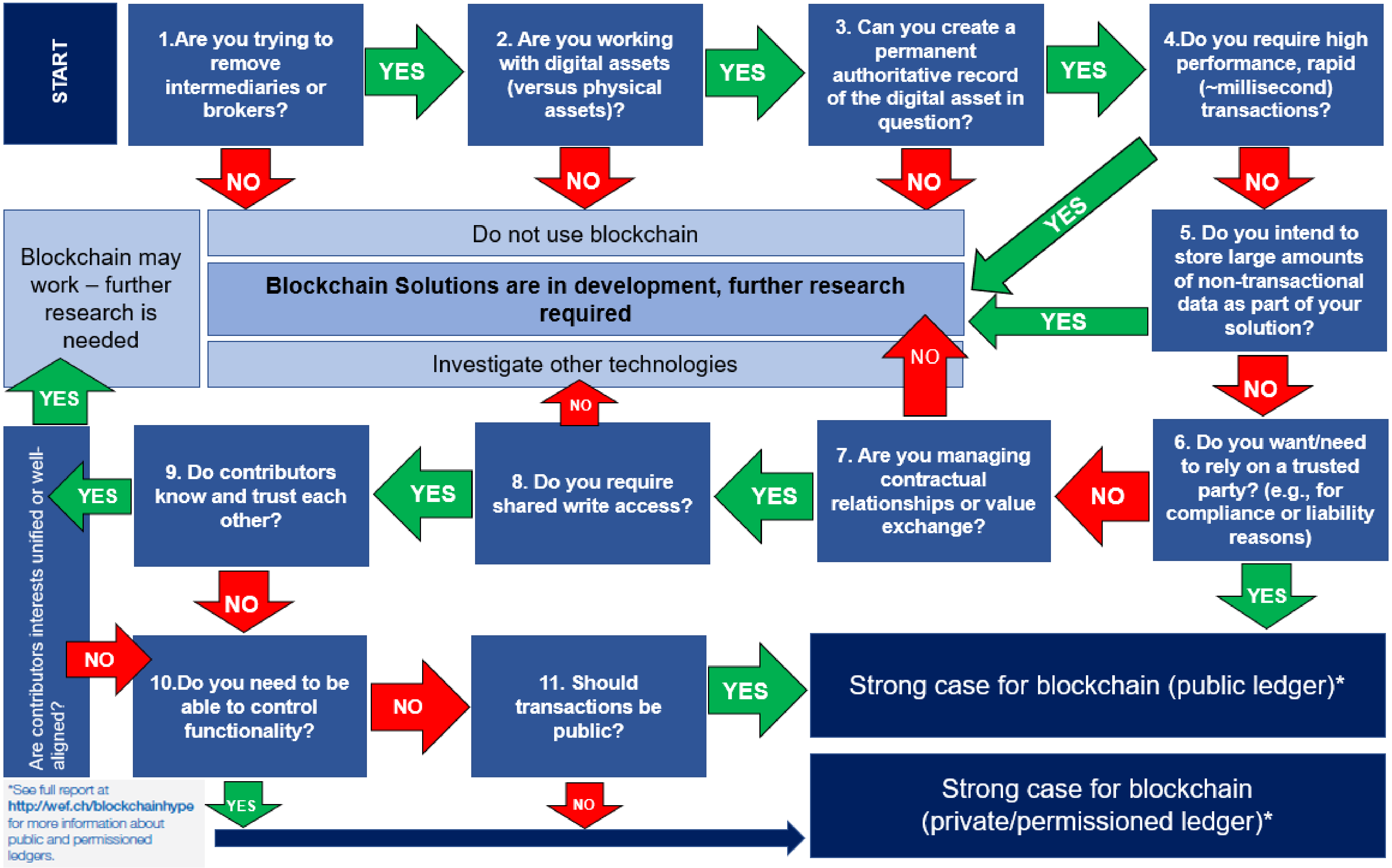


Figure 22: Blockchain application decision tree (adapted from Mulligan, et al., 2018)

Significance of available information

This decision tree starts with the premise that an organization would like to remove intermediaries. It should be noted that the use cases of BCT as previously discussed in Section 2.1 highlighted far more benefits that just removing middlemen. Therefore it is important to understand what the business is trying to achieve. Some businesses focus on reducing costs, while others focus on improving data traceability. The removal of intermediaries may result in reduced costs or more efficient business processes, but this should not be the sole focus for BC application. The framework discussed above assists mining organizations with determining whether BCT could be suitable/feasible for a particular business problem, but it does not articulate how the application could add value.

2.3.2 Blockchain value framework

Another framework was published in 2019 by the WEF intended to help organizations build up a business case for BC investment. The framework was based on a global survey of 550 individuals across 13 industries, dozens of interviews with public sector leaders and private sector chief executive officers, and an analysis of 79 blockchain projects. The survey identified the following advantages of using BCT in different industries (Warren, 2019):

- Full traceability of any information on the BC
- Ability to ensure data has not been tampered with
- Distributed nature of the technology
- Smart contracts and automation
- Increased speed and efficiency
- Increased security
- A holistic view, with transparency for all appropriate parties
- New business products or services

The value driver framework consists of a four-step process that enables anorganization to assess what value a particular BC use case could add to their business. These steps are as follows(Warren, 2019):

1. **Understanding the impact of the idea in relation to the business:** The first question to ask is “What are the pain points and areas of opportunity? The specific use case should be assessed in order to identify the pain points/challenges it addresses and/or the possible opportunities that exist. These challenges and opportunities should then be prioritized in accordance to the organization’s interests. This process should ideally be supported by an organization “profit and loss group” to ensure that an honest picture of the organization’s present state is captured when assessing BC applications.

2. **Assess the role of BC in the use case:** Group the use case challenges and opportunities into the following three dimensions: (1) improving productivity and quality; (2) increasing transparency among parties; and (3) reinventing products and processes by assessing BC characteristics. Consider cost, risk and speed of implementation.

3. **Assess how BC characteristics map to enabling capabilities by using the BC value framework cheat sheet (Figure 23):** This assessment will assist in moving from current-state assessment to future-state BC opportunity for further development. The dimensions include the enabling capabilities of BC that could provide a solution to the identified challenges or present areas of opportunities.

4. **Identify where the value will be created:** This is done by assessing what value drivers map to a particular challenge or opportunity. The cheat sheet highlights the value drivers where businesses will receive applicational bennifits. These value drivers can become the basis or a business case for further development.

<table>
<tr><th>KEY DIMENSIONS</th><th colspan="4">Improving profitability and quality</th><th colspan="2">Increasing transparency among parties</th><th colspan="2">Reinventing products and processes</th></tr>
<tr><td rowspan="3">CAPABILITIES</td><td colspan="2">Automation
Self-validating network + smart contracts enable auto execution of business rules.</td><td colspan="2">Control
Control at the individual data element level, maximum flexibility over what data is shared and how.</td><td colspan="2">Distributed
No single-entity data ownership, consensus applied to transactions and shared access with no central point of failure.</td><td colspan="2">DAx (Decentralized Autonomous x)
Transparent, predefined rules mean new ventures may be created, providing autonomous products/services through decentralized model.</td></tr>
<tr><td colspan="2">Full traceability
Provenance and complete history of all new data added is known.</td><td colspan="2">Security
Data can be encrypted and segregated at the data element level, while also enhancing overall data security.</td><td colspan="2">Holistic view
Single source of truth - all stakeholders see the same information to which they have access.</td><td colspan="2">Enhanced identity
A combination of capabilities with advancements in digital identity (e.g. biometrics) increase confidence in, and improvement of, security and management of customer and personal identity data.</td></tr>
<tr><td colspan="2">Speed | efficiency
Can enable faster data transfer, streamline tasks to optimize process efficiency, particularly where intermediaries have been removed.</td><td colspan="2">Evidence tampering
Underlying mathematics and cryptography allow users with appropriate access to verify data has not been altered.</td><td colspan="2"></td><td colspan="2">Tokenization and digital assets
Physical objects with verified unique digital representation enable digital ownership, management and transfer.</td></tr>
<tr><td rowspan="3">VALUE DRIVERS</td><td>Auditability</td><td>Compliance</td><td>Data management</td><td>Data security</td><td>Data sharing</td><td>Resiliency</td><td>Authentication</td><td>Identity management</td></tr>
<tr><td>Ownership</td><td>Payments</td><td>Process automation</td><td>Reconciliation</td><td>Transparency</td><td>Trust</td><td>Marketplace creation</td><td>New | enhanced products and services</td></tr>
<tr><td></td><td>Standardization</td><td>Track and trace</td><td></td><td></td><td></td><td colspan="2">New | expanded partnerships</td></tr>
</table>

Figure 23: Blockchain value framework cheat sheet (Warren, 2019)

Significance of available information

This value framework can help illustrate how BC capabilities can map to the different mining industry value chain processes use cases. The framework also highlights the benefits of applying BCT in any industry sector in relation to the technology's capabilities. This framework is intended to articulate the value that BCT can deliver for a specific use case. The mining industry can use this framework for further research into developing mining-specific BCT applications (engineering handover, compliance/lease management, supply chain applications, etc.).

2.4 Significance of Chapter 2 in the Context Applications in the Mining Industry

The results from Chapter 2 indicated the various opportunities for applying BCT in the mining industry. These opportunities are:

- Engineering construction and project handovers
- Compliance and lease management
- Supply chain applications
- Tracking and tracing of important data
- Data sharing of OEMs
- New business models.

These potential use cases were then analysed to see where the applications could fit into the mining industry's enterprise processes and what value they could add.

Additionally, the other industry BCT applications (Banking and Finance, Government, Insurance, Healthcare, Media, Entertainment and Gaming) provide insight on how and where the technology could potentially be applied in the mining industry.

CHAPTER 3

RESULTS AND EVALUATION OF RESULTS

This chapter condenses the different industry use cases of BCT and the associated applicational benefits. The benefits are grouped into value drivers which were derived from the applicational capabilities associated with BCT, as well as from the BC value framework. The use cases identified from the literature, along with the capabilities and value drivers, are then mapped to the mining industry's enterprise processes from a technology push perspective in order to highlight potential focus areas for developing mining industry-specific BC applications.

3 RESULTS AND EVALUATION OF RESULTS

This chapter presents the research findings as follows. Firstly, the use cases were analyzed to summarize the technology's capabilities. These capabilities highlight the different functions that BCT could fulfil within the mining industry. Secondly, the different industry applicational areas and associated benefits are summarized. The value drivers deduced from these different applications can be used to justify the opportunities for BCT for potential business use in the mining industry. Lastly, the BCT use cases, capabilities and value drivers are used to highlight potential focus areas within the mining industry's enterprise processes for further research and development.

3.1 Identified Blockchain capabilities

Based on the use cases identified in the literature review, Table 12 summarizes the deduced BC applicational capabilities. Before a technology is used, it is important to understand what the technology can do. The mining industry can assess these highlighted capabilities of BCT in order to better understand what the technology can do when applied in mining.

Table 12: Blockchain technology capabilities

Blockchain technology capabilities	Description
Automation	Blockchains' self-validating network and the use of smart contracts enables the automatic application of business logic and processes.
Disintermediation	Blockchain technology can provide disintermediation of third parties. Because BCT uses cryptography and different consensus mechanisms to ensure that data is trustworthy, third-party data validators are no longer required.
Improving security measures	Data can be encrypted and shared between multiple nodes, improving overall data security.
Data traceability (track and trace)	All new data added to a BC ledger can be known to anyone or only to authorised parties. The provenance and complete history of all data communication/exchange/movement/changes is recorded.
Data processing speed and efficiency	BCT can enable faster data transfers and can streamline tasks to increase process effectiveness. This capability also relates to disintermediation.
Distributed data storage	Data ownership by a single entity can be reduced, and open access to data without a single point of failure is provided by BCT.
Tokenization	Physical objects can be owned, managed and transferred digitally if they have a validated unique digital representation (token).
Enhanced identity management	The combination of BCT capabilities integrates different data to verify and manage customer and personal identity data.
Data permanence	Data records on a BC can be stored permanently using the cryptography and consensus mechanisms.
Tamper evident	Users with the proper access can confirm that data has not been altered thanks to the underlying mathematics and cryptography of BCT.
Data control	Permissions can be programmed on BC, enabling a wider range of data control.

Blockchain technology capabilities	Description
Smart contract	Smart contracts on a BC enable new product/services and partnerships.
Holistic view	All authorised parties have access to a single source of truth (same data).

3.2 Identified industry use cases and associated benefits

The BC applications in the different industries and the associated applicational benefits are summarized in Table 13. These benefits were analyzed and grouped into value drivers (Table 14). This process condenses the various applicational benefits into simplified value drivers that can then be linked to the technology's capabilities. This was done to clarify what benefits (value drivers) could be derived from each capability for mapping purposes in the different mining enterprise processes.

Table 13: Blockchain applications by industry and associated benefits

Industry	Use cases / areas	Benefits
Banking and Finance	Payment systems (local and international)	• Speed and efficiency improvements in transaction processing • Reduced intermediaries • Reduced financial activity costs
	Securities	• Reduced settlement latency • Reduced operational and custody risk • Increased transparency to issuers, end investors and regulators • Reduced financial processing costs • Automated financial services through smart contracts
	Fundraising	• Alternative fundraising mechanism – (ICO -Initial Coin Offering) • Reduced time to gain access to capital • Liquidity • No capital sourcing restrictions (access to global communities) • Ownership. • Peer-to-peer (P2P) or Business-to-Business(B2B) loans
	Customer KYC and fraud prevention	• Reduced human labour and expenses (compliance) • Enhanced Identity management • Security improvements • Compliance improvements (increased data confidence) • Reduced onboarding time (financial institutions) • Speed and efficiency improvements in data processes
Government and Public Goods	Public procurement process	• Procedural transparency • Full traceability of permanent records • Improved trust (honest disclosure
	Voting	• Full traceability of permanent records • Identity verification
	Central Bank Digital Currencies (CBDC)	• Transparency and traceability of financial transactions • Supervision • Control
	Education	• Ownership of digital certificates (NSC) • Automated verification process of certificates
	ID management	• Tokenised identities

Industry	Use cases / areas	Benefits
		• Improved data management • Authentication
	Payment and taxation	• Full traceability of payments and tax records • Speed and efficiency improvements in tax process
	Storing records	• Evidence of tampering provided • Facilitates mandatory regulatory reporting
	Electronic voting systems	• Transparency of voting process • Enhanced ID management • Security improvements
	Public healthcare	• Preservation of historical health data • Track and trace improvements • Improved data management and security
	Asset management (Land registry and transactions)	• Decentralised registry • Process automation
Insurances	Property and casualty insurance underwriting	• Efficient exchange of information • Improved risk profiling • Automation through smart policy • Enhance client onboarding
	Property and causality insurance claims processing	• Simplified/automated claim submission • Reduced fraud loss • Enhanced customer experience and no manual inspection • Automated compliance
Healthcare	Supply chain	• Transparency improvements – provenance track and trace of medical goods • Enhanced patient safety compliance (reporting process for manufacturers and pharmaceutical companies) • Supply chain optimization (AI tools for accessing BC data stored from device manufacturers, pharmaceutical companies, medical institutions)
	Patient centric electronic health records	• Improved patient and healthcare provider experience • Improved patient data transparency and control • Process efficiency improvements and reduced costs
	Medical staff credential verification	• Efficient and faster verification process • Data monetization of staff competencies • Transparency and reassurance on staffing capabilities
	IoT security for remote monitoring	• Improved IoT security through decentralized device communication
Media, Entertainment and Gaming	P2P sales and content distribution	• Smart contract automation of content licensing and payments • Disintermediation of third-party involvement • Improved security of content distribution • Data monetization of staff competencies • Transparency and reassurance on staffing capabilities
	Streamline royalty payments	• Enhanced data management (content creator) • Automated royalty payments for content use • Improved security of content distribution
	New pricing options for paid content	• Pay-per-use consumption-based model enabling micropayments with cryptocurrencies
	Monetization of in-game assets	• Ownership of virtual assets • Buy, sell and exchange NFT's for cryptocurrencies
	Blockchain-based gaming platforms	• Play-to-Earn incentive system • Enhanced security for online games • Improved gaming user experience

Table 14 summarizes the condensed applicational benefit of BCT into value drivers for the purpose of linking the technology's capabilities with expected benefits.

Table 14: Value drivers of blockchain technologies

Applicational value drivers	Description
Data sharing	Parties can share real-time data, data history as well as modifications, enabling collaboration and other value drivers such as track and trace.
Data security	Data can be encrypted and stored on multiple nodes with no single point of failure/attack. BC offers various levels of data encryption, reducing the risk of data breaches.
Data management	Blockchain technology enables the unified sharing of real-time data from a single data source, providing data provenance, data authorization and data sharing capabilities that all add to better/improved data management.
Process automation	There is automatic process execution through smart contracts which may result in efficiency improvements, cost reductions, manual labour reduction and less admin.
Transparency	Full transparency of data by authorized parties could lead to additional opportunities such as track and trace, compliance and cooperation.
Authentication	The use of public and private key cryptography serves as a basis for authenticating users across multiple networks. This translates into trust in the network, data sharing and identity management.
Identity management	Blockchain technology enables a process of recording digital identities and the management thereof. There is no longer a need for paper-based systems and manual verification/authentication processes.
Ownership	True and verifiable digital ownership of physical and digital assets is provided.
New business processes and marketplace establishment	With the increase trust in digital information and the use of smart contracts, new business processes and marketplaces could emerge, such as Play-to-Earn and digital rights management.
New products/services	Blockchain technology increases consumer trust in digital goods and services, while also enabling peer-to-peer transactions of digital assets in real time via a shared ledger, the use of smart contracts and tokenization..
Trust	Blockchain can facilitate and even automate the creation of trust in the digital dominion by cryptographically protecting data, revealing the status and history of data, and providing transparency.
Track and trace	Blockchain technology enables the tracking and tracing of data/products within a supply chain because of the its ability with providing a holistic view within a BC network of trading organizations.
Compliance	Blockchain technology increases the level of data confidence because it is tamper-evident/tamper-proof. This enables a more efficient compliance management process as less administration is required to verify information.
Reconciliation	Blockchain technology can improve data reconciliation processes because of improved data traceability, management and transparency.
Auditability	Blockchain technology can provide transparency with regard to permanent, tamper-proof records of transactional data, shared amongst relevant parties. This improves the level of data accountability and auditability. The use of smart contracts can enable automatic auditing on ledgers to assist with compliance management.

3.3 Identified potential mining industry applicational areas and value drivers

Table 15 was created by matching the different value drivers from Table 14 to the associated technological capabilities of BCT, identified in Table 12. This was done using the following reasoning as explained using the first capability (Automation) as an example.

Automation: Blockchain technology is a self-validating network that is able to automate business applications and logic through the use of smart contracts. Process automation can lead to better data management resulting in improved data auditability and compliance. All of this may result in efficiency improvements, cost reductions, manual labour reduction and less admin.

The above example highlights that the value drivers associated with the different capabilities are stackable: one capability could enable the realization of multiple value drivers which may form the premise for a particular business case.

Table 15: Blockchain technology capabilities and expected value drivers.

Blockchain technology capabilities	Expected applicational value driver
Automation	Process automation; Data management; Auditability; Compliance
Disintermediation	Trust; Process Automation; New products/services
Improving security measures	Authentication; Data security; Ownership
Data traceability (track and trace)	Reconciliation; Compliance; Track and trace; Transparency
Data processing speed and efficiency	Process automation; Data sharing
Distributed data storage	Transparency; Data security; Data sharing
Tokenization	Ownership; New products/services
Enhanced identity management	Authentication; Ownership
Data permanence	Compliance; Track and trace
Tamper evident	Auditability; Track and trace
Data control	Data management
Smart contract	New business processes and marketplace establishment
Holistic view	Transparency; Trust; Data sharing

The capabilities and value drivers (Table 15) along with the mining industry value chain definitions and outputs (Table 11) were used to suggest potential applications of BCT. These applications are shown as focus areas in Table 16, highlighting the suggested applicational capabilities and expected value drivers.

Table 16: Potential focus areas for BCT application in the mining industry

Business enterprise processes	No	Mining value chain processes	Potential for blockchain applications			
			Yes	No	Capabilities	Value drivers
Discover	1	Prospect/Explore	✓		Tokenization	New business processes and marketplace establishment; New products/services
	2	Assess Mineral Resource	✓		Holistic view; Tokenization	Transparency; Data sharing; Trust; New products/services
	3	Examine Production Options	✓		Distributed data storage	Transparency; Data sharing; Data security
	4	Develop Business Plan	✓		Enhanced identity	Authentication; Data management
	5	Acquire	✓		Smart contracts; Tamper evident; Holistic view	Transparency; Compliance; New business processes
Establish	6	Initiate Establishment	✓		Data traceability; Automation	Compliance; Transparency
	7	Engineering Design	✓		Data storage; Data traceability	Transparency; Data sharing; Track and trace
	8	Construct	✓		Data traceability; Automation; Holistic view; Improved security	Compliance; Transparency; Data sharing; Track and trace
	9	Commission	✓		Data traceability; Automation	Compliance; Transparency
Exploit	10	Break Rock	✓		Data traceability; Automation	Track and trace; Transparency
	11	Remove Rock	✓		Holistic view; Data traceability	Track and trace; Transparency
Beneficiate	12	Handle Material	✓		Data traceability	Track and trace; Transparency
	13	Treat Material	✓		Smart contract; Automation	Process automation, Data management; New business process
	14	Refine Material	✓		Data permanence	Track and trace
	15	Handle Product	✓		Data permanence	Track and trace
Sell	16	Engage Customer	✓		Identity Management; Track and trace; Transparency; Reconciliation; Improving security measures	Speed and efficiency; Data traceability; Enhanced identity; Authentication
	17	Handle Order	✓		Data traceability	Track and trace; Transparency
	18	Ship and Distribute	✓		Automation; Data traceability	Process automation; Track and trace; Transparency
	19	Process Financial Transaction	✓		Speed and efficiency; Disintermediation	Track and trace; Transparency; Process automation
	20	Support Product Marketing	✓		Track and trace; Transparency	Full traceability; Authentication
Rehabilitate	21	Initiate Rehabilitation	✓		Data traceability; Automation	Compliance; Transparency
	22	Design Rehabilitation	✓		Data storage; Data traceability	Transparency; Data sharing; Track and trace
	23	Execute Rehabilitation	✓		Full traceability; Automation	Compliance; Transparency

3.4 Evaluation of results

This section discusses the reasoning behind the results obtained in Table 16. The applicational opportunities for BC in each of the value chain processes within the mining industry are discussed. The justification for applying BCT within each value chain process is subjective and open to interpretation. However, by mapping the capabilities and value drivers associated with the opportunities for application, focus areas for further research and development can be suggested/highlighted.

3.4.1 Prospect/Explore

Explore aims to locate the presence of economic deposits and establish their nature, extent and grade in order to produce geological and mineralogical data with spatial attributes. Blockchain technology can be used for creating digital tokens that represent physical assets such as ore deposits in the ground. These tokens offer a different model of wealth monetization as mining companies (e.g. junior miners) that focus on the Discover enterprise process could profit from these tokens without even having to mine. The geological and mineralogical data of a deposit can be tokenized with different levels of confidence associated (measured by the amount of accurate and verifiable data gathered during prospecting). These tokens can then be sold and traded on a BCT platform, providing liquidity in the junior mining sector which will encourage more exploration projects and potential mining activities in the future.

A resource database can then be created using BCT to track the tokens and what type of ore deposits they represent. As the database grows and global demand for new resources change, mining companies can position themselves accordingly. For example, consider the following scenario: Global cobalt demand increases steadily each year while supply reduces. A mining company can purchase a token linked to a cobalt deposit that has already been discovered but not assessed to the level of certainty required for economic extraction. This miner can then further develop the resource using the geological and mineralogical data that was already collected.

- Blockchain capability: Tokenization
- Value drivers: New business processes and marketplace establishment; New products/services

3.4.2 Assess Mineral Resource

The value chain process of assessing the mineral resource focuses on assessing the attributes of structure, density, grade and tonnage of an ore deposit to produce a geological model used as a basis for mine planning.

This information can be stored on a BC and shared with all relevant stakeholders. All relevant parties can collaborate on the BC to develop the assessment of an ore deposit. The drill rig data can be logged onto a BC, along with the assaying information and laboratory test results. This information can then be used along with other technologies such as AI to evaluate the mineral resource.

Assessing the mineral resource can also be a costly affair, especially if the resource is in a remote place with no access to infrastructure such as roads, water or electricity. This often requires a large amount of start-up capital. Using BCT, mining organizations can create an Initial Coin Offering (ICO) that represents a stake in the exploration project. Capital can be sourced from anyone around the world with access to the internet and a crypto wallet.

- Blockchain capability: Holistic view; Tokenization
- Value drivers: Transparency; Data sharing; Trust

3.4.3 Examine Production Options

This value chain process involves the production of a mine and beneficiation plan at an appropriate level of confidence. It requires the collaboration of a multi-disciplinary team to predict volume and production profiles over time. Blockchain technology can be used to store technically related information regarding mining, economic, metallurgical, environmental, legal and marketing modifying factors. All stakeholders responsible for providing data related to these modifying factors could be connected on a BC-based platform to share relevant and accurate information. All of this information could be used along with AI tools to examine production options. By having a distributed BC ledger that permanently stores all historical and modifying factor-related data, future production studies will be easier and more accurate.

- Blockchain capability: Distributed data sharing; Data permanence
- Value drivers: Transparency; Data sharing; Data security

3.4.4 Develop Business Plan

This process focuses on producing a documented business case which includes different financially viable options associated with the establishment of a mining site. This document will guide the decision-making process on whether either to go ahead with the project or not. The output of this value chain process depends on the type of study (green fields, brown fields, or operational mine site) but is focused primarily on the financial aspects of the project. No matter what type of study a mining company focuses on, these projects need to be approved by the relevant stakeholder. Blockchain technology offers enhanced identity management, which is a combination of BCT capabilities integrating different data to verify and manage the identity of all relevant project stakeholders. These parties will have private cryptographic keys that can be used to authorize or approve project components.

- Blockchain capability: Enhanced identity management
- Value drivers: Authentication; Data management

3.4.5 Acquire (Acquisition of rights)

This process involves securing all the necessary rights applicable to a mine at a particular site, including: mineral rights; Environmental Impact Assessment (EIA); approved environmental plan surface rights; access rights; approved social and labour plan; and water rights.

The benefits associated with using BCT for lease management could be applied in this instance for obtaining all the necessary rights. Storing digital mining rights on a BC that is transparent to all relevant parries (mining company, DMRE, investors, etc.) will enable compliance with mining regulations, and also provide a holistic view of current mining applications. Mining regulation entities can easily assess whether a certain company has all the legal documentation required before mining activities ensue., Once issued on a BC, mining permits cannot be tampered with and can be managed with smart contracts in accordance with regulatory requirements.

- Blockchain capability: Smart contracts; Tamper-evident; Holistic view
- Value drivers: Transparency; Compliance; New business processes

3.4.6 Initiate Establishment

BCT for improving supply chain transparency can be applied throughout the mining enterprise processes (from discovery through to rehabilitation). A blockchain platform could connect all the resource vendors needed to supply materials to the mining site. This will enable collaboration between the parties involved during site establishment, and the project plan can be approved once all marshalled resources have been verified.

- Blockchain capability: Data traceability; Automation
- Value drivers: Compliance; Transparency

3.4.7 Engineering Design

This process produces the final (approved) engineering design and mining layout plan. These plans need to include all technical inputs for the different mining departments (ventilation, rock engineering, production equipment, health, and safety, etc.). This plan can be shared and developed on a BC network internally with all the associated departments. Instead of working in silos, this information can be distributed to all relevant parties and they can collaborate on providing the technical specifications needed for the engineering design plan. Any changes made to the design plan can be tracked and traced to the various departments. All parties will be aware of the changes and can make design adjustments accordingly.

- Blockchain capability: Distributed data storage; Data traceability
- Value drivers: Transparency; Data sharing; Track and trace

3.4.8 Construct (Construction of Facilities and Infrastructure)

This process develops the facilities and infrastructure required for an operational mine site and beneficiation site. Blockchain capabilities can be exploited from a project management perspective. BCT can be used to provide transparency in stakeholder communications, managing data security, guaranteeing corporate compliance, offering real-time reporting, and the opportunity for automation of project management operations.

- Blockchain capability: Data traceability; Automation; Holistic view; Improved security measures
- Value drivers: Compliance; Transparency; Data sharing; Track and trace

3.4.9 Commission

This process involves ensuring operational readiness by piloting the operational environment and the handing over of this environment to operations. The information traceability aspect of BC could ensure trust and work compliance during the complex process of managing the regulations and standards associated with the construction and commissioning value chain processes within a mining organization. The use of smart contracts could also provide automated hand-over when engineering projects are completed.

- Blockchain capability: Data traceability; Automation
- Value drivers: Compliance; Transparency

3.4.10 Break Rock

This is another BC supply chain use case where OEMs can track and trace where components are sourced from. By connecting mining companies, OEMs and their vendors on a BC platform, real-time information exchanges can be tracked and be visible to all parties. This application would assist in the exploit enterprise process of the mining industry where equipment and machinery are used for production tasks.

- Blockchain capability: Data traceability; Automation
- Value drivers: Track and trace; Transparency

3.4.11 Remove Rock

The removal of rock includes the classifying, moving and stockpiling of the ore. A real-time BC stockpile ledger could be beneficial to the mining industry. By keeping track of stockpiles on such a ledger, mining organizations can improve inventory management by assessing the stockpile levels at various mining locations within their business. This could help managers identify supply chain issues associated with the organization’s product before they materialize.

- Blockchain capability: Holistic view; Data traceability
- Value drivers: Track and trace; Transparency

3.4.12 Handle Material

This process involves the blending and classification of material ready for treatment. Storing the different blends of materials on a BC ledger will assist with tracking and tracing what stockpiles were used to blend what grade or quality of material. Some mines might blend aggregate and sell this as a final product, whereas other mines require a certain quality of material for beneficiation purposes. The technology’s capabilities in terms of data traceability will enable better management of material blending.

- Blockchain capability: Data traceability
- Value drivers: Track and trace; Transparency

3.4.13 Treat Material

This process focuses on the liberation of the valuable material from the ore which includes crushing, grinding and different metallurgical processes (magnetic separation, flotation, etc.). Blockchain can be used for supply chain tracking of resources used to Treat the material. The beneficiation plant and associated OEM suppliers can be connected on a BC network. Crushing and grinding machines break down the ore into smaller pieces for further beneficiation processes. These machines have parts that wear out and need to be replaced. By connecting the beneficiation plant's managing team and the associated OEM vendors on a BC platform, real-time information exchanges can be tracked and be visible to all parties. Parts can be quickly sourced and replaced before breakdowns occur. Smart contracts could be created to order parts from the OEM automatically after a certain number of operating hours, cycle times or any specific measure used to assess a part's durability or operating life. These contracts might need to be authorized by the relevant person.

- Blockchain capability: Smart contract; Automation
- Value drivers: Process automation, Data management; New business process

3.4.14 Refine Material

This process involves further treatment of the material into a refined product. Typical processes include electrowinning, solvent extraction, leaching, etc. Blockchain technology can be used to record all material-refining data (process temperature, chemical agents used, energy consumed, etc.) used to produce a final refined product. This information can be used to better understand and improve the refining process.

- Blockchain capability: Data permanence
- Value drivers: Track and trace

3.4.15 Handle Product

This process involves the classification, blending, packaging and storage of saleable materials. Blockchain technology can be used to store the product codes for record-keeping purposes.

- Blockchains' capability: Data permanence
- Value drivers: Track and trace

3.4.16 Engage Customer

This process focuses on the interaction with the customer, including the necessary information to identify and interact with the customer. The application of BCT in the know your customer (KYC) process can lower the turnaround/onboarding time of clients with financial institutions as KYC information can be stored on a decentralized database, saving data gathering and processing time. Data quality is also improved as alterations are tracked and monitored in real time via the BC network. Manual labour is reduced using BCT as the process can be automated using smart contracts, eliminating the need for paperwork. Mining organizations have to deal with financial institutions, so using BC-based KYC processes will enable these benefits within the organization, allowing mining companies to focus on their core business objectives.

- Blockchain capability: Speed and efficiency; Data traceability; Enhanced identity; Improving security measures

- Value drivers: Identity management; Track and trace; Transparency; Reconciliation; Authentication

3.4.17 Handle Order

This process focuses on obtaining the correct information regarding the specific products and the associated quality and quantities ordered so that the organization is in a position to fulfil the order and analyze trends regarding customer preferences. Blockchain capabilities enable data sharing across a network of buyers and sellers. The technology provides full traceability of digital information that is regarded as a verifiable source of truth.

- Blockchain capability: Data traceability
- Value drivers: Track and trace; Transparency

3.4.18 Ship and Distribute

This process involves the shipping and distribution of products ordered to the correct customers. Blockchain technology can be used here for supply chain applications. The shipping and distribution process often involves matching invoices against the services rendered prior to payment remittance along the supply chain. BCT can be used to assist with automating such processes and tracking if products are delivered.

- Blockchain capability: Automation; Data traceability
- Value drivers: Process automation; Track and trace; Transparency

3.4.19 Process Financial Transaction

The application of BCT enables significant time reduction in settling payments and improves time efficiency. All completed and pending transactions can be viewed simultaneously by multiple or specific entities (depending on open or private BC applications). This may increase the velocity of money, potentially enabling faster service/resource delivery. This may increase the velocity of money, potentially enabling faster service/resource delivery. For example, if an underground mine's production is put on hold due to a lack of support units (no stock/oversight), then by using a blockchain payment network, support units can be ordered and payment settled within 10 minutes to one hour. The supplier could then immediately initiate the delivery process, no purchase order or excessive paper work is needed, reducing the mine's downtime.

The adoption of blockchain technology by mining organizations could potentially reduce the number of intermediaries and improve time efficiencies within the payment structure of their business operations. Cost reduction in terms of payment processing, settlement and reconciliation costs could improve the company's bottom line.

- Blockchain capability: Speed and efficiency; Disintermediation
- Value drivers: Track and trace; Transparency; Process automation

3.4.20 Support Product Marketing

Product marketing requires information from customers and orders as well as input of a strategic nature to ensure that the correct products are marketed to the correct customers in line with the organizational strategy. By verifying product provenance, the application of BCT can support product marketing. Provenance has to do with tracking an item (matter – anything physical) through its value chain (how that item came to be) so that the item's origin can be verified. An example of this is the purchasing of a diamond ring. Customers might want to know where that diamond came from. By using BCT, that diamond can be traced back to where it was mined. Information pertaining to that diamond (geographical region, mining company, production batch data, cutting and polishing company, inspection and certification, manufacturer, reseller) could be recorded on a BC to prove its origin.

- Blockchain capability: Full traceability; Authentication
- Value drivers: Track and trace; Transparency

3.4.21 Initiate Rehabilitation

This process focuses on marshalling the resources needed to start the rehabilitation process. As with the initiate establishment value chain process, BCT can be applied for improving supply chain transparency. A blockchain platform could connect all required resources and vendors needed to supply materials for the rehabilitation of the mining site. This will enable collaboration between the parties involved during rehabilitation and the project plan can be approved once all marshalled resources have been verified.

- Blockchain capability: Data traceability; Automation
- Value drivers: Compliance; Transparency

3.4.22 Design Rehabilitation

This process focuses on the designs, approaches and methods for returning the mining site to the desired final state. These plans need to include all the technical inputs from rehabilitation specialists. The plans can be shared and developed on a BC network internally in cooperation with all the associated parties. Instead of working in silos, this information can be distributed to all relevant parties and they can collaborate on providing the technical specifications needed for the rehabilitation. Any changes made to the design plan can be tracked and traced to the various departments. All parties will be aware of the changes and can make design adjustments accordingly.

- Blockchain capability: Distributed data storage; Data traceability
- Value drivers: Transparency; Data sharing; Track and trace

3.4.23 Execute Rehabilitation

This process delivers the projects that are focused on ensuring that the site is in an acceptable state after the end of mine life. The information traceability aspect of BC could ensure trust and work compliance during the complex process of managing the regulations and standards associated with the rehabilitation process. The use of smart contracts could also provide automated hand-over processes when the projects are completed.

- Blockchain capability: Full traceability; Automation
- Value drivers: Compliance; Transparency

3.5 Summarized findings

The results of the study highlighted the different capabilities and value drivers associated with BCT. These capabilities were mapped to the 23 different mining value chain processes by suggesting potential opportunities for BC applications. The value drivers were also highlighted in the different focus areas. The results show that there are opportunities in all 23 focus areas for the application of BCT. Industry leaders can use these capabilities and value drivers to assess whether potential opportunities exist within their own specific operations.

Figure 24 summarizes the number of times each *capability* was identified within the mining industry's enterprise processes. The top three capabilities are: Data traceability, Automation and Holistic view.

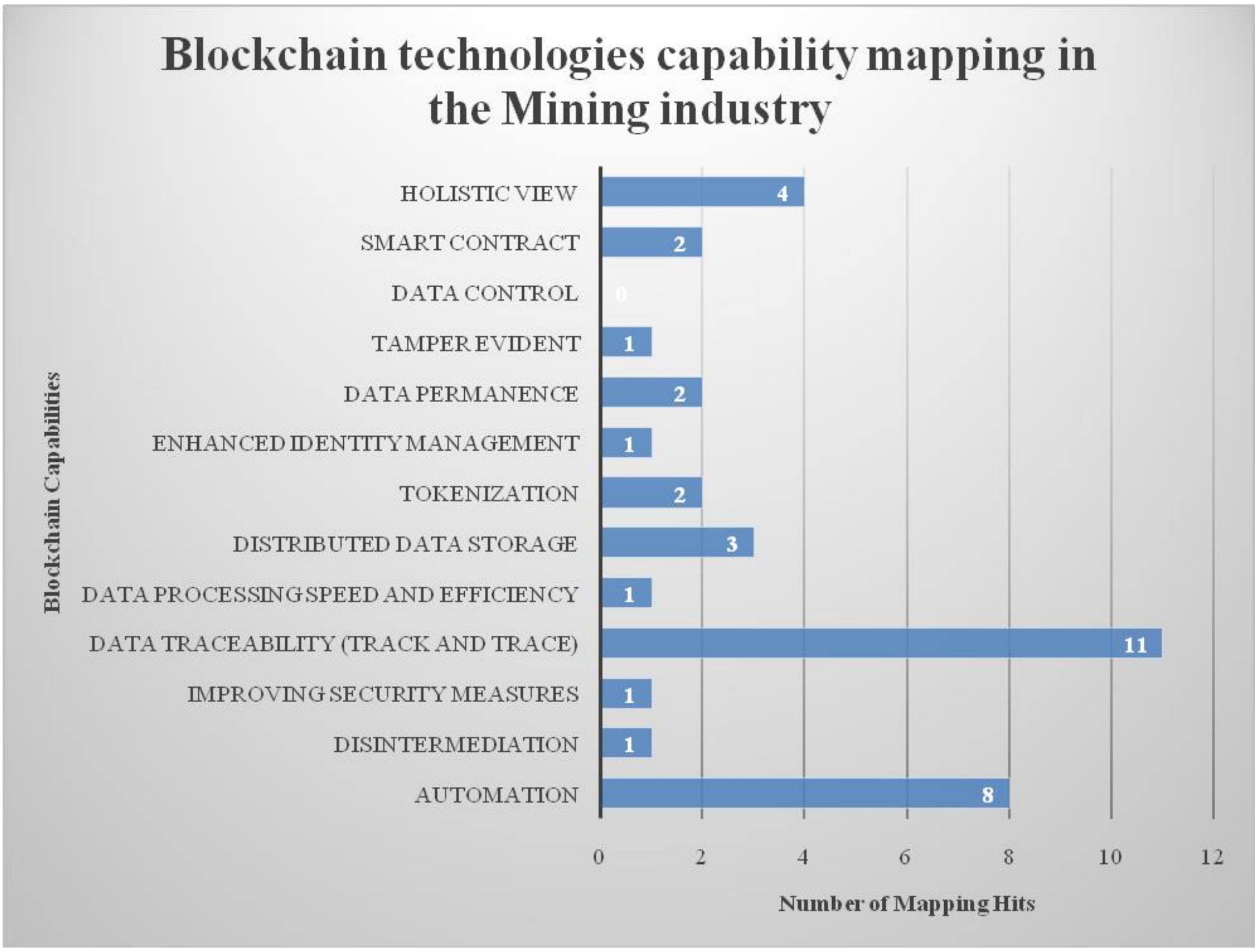


Figure 24: Number of BCT capability mapping hits

Additionally, the *value drivers* are summarized in Figure 25, highlighting the top three value drivers: Transparency, Track and trace and Compliance.

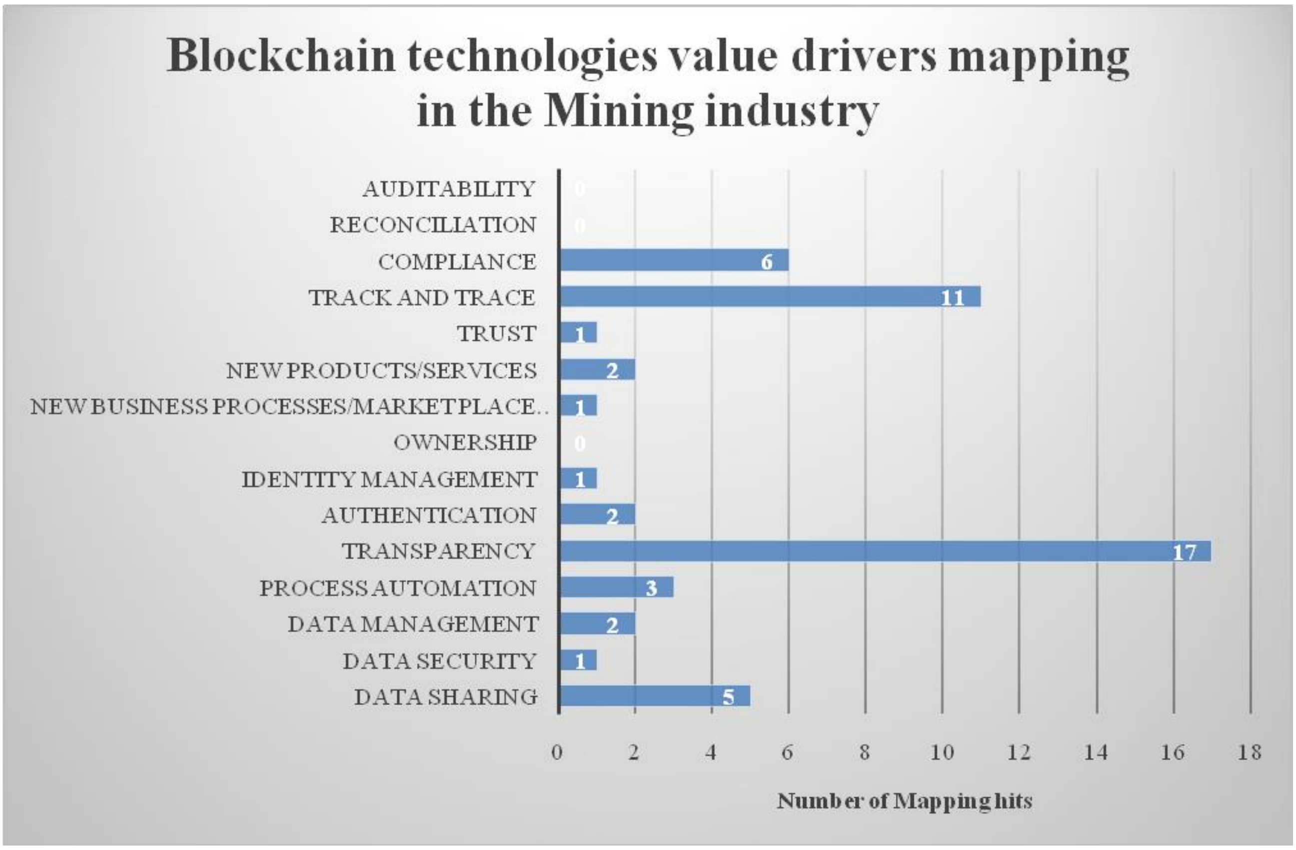


Figure 25: Number of value driver mapping hits

CHAPTER 4

CONCLUSIONS

This chapter concludes the findings of the research by condensing the important information from the study and relating them to the project objectives.

4 CONCLUSIONS

As mining companies embark on their digital transformation journey, the industry will need to focus on safeguarding digital information in relation to their day-to-day business operations. Digital information is becoming more valuable as disruptive technologies such as AI and IoT penetrate business operations. Organizations understand that they need to innovate or risk being disrupted.

The application of BCT has numerous associated benefits. These benefits were identified and are summarized as value drivers in Figure 26. The value drivers can translate to improvements in operational quality and profitability, increasing data transparency within an organization and with relevant stakeholders, as well as new opportunities for business partnerships, products and services. These value drivers highlight why the mining industry needs to investigate implementing blockchain technology within their organizations.

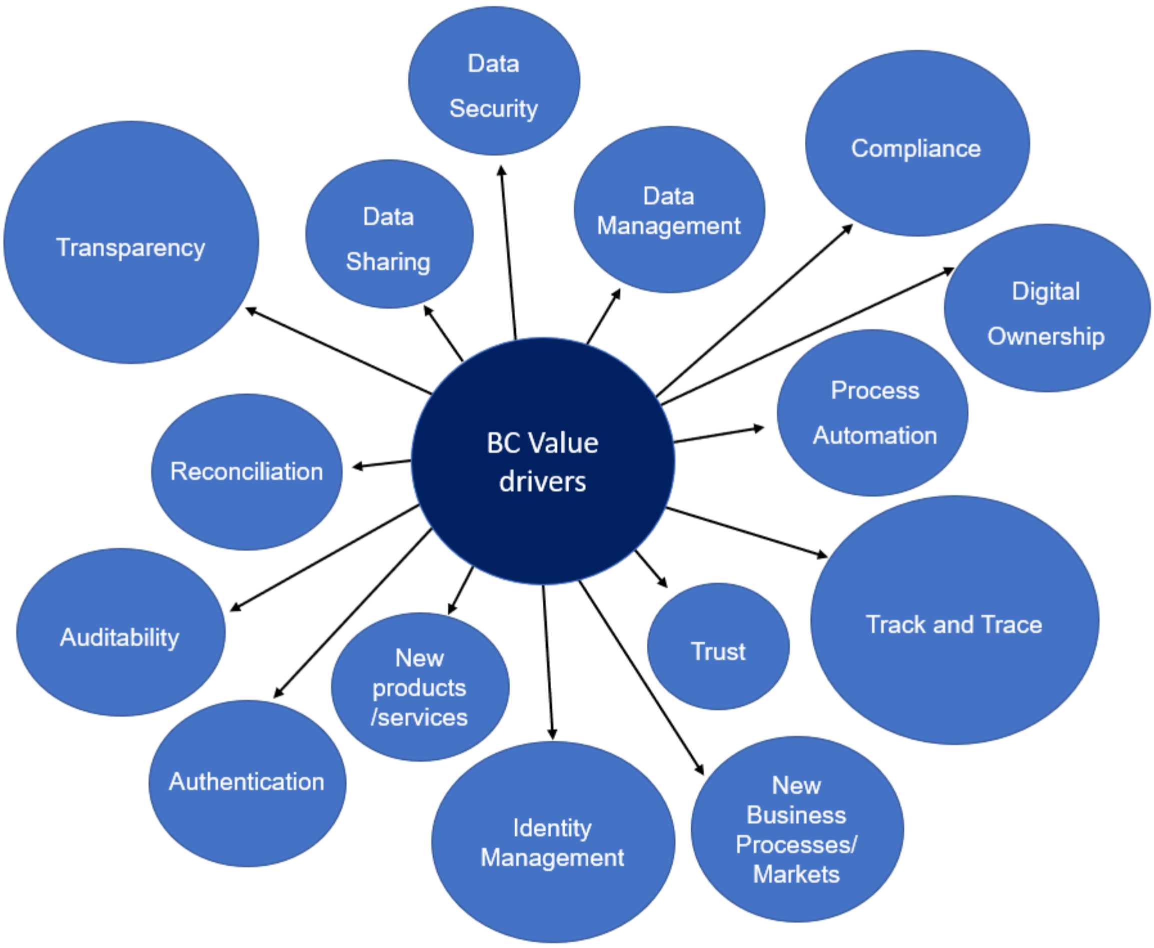


Figure 26: Blockchain value drivers

Blockchain is a revolutionary technology with the potential to disrupt all industries that use digital information in their business operations. Blockchain technology can be viewed as a metaphorical Swiss army knife. It is an extremely versatile technology with applications that can be designed and tailored for specific use cases. The technology's capabilities range from process automation to tokenization, through to providing a holistic view of all data records. The capabilities identified in this study are summarised in Figure 27.

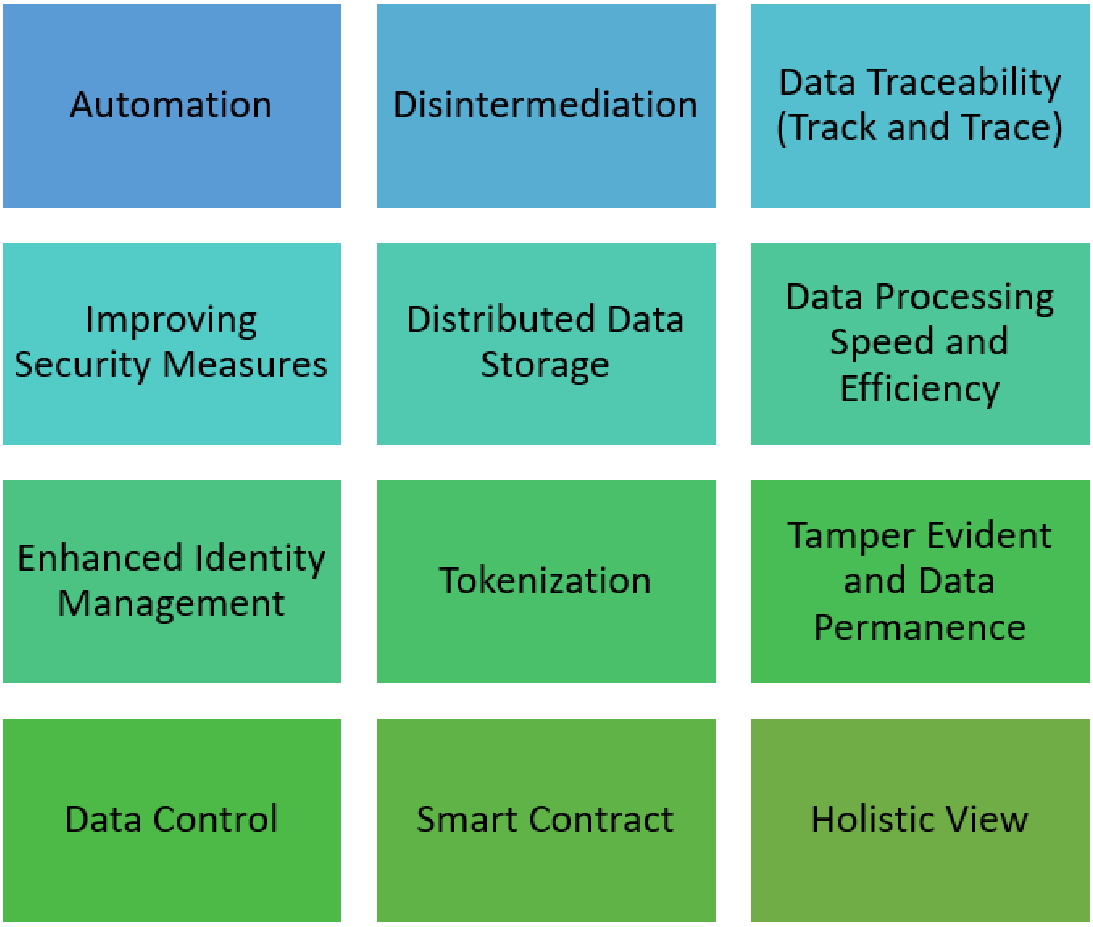


Figure 27: Capabilities of blockchain technologies

The capabilities and value drivers were used to identify potential focus areas for applying BCT in the mining industry. These focus areas are application–specific, relating to where data traceability, process automation, and the need for a holistic view occur within the mining industry's value chain processes.

All new data added to a BC ledger can be known to anyone or only to authorized parties, giving access to a single source of truth (same data). Data provenance and a complete history of all data communication/exchange/movement/changes can be recorded on a BC ledger. Blockchains' self-validating network and the use of smart contracts further enable the automatic application of business logic and processes within the mining industry.

The main benefits of applying BCT in these key applicational areas are improvements in data transparency, efficiencies in tracking and tracing data, and automated compliance.

Blockchain technology offers a valuable solution for traceability and transparency in engineering design and other non-financial processes. By creating a decentralized, immutable ledger, blockchain allows for the secure and efficient tracking of data and information throughout the entire design process. This means that every step and change made in the process can be easily traced and verified, improving accountability and reducing the risk of errors. Additionally, blockchain's transparency allows for greater collaboration and communication among team members, as well as increased trust and confidence in the final product. Overall, blockchain's ability to provide secure and transparent tracking of non-financial data makes it an ideal solution for a wide range of industries and processes.

It is worth noting that the implementation of BCT in engineering design and other non-financial processes, may not always follow the same design as its implementation in purchasing processes and platforms. While both implementations aim to increase traceability and transparency, the specific use cases and goals of each implementation can vary greatly. For example, in purchasing, BCT may be primarily used for tracking financial transactions and ensuring compliance, while in engineering design, it may be used for tracking changes and approvals throughout the design process. Additionally, the level of decentralization and accessibility may differ between the two implementations, with purchasing implementations tending to be more centralized and private, while engineering design implementations may be more decentralized and public. Therefore, it is important to consider the unique needs and goals of each specific implementation when designing and implementing BCT solutions.

The capabilities and value drivers identified in this study can be used to assess what benefits could materialize through BCT applications and how the technological capabilities could deliver value.

Additionally, the BC decision tree framework and BC value chain framework can be used for further specific use case investigations into the applicability of BCT in the mining industry. The BC decision tree framework discussed can assist mining companies with determining whether BCT could be suitable/feasible for a particular business problem, although it does not articulate how the application could add value.

The BC value framework highlights the benefits of applying BCT in any industry sector. It is intended to articulate the value that BCT can deliver for a specific use case. The mining industry can use this framework for further research into developing mining-specific BCT applications.

CHAPTER 5

RECOMMENDATIONS

5 RECOMMENDATIONS FOR IMPLEMENTING BCT

The recommendations are based on the research results and conclusions, as well as recommending steps a mining company can take towards realising blockchain applicational benefits.

In order to assess the applicability of BCT for the mining industry, the following steps are recommended:

1. The application of BCT requires a specific use case for analysis. The mining industry decision-makers should first have a brainstorming session with all relevant organizational parties. This session should identify specific pain points within the organization that they would like to address.
2. These pain points can be assessed and prioritized according to the effects that they might have on the business's operations.
3. The decision tree framework can then be worked through for each pain point to identify whether BCT is likely to be an option for addressing the different pain points.
4. When the team has decided or concluded that BCT can be a possible solution, then the BC value framework can be used, along with the value drivers and capabilities, to assess what value can possibly be gained by addressing the pain points with BCT.
5. These value drivers will form the foundation for discussing potential investment in developing a BC "proof of concept" for a specific application.

CHAPTER 6

SUGGESTIONS FOR FURTHER WORK

6 SUGGESTIONS FOR FURTHER WORK

This study provided a holistic view of where BCT can be applied in the mining industry-related value chain processes. This is just a starting point for assessing what real applicational benefits can be achieved. For further research a mining industry survey is proposed to gain deeper insight into the possible pain points associated within the different value chain processes.

The survey results will give the mining industry perspective on different pain points experienced in the various value chain processes. These pain points can then be summarized and assessed to see whether BCT has the capabilities of addressing the different issues. The BC recommendations from this research can be followed to confirm BC applicability and assess the potential value that can be gained from a specific real-world application.

The results from the assessment can be published and presented to the mining industry for further debate and potential collaboration on a specific use case. These specific use cases can then be critically analyzed using a multi-criteria decision analysis to develop a “proof of concept” that can be tested in the mining industry.

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