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

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*Paper written on project work carried out in partial fulfilment of MEng (Mining Engineering Degree)

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Dates:
Received: 27 Jan. 2023
Revised: 16 Sept. 2023
Accepted: Feb. 2024
Published: June 2024

How to cite:
Philo, K.G., and Webber-Youngman, R.C.W. 2024. A critical investigation into identifying key focus areas for the implementation of blockchain applications in the mining industry. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 124, no. 6. pp. 319–330

DOI ID:
http://dx.doi.org/10.17159/2411-9717/2597/2024

Abstract

Digital information and data are crucial drivers of progress in various industries, including mining, where data-driven decision making optimizes resource extraction, enhances safety, and ensures sustainability. The adoption of digital technologies like artificial intelligence (AI) and the Internet of Things has amplified the importance of digital information. However, the integrity and security of this information are paramount, leading to the exploration of blockchain technology as a potential solution for secure digital value exchange in mining. This research examines blockchain's capabilities, drawing insights from its applications in sectors like banking, government, healthcare, and entertainment, and evaluates their relevance to mining's core value chain processes. The study identifies blockchain's distributed ledger technology, cryptographic security, and decentralization as unique advantages that can revolutionize mining by enhancing transaction speed, reducing costs, and improving supply chain transparency and compliance with sustainability standards. Blockchain's transparent and auditable records can enhance business transparency, fostering trust among stakeholders, including investors and regulatory bodies. The technology's consensus mechanisms and smart contracts further promote trust in collaborative ventures. This research provides a foundational understanding for decision-makers in the mining industry to evaluate blockchain's feasibility and potential return on investment, guiding strategic planning and resource allocation for blockchain applications. By leveraging blockchain, mining companies can optimize operations, improve sustainability practices, and establish a robust foundation for future growth, positioning blockchain as a transformative technology in the sector.

Keywords

blockchain technology, value driver; capability; digital transformation

Introduction

The mining industry is undergoing a digital transformation, with technologies such as autonomous vehicles and drones being adopted to increase productivity and safety (Bliss, 2018). The World Economic Forum (WEF) predicts that many mining organizations will adopt autonomous mining machines, which will bring an estimated USD 47 billion to the industry by 2025. The WEF highlights four key areas for digital transformation in the mining industry: automation and robotics, a digitally enabled workforce, integrated enterprise systems, and advanced analytics (World Economic Forum, 2017).

The technologies associated with these four themes share a common aspect; namely, the utilization of 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. Machine-readable data has become one of the most valuable resources in current times, thus it is important to protect and better manage digital information.

It is evident that artificial intelligence (AI), the Internet of Things (IoT) and blockchain technology (BCT) will play an important role in the digital economy (UNCTAD, 2019). 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. BCT was identified as being potentially able to provide the mining industry with a trusted system for securely exchanging digital value (Philo and Webber-Youngman, 2021). However, there is still little evidence or understanding of how BCT can be implemented and what benefits the mining industry could obtain.

Table I

Differences between Bitcoin and blockchains

Bitcoin	Difference	Blockchains
A decentralized digital currency used for commerce on the internet	**What is it?**	Tamper-evident and tamper-resistant digital ledger implemented in a distributed fashion and usually without a central authority
To create a global, peer-to-peer electronic cash system that allows for fast, inexpensive, and secure transactions without the need for intermediaries such as banks or governments	**The goal**	To provide a secure and transparent way to record and verify transactions across a decentralized network of computers
Bitcoin is limited to trading as a currency	**Trade**	Anything that can be represented digitally, such as currencies, land titles, securities, etc.
Limited scope as a cryptocurrency	**Scope**	Open scope as blockchains can be designed for different use cases

Background

Blockchain technology was first proposed by an individual or group of individuals using the pseudonym Satoshi Nakamoto in a White Paper entitled 'Bitcoin: A Peer-to-Peer Electronic Cash System.' The White Paper was published in 2008 and it introduced the concept of Bitcoin, which has since grown to become the first and most well-known application of BCT.

Understanding the distinction between Bitcoin and blockchains is crucial as it can help to understand the unique properties and capabilities of BCT. Table I explains the important differences between Bitcoin and blockchains.

While BCT is viewed as a relatively 'new' technology, in essence it is more of an innovatively constructed combination of different existing technologies such as peer-to-peer (P2P) networking, cryptographic hash functions, distributed timestamping, digital signatures, and Merkle trees (Hileman and Rauchs, 2017). For this reason, BCT applications can be designed for a variety of different use cases but it 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 P2P or decentralized network) with no central authority; it enables the distribution of digital information that cannot be copied or forged (Rosic, 2018).

Research objectives and methodology

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

- ➤ How could BCT be used in the mining industry?
- ➤ What are the potential benefits for implementation in the mining industry?
- ➤ Where are the potential focus areas for BCT in mining?

Figure 1 illustrates the research roadmap that was followed during the study, starting with an investigation into BCT use cases in different industries. These use cases were examined to identify what capabilities of BCT are used and the associated benefits. Mining industry use cases were then researched from a technology-push perspective to try and find possible focus areas within the

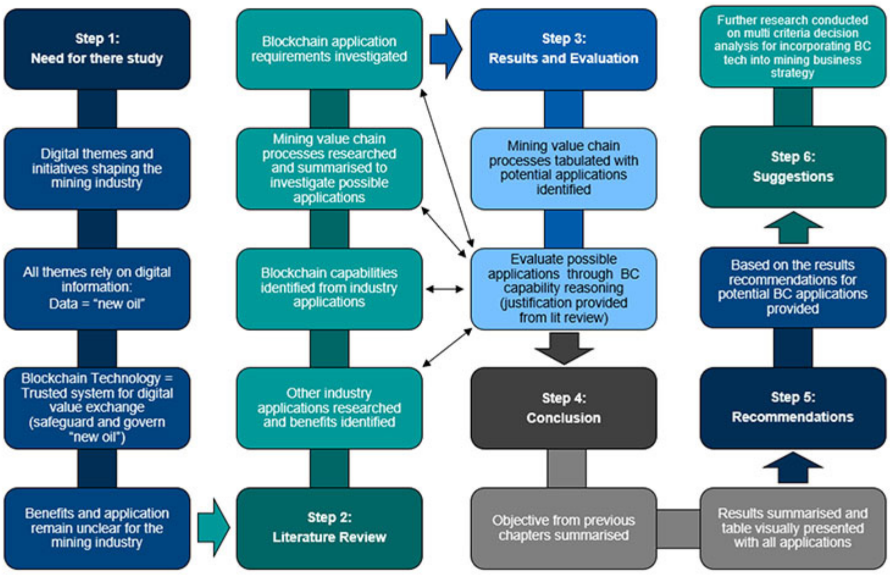


Figure 1—Research roadmap used in the study

mining industry's business processes for further research. From the findings of the literature review, the capabilities and value drivers of BCT were mapped to the mining industry's business processes to highlight potential focus areas for application in mining.

Literature review

Blockchain technology fundamentals

BCT is also commonly referred to as Distributed Ledger Technology (DLT). There are also other terms, such as P2P databases, mutual distributed ledgers, synchronous ledgers, and consensus ledgers. These terms, among others, unfortunately add to the confusion around BCT as they are often interchangeably used. What distinguishes BCT from these other databases or ledgers is the data structure (how data are stored: chain of cryptographically linked blocks) and the data diffusion (how data are shared/communicated: global data broadcast) (Hileman and Rauchs, 2017).

The other characteristics that make BCT unique can be summarized into the following five points (Lansiti and Lakhani, 2017):

➤ The technology is **decentralized**. This means that it is a distributed database where each party on the blockchain network has access to the entire records and their complete history. Every participant can verify the records of transaction partners directly and without a trusted third party/intermediary.

➤ 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.

➤ The blockchain 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 transactions occur between these addresses, and users can choose to remain anonymous or provide proof of their identity to others.

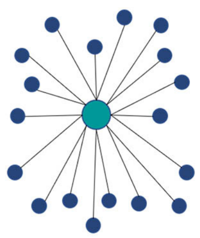
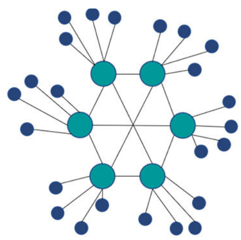
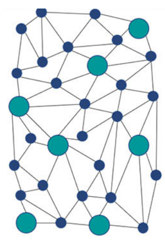
➤ The blockchain **records are designed to be irreversible**. When transactions are entered into the database and the accounts are updated, the records cannot be simply altered. The blockchain protocol deploys various computational algorithms and approaches to ensure that the recording on the database 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'.

➤ The blockchain **uses computational logic**. Owing 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 blockchain 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.

One of blockchain's notable features is the ability to transfer value (digital information) securely across a decentralized network. Table II illustrates distinctions between three network architectures; namely, centralized, decentralized, and distributed, while highlighting the positive and negative aspects of each.

Table II

Centralized vs decentralized vs distributed systems (Touron, 2019)

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 need to be centrally controlled	**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

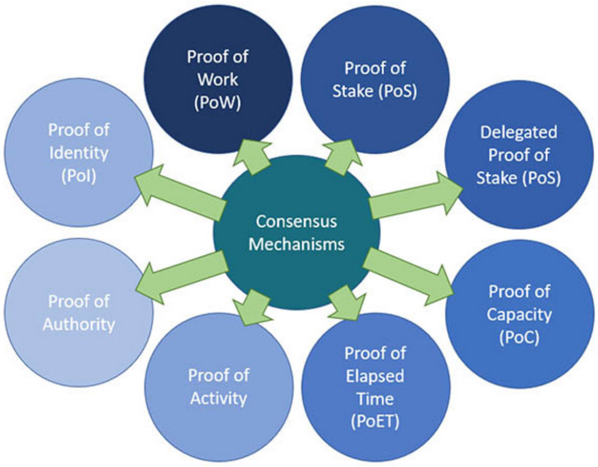


Figure 2—Blockchain consensus algorithms (Anwar, 2018)

The main concern 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 (in terms of data access, storage, and usage) as power 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 exchanges.

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. Figure 2 shows the various consensus mechanisms that are used in different applications.

Each consensus mechanism is designed to achieve consensus in different ways. How consensus is achieved can typically influence three main features of a blockchain; namely, security, decentralization, and scalability. Vitalic Buterin (co-founder of Ethereum) conceptualized a model (Figure 3) named the

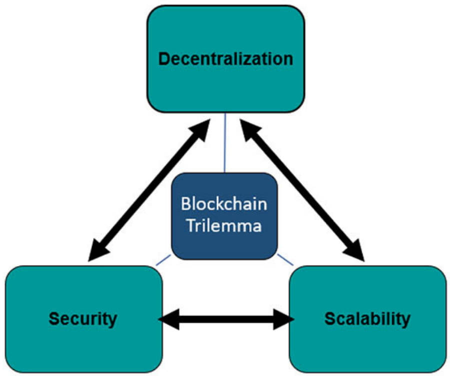


Figure 3—The blockchain trilemma

'blockchain trilemma', which highlights these features as challenges that programming engineers face when developing a blockchain (CertiK, 2019).

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

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

When developing a BCT application for the mining industry, it is important to make informed decisions when choosing a consensus mechanism, as different consensus applications will have different outcomes in terms of decentralization, scalability, and security. When a company has set an applicational objective, the desired results can be used to work backwards and identify a suitable consensus mechanism that may align with that objective. A decision tree for choosing an appropriate consensus algorithm was published by Ferdous et al. (2020), which can be leveraged to help develop or select a blockchain for a particular use case.

Industry applications

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,

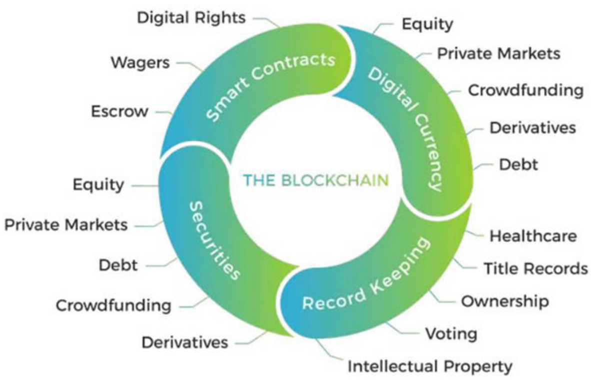


Figure 4—Blockchain applications (Goyal, 2018)

Table III

Summary of blockchain technology applications from the literature review findings

Industry	Use cases / Application areas	Benefits	Sources
Banking and Finance	Payment systems (local and international)	• Speed and efficiency improvements in transaction processing • Reduced intermediaries • Reduced financial activity costs	Baur et al., 2018 CBinsights.com, 2021 Wisdomtree.com, 2019
	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	Natrajan and Nuthi, 2022 Symons, 2017
	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	Frankenfield, 2022 Saiedi et al., 2022 Thurman, 2021
	Customer KYC (know your customer) 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	CFI, 2021 Cheng et al., 2022 Chirag, 2022 Schram, 2021
Government and Public Goods	Public procurement processes	• Procedural transparency • Full traceability of permanent records • Improved trust (honest disclosure)	Lannquist and Raycraft, 2020
	Voting	• Full traceability of permanent records • Identity verification	Aburumman et al., 2020 Clavin et al., 2020
	Central Bank Digital Currencies (CBDC)	• Transparency and traceability of financial transactions • Supervision • Control	Clavin et al., 2020
	Education	• Ownership of digital certificates (National Senior Certificate) • Automated verification process of certificates	Aburumman et al., 2020 Clavin et al., 2020
	Identity management	• Tokenized identities • Improved data management • Authentication	Aburumman et al., 2020 Clavin et al., 2020
	Payment and taxation	• Full traceability of payments and tax records • Speed and efficiency improvements in tax process	Aburumman et al., 2020 Clavin et al., 2020
	Storing records	• Evidence tampering • Facilitates mandatory regulatory reporting	Hileman and Rauchs, 2017
	Electronic voting systems	• Transparency of voting process • Enhanced identity management • Security improvements	Aburumman et al., 2020 Calvin et al., 2020
	Public healthcare	• Preservation of historical health data • Track and trace improvements • Improved data management and security	Lannquist and Raycraft, 2020
	Asset management (Land registry and transactions)	• Decentralised registry • Process automation	Ølnes et al., 2017

Table III (continued)

Industry	Use cases / Application areas	Benefits	Sources
Insurance	Property and causality insurance underwriting	• Efficient exchange of information • Improved risk profiling •Automation through smart policy • Enhances client onboarding	Arpan and Navin, 2012 Colaco et al., 2022
	Property and causality insurance claims processing	• Simplified/automated claim submission • Reduced fraud loss • Enhanced customer experience and no manual inspection •Automated compliance	Colaco et al., 2022
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 blockchain data stored from device manufacturers, pharmaceutical companies, medical institutions)	Babaei et al., 2023 Oderkirk and Slawomirski, 2020 STLPartners, 2021
	Patient-centric electronic health records	• Improved patient and healthcare provider experience • Improved patient data transparency and control • Process efficiency improvements and reduced costs	Krawiec, 2016 Oderkirk and Slawomirski, 2020
	Verification of medical staff credentials	• Efficient and faster verification process • Data monetization of staff competencies • Transparency and reassurance on staffing capabilities	STLPartners, 2021
	IoT security for remote monitoring	• Improved IoT security through decentralized device communication	Sehar et al., 2023 STLPartners, 2021
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	Camila and Alberto, 2018 ConsenSys.net, 2022
	Streamlining of royalty payments	• Enhanced data management (content creator) • Automated royalty payments for content use • Improved security of content distribution	Bamakan et al., 2022 ConsenSys.net, 2022
	New pricing options for paid content	• Pay-per-use consumption-based model enabling micropayments with cryptocurrencies	ConsenSys.net, 2 022
	Monetization of in-game assets	• Ownership of virtual assets • Buy, sell, and exchange NFT (non-fungible tokens) for cryptocurrencies	CIOReview, 2019 Kraken.com, 2020
	Blockchain-based gaming platforms	• Play-to-Earn incentive system • Enhanced security for online games • Improved gaming user experience	Chirag, 2022 Kalra et al., 2018
Mining	Engineering, construction, and hand-over of the mine site	• Improved trust and work compliance • Improved data process management and maintenance	Cosgrove, 2019 Kamel et al., 2023.
	Compliance and mining lease management	• Eliminates the need for intermediaries, reduces administrative costs, and eliminates errors	Cosgrove, 2019
	Supply chain	• Improved supply chain transparency	Cosgrove, 2019 Kshetri, 2018
	Mineral provenance	• Improvedtrust when transparent sourcing of mineral resources is verified on a blockchain	Cosgrove, 2019

safe, and secure data-exchange process. The technology allows all or specific network participants (depending on private or public 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 blockchain can be tamper-proof (changes on a blockchain need to be authorized by the majority of network participants, i.e., they are consensus-dependent) and or tamper-evident (any suspicious data alteration 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 4 attempts to summarize the applications of BCT from a holistic perspective, but some applications are duplicated, especially with regards to securities and digital currencies. The real benefits of applying BCT within different industries are at present still underutilized.

The literature review investigated different applications of BCT in various industries to identify and summarize the technology's capabilities and associated benefits. Table III condenses the findings from the literature review and highlights the different applications and associated benefits of using BCT in the banking, government, insurance, healthcare, entertainment, and mining sectors.

Results and discussion

Based on the use cases identified in the literature review, the various applicational capabilities of BCT were deduced, as shown in Table IV. 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 for a better understanding of what the technology can do for their business.

Table V summarizes the identified benefits of BCT found from the literature survey and condenses them into value drivers for the purpose of linking the technology's capabilities with expected benefits.

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

Automation: BCT is a self-validating network that can automate business applications and logic using 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 administration.

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 that may form the premise for a particular business case. Industry leaders can use these capabilities and value drivers to assess whether potential opportunities exist within their own specific operations.

The capabilities and value drivers (Table VI), along with the mining industry 23 value chain definitions and outputs from the Open Group's Exploration and Mining business process model (which defines the standard business activities for organizations that operate in the exploration and mining sectors), were used to suggest potential applications of BCT. Using the mining industry's

Table IV

Blockchain technology capabilities

BCT capability	Description
Automation	Blockchains' self-validating network and the use of smart contracts aids the automatic application of business logic and processes.
Disintermediation	BCT can provide disintermediation of third parties. Because BCT uses cryptography and different consensus mechanisms to ensure that data are 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 blockchain ledger can be known to anyone or only to authorised parties. The provenance and complete history of all data communication/exchange/movement/changes are 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 digitally transferred 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 blockchain can be permanently stored using different cryptographic algorithms 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	Different permissions (open/closed systems) can be granted to users, enabling a wider range of data control.
Smart contracts	Smart contracts on a blockchain enable new product/services and partnerships (e.g., royalty payments).
Holistic view	All authorized parties have access to a single source of truth recorded on the blockchain (same data).

Table V

Value drivers of blockchain technology

Value driver	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. Blockchain technology offers various levels of data encryption, reducing the risk of data breaches.
Data management	BCT 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 administration.
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	BCT 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 increased trust in digital information and use of smart contracts, new business processes and marketplaces could emerge, such as Play-to-Earn and digital rights management.
New products/services	BCT 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	BCT 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	BCT enables the tracking and tracing of data/products within a supply chain because of the ability to provide a holistic view within a blockchain network of trading organizations.
Compliance	BCT 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	BCT can improve data reconciliation processes because of improved data traceability, management, and transparency.
Auditability	BCT can provide transparency with regards to permanent, tamper-proof records of transactional data, shared among 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.

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

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 applications. The value drivers were also highlighted in the different mining value chain processes. Figure 5 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.

In addition, the value driver hits are also summarized in Figure 6, highlighting the top three value drivers: transparency, track and trace, and compliance.

Conclusion

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.

Table VI

Blockchain technology capabilities and expected value drivers

Blockchain technology capability	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

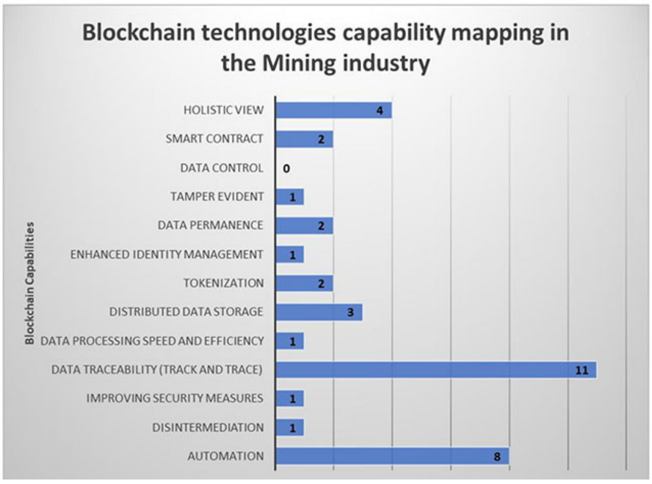


Figure 5—Number of blockchain technology capability mapping hits

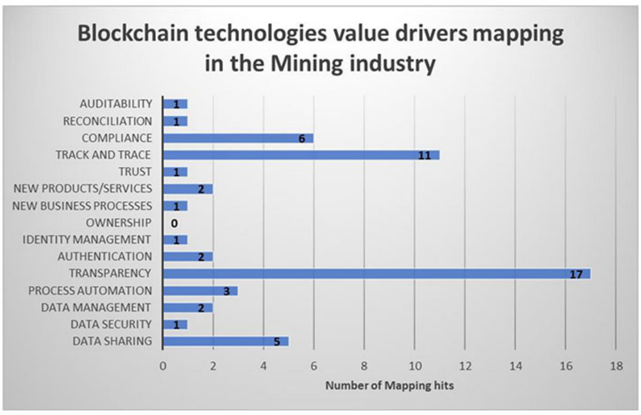


Figure 6—Number of value driver mapping hits

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 7. 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 pointing to new opportunities for business partnerships, products, and services. These value drivers highlight why the mining industry needs to investigate implementing BCT within their organizations.

Blockchain is a revolutionary technology with the potential to disrupt all industries that use digital information in their business operations. BCT 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 summarized in Figure 8.

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 blockchain 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 blockchain ledger. Blockchains' self-validating networks 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.

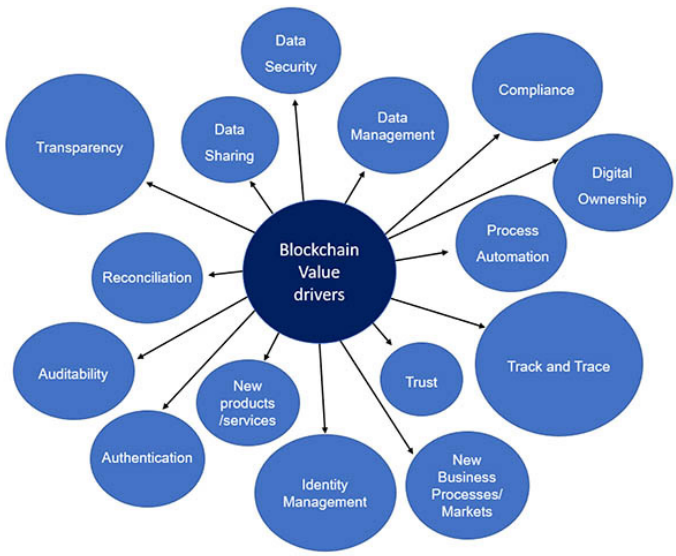


Figure 7—Blockchain value drivers

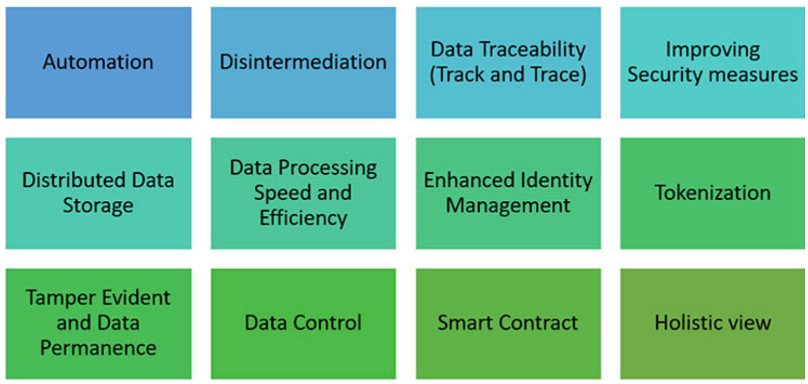


Figure 8—Capabilities of block chain technology

BCT 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 use case.

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.

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. The focal areas for blockchain integration within the mining industry primarily revolve around business units, processes, and activities that demand a comprehensive perspective, meticulous data tracking and tracing, and streamlined process automation. BCT offers its greatest advantages in situations where a holistic view of operations is essential, ensuring that all stakeholders have access to a single, immutable source of truth. Additionally, blockchain's secure and transparent ledger capabilities are particularly valuable for tracking and tracing data across the intricate web of mining activities, allowing for a precise account of every step and change in the process. Furthermore, its potential for deploying smart contracts enables the automation of complex workflows, enhancing efficiency and accuracy in various mining-related tasks. As such, the mining industry can harness blockchain's transformative potential by strategically implementing it in these key areas, ultimately revolutionizing the way mining companies conduct and manage their operations.

Recommendations

The recommendations are based on the research results and conclusions, as well as steps a mining company can take towards realising blockchain applicational benefits. 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. Mining industry decision-makers should first have a brainstorming session with all relevant organizational parties. This session should identify specific problems in respect of their operations, employees, and customers (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. When the team has decided or concluded that BCT can be a possible solution, then the blockchain 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.
4. These value drivers will form the foundation for discussing potential investment in developing a blockchain 'proof of concept' for a specific application.

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