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Blockchain in the Transportation Industry

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ABSTRACT

Blockchains are a form of distributed ledger technology, where transaction data is shared by the nodes (computers) on a network to which transactions are recorded and validated. In the evolving landscape of transportation, blockchain technology is emerging as a potential game-changer. Blockchain technology is revolutionizing many industries, including transportation. Blockchain could impact various areas within transportation, including supply chain management, documentation, payment processes, vehicle lifecycle management, and last-mile delivery. Blockchain technology can improve transportation by increasing security, efficiency, and transparency. This paper presents various applications of blockchain-based systems in transportation.

KEYWORDS: *blockchain, distributed digital ledger, transportation, transportation industry*

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INTRODUCTION

Blockchain is a technology that originated out of a branch of mathematics called cryptography. Since it came to prominence within financial services applications such as cryptocurrencies and digital asset exchanges, the race to find breakthrough applications for blockchain technology in other industries has been intense. Blockchain seems the perfect solution for the complex, decentralized supply chains of the transport sector, but results to date have been disappointing. It seems that blockchain today has failed to deliver benefits in the transport industry. The path to successful implementation remains unclear. However, research indicates that the transportation industry still views blockchain as potentially disruptive [1]. Companies across the industry spectrum are coming to the realization that they can use blockchain technology to streamline their operations and provide better service to their clients. Blockchain has a chance to completely revolutionize the way that the transportation industry does business. The symbol of a blockchain is depicted in Figure 1 [2].

WHAT IS BLOCKCHAIN?

Blockchain, a type of distributed digital ledger technology (DLT), is a relatively new and exciting way of recording transactions in the digital age. It is a decentralized and distributed digital ledger technology that securely records and verifies transactions across multiple computers or nodes in a network. Basically, it is a chain of blocks in which each block contains a list of transactions. The blockchain technology was created as the foundational basis for Bitcoin – a digital currency in which secure peer-to-peer transactions occur over the Internet. It is expected that the spending on blockchain solutions worldwide would grow from 4.5 billion USD (2020) to an estimated value of 19 billion USD by 2024 [3].

Originally developed as the accounting method for the virtual currency Bitcoin, Blockchains are appearing in a variety of commercial applications today. Blockchain technology is a type of distributed digital ledger that uses encryption to make entries permanent and tamper-proof and can be programmed to record financial transactions. It is used for secure

transfer of money, assets, and information via a computer network such as the Internet without requiring a third-party intermediary. It is now being adopted across financial and non-financial sectors. As a catalyst for change, the Blockchain technology is going to change the business world and financial matters in major ways.

The first Blockchain was conceived in 2008 by an anonymous person or group known as Satoshi Nakamoto, who published a white paper introducing the concept of a peer-to-peer electronic cash system he called Bitcoin [4,5]. Bitcoin and Ethereum are the first two mainstream blockchains. Other modern blockchains include Namecoin, Peercoin, Ether, and Litecoin. Figure 2 shows different components of blockchain [6].

Blockchain combines existing technologies such as distributed digital ledgers, encryption, immutable records management, asset tokenization and decentralized governance to capture and record information that participants in a network need to interact and transact. As illustrated in Figure 3, a complete blockchain incorporates all the following five elements [7]:

- *Distribution:* Digital assets are distributed, not copied or transferred. A protocol establishes a set of rules in the form of distributed mathematical computations that ensures the integrity of the data exchanged among a large number of computing devises without going though a trusted third party. A centralized architecture presents several issues including a single point of failure and problems of scalability.
- *Encryption:* BC uses technologies such as public and private keys to record data securely and semi-anonymously. Completed transactions are cryptographically signed, time-stamped, and sequentially added to the ledger.
- *Immutability:* The blockchain was designed so these transactions are immutable, i.e. they cannot be deleted. No entity can modify the transaction records. Thus, Blockchains are secure and meddle-free by design. Data can be distributed, but not copied.
- *Tokenization:* Value is exchanged in the form of tokens, which can represent a wide variety of asset types, including monetary assets, units of data or user identities.
- *Decentralization*: No single entity controls a majority of the nodes or dictates the rules. A consensus mechanism verifies and approves transactions, eliminating the need for a central intermediary to govern the network.

Bitcoin and its underlying blockchain technology increasingly impact all facets of society. Bitcoin's status as digital gold is merely the tip of this technology. Figure 4 shows Bitcoin [8], while Figure 5 shows how blockchain works [9]. Although blockchain technology will for all time be associated with Bitcoin due to their common genesis, it has broader applications. Cryptocurrency will increasingly become a factor in family law issues as well.

A blockchain is a tamper-proof, distributed database that stores blocks of information for cryptographically bound transactions via peer-to-peer networks. At the heart of blockchain's functionality is cryptographic hashing. Each block in a blockchain contains a cryptographic hash of the previous block, creating an immutable chain of blocks. If anyone attempts to tamper with the data in a block, it would alter the block's hash. This would disrupt the entire chain, making it virtually impossible to manipulate. The security feature ensures data integrity and prevents unauthorized changes [10].

In a nutshell, blockchain technology involves three basic concepts [11]: (1) It is a system for recording a series of data items (such as transactions between parties); (2) It uses cryptography to make it difficult to tamper with past entries; (3) It has an agreed process for storing copies of the ledger and adding new entries (also called a consensus protocol).

Blockchain is a novel decentralized infrastructure and distributed computing paradigm that uses a chained data structure for verification, storage, and distributed consensus algorithms to generate and update data. Decentralization is a key feature of blockchain technology, which refers to the distribution of power and decision-making across a network of nodes or participants rather than being controlled by a central authority or system. It provides robustness while eliminating many-to-one traffic flows to avoid delays and single points of failure. Figure 6 shows the decentralized property of blockchain [9]. The advantages of decentralized property of blockchain network include the following [9]:

- The decentralized property of blockchain makes it less prone to failure and more expensive for hackers to attack the network.
- There is no third-party involvement; therefore, there is no added risk.
- Every change made in the network is traceable and concrete.
- Users maintain full autonomy of their properties and are not dependent on third parties to maintain and manage their assets.

- It provides enhanced security.

BLOCKCHAIN IN TRANSPORTATION

By transportation we intend the movement of people or goods from one place to another. Transportation is crucial on a personal and systemic level. Companies in the commercial transportation industry sink or swim based on their ability to adapt to consumer needs, and implement new technologies that help them increase efficiency and lower the costs of shipping. Blockchain is a technology that is utilized in cryptocurrency and useable for other purposes, such as transportation management.

Blockchain technology in transportation is not just about improving existing processes; it is about reimagining the entire industry. Blockchain technology can help transport companies manage fleets, routes, and overall operations. It has become a very powerful tool that provides new and efficient methods for managing data, business processes, and transactions. As shown in Figure 7, blockchain can address some pain points in transportation and logistics [10].

APPLICATIONS OF BLOCKCHAIN IN TRANSPORTATION

There are already some pioneering use cases for different applications in the transport industry. Transportation management can be positively affected by the adoption of blockchain technologies, in many ways. Blockchain technologies applied to the transportation sector are in an early phase of development, but there are also some concerns about practical applications, since some early blockchain projects have failed in the first years of deployment. Blockchain facilitates real-time tracking of items, expedites administrative procedures, and lowers fraud by offering a decentralized, unchangeable ledger. Figure 8 shows transportation applications of blockchain [11]. Common areas of applications include the following [12-14]:

- *Logistics:* This is the most widely discussed topic in terms of application of the blockchain in transportation. Blockchains can serve many different functions by securing goods and data from any malicious attacks in multi-agent supply chains. Blockchains provide the possibility of controlling product storage quality during transportation and guaranteeing the origin of products, thereby creating trust among suppliers.
- *Transportation Management:* Blockchain technology in transportation management ameliorates efficacy because of the technology's capability and chronological elements. In cases like transportation management, we can utilize blockchain to capture and store data. Yet, if the technology can store all pieces of information in a single place, it could very well accommodate as a master data management (MDM) system. Because it inherently fortifies data validation by network members, Blockchain could provide the function of "data stewards" in an MDM solution.
- *Trucking Industry:* The trucking and commercial transportation industry has been particularly active with blockchain implementation. Many trucking companies already invest in great tracking technology, but scaling this technology to more difficult user demands is proving difficult. As inefficiency mounts in the world of logistics and transportation, more companies are joining the charge to incorporate blockchain-based technologies into the trucking industry. The Blockchain in Trucking Alliance, also known as BiTA, is a large organization that boasts major members from just about every corner of the trucking supply chain, with UPS and FedEx as typical members. The organization is working on creating universal standards for blockchain's mass adoption in the transportation and logistics industry.
- *Smart Contracts*: Smart Contracts may be the single most impactful blockchain enabled feature to the freight industry. A smart contract is a program that is stored in a blockchain. It will only run when certain conditions are met. Smart contracts are essentially self-executing tasks that are coded through the blockchain and executed when a certain condition is met. By using blockchain, smart contracts could completely eliminate the need for all of these administrative steps, cutting costs and virtually removing all possibilities for error. The amount of money saved by using smart contracts effectively could be staggering. Figure 9 compares conventional contracts with smart contracts [15].
- *Public Transportation*: Blockchain can be leveraged to improve public transport systems. It can significantly reduce costs, risks, and wasted resources in this sector. It can be used to create a transparent audit trail to ensure regulations compliance and review contract management for public transport providers. Blockchain networks enable passengers to pay fares digitally and securely, eliminating the need for a physical ticket while minimizing the risk of fraud. Simultaneously, drivers can automate fare collection and payments for a much more efficient operation. Blockchain enablement can benefit shared bus service schedules and

management systems. For example, a city's public transportation network can implement a blockchain-based ticketing system that ensures secure payments.

- *Order Delivery Tracking:* Intelligent order delivery tracking systems use blockchain. Many companies now offer same-day or express delivery within one or two hours. Doing this requires a digital solution that can immediately authenticate orders, complete them, and initiate delivery and tracking. A blockchain platform can easily coordinate these processes and provide the information required through a shared database. Blockchain improves the flow of data from the moment a customer places an order. It also provides a reliable verification system that remains secure. FedEx is using blockchain technology to improve delivery and packaging services. Customers can now easily track packages in transit from the factory to their doorstep
- *Intelligent Transportation Systems* (ITS): These are a growing space of innovation that many industry experts believe will be one to benefit from blockchain's capabilities. They allow traffic operators to monitor road conditions, track vehicles, and communicate efficiently with other drivers on the road. These systems allow cities to build safer roads, authorities to implement better traffic management schemes, and businesses to enhance transportation operations. With blockchain enablement, these processes can significantly improve, creating a secure and efficient infrastructure that those involved can trust much more. Blockchain's network qualities lend itself well to enhancing how businesses use ITS.
- *Electric Vehicle Recharging*: Electric vehicles are becoming more widespread, as are the stations for recharging them. The application of blockchain technology in this area is something new and little explored. One of the main purposes concerns the right matching between energy demand and supply. Important efforts are needed to make the blockchain-based architectures sufficiently scalable; in fact, over the years the number of motorists and suppliers who could decide to join the electric vehicle ecosystem could dramatically grow. The functionalities offered by the blockchain (e.g., secure payments through cryptocurrency) could, however, constitute the trigger to give a definitive impulse to the spread of electric cars.
- *Smart City*: Many cities are defined "smart" when the following features are present: broadband connectivity, a knowledge workforce, and digital inclusion. One of the main goals of smart cities is to improve the services offered to citizens, reducing administrative costs through the use of technology. Blockchain can power smart city initiatives by enabling secure and decentralized data exchange. From parking management to public transit, blockchain can optimize urban mobility. The development of smart cities, where the above-listed services and technologies are implemented, can create demand for blockchain technology. As an example, blockchain systems could satisfy the future needs of citizens and authorities to exchange and store personal data safely.

BENEFITS

Blockchain technology offers several promising applications in the transportation industry. Organizations need updated, secure, and authentic data to make decisions. Blockchain ensures trustworthy data across the transportation and logistics ecosystem. It has many benefits that can solve many issues in the transport industry. Blockchain is rapidly evolving in helping to improve traceability of cargo trade flow across borders. Other benefits include the following [13,16,17]:

- *Enhanced Security:* In an industry challenged by counterfeiting, theft, and data breaches, blockchain's security features are of particular interest. Its tamper-resistant nature means that once data is recorded, it is extremely difficult to alter without detection. This characteristic could potentially reduce the risk of cargo theft and tampering. A blockchain-based identity system could streamline check-in processes, enhance security measures, and facilitate seamless transfers between different modes of transportation. Blockchain can help reduce fraud and errors by ensuring that all parties have access to validated records.
- *Efficiency:* Blockchain can help reduce the need for manual paperwork and manual checks for errors. Blockchain technology could potentially revolutionize payment processes in the transportation industry. Smart contracts might trigger instant payments upon delivery confirmation or when specific conditions are met. By using smart contracts, approvals and customs clearance can be quicker and more efficient, reducing processing times for goods at customs checkpoints.

- *Maintenance:* Another area where blockchain could potentially innovate is vehicle tracking and maintenance. The technology might create an immutable record of a vehicle's history, including maintenance records, accident reports, ownership changes, and performance data.
- *Automation:* Blockchain technology can also help automate tasks and reduce the need for manual paperwork. Smart contracts automate routine tasks such as order processing, payment settlements, and inventory management. Using blockchain reduces bureaucracy and paperwork through automated data and information storage. For example, when a shipment reaches its destination, the smart contract can trigger payment release to the carrier, eliminating delays and paperwork.
- *Improves Tracking Systems*: Blockchain enables companies to track updates across all processes.. All parties are also identified immediately when an unfortunate incident occurs. Companies can easily track the movement of a parcel for delivery. Blockchain also makes it easy to trace where delays occurred to improve operations.
- *Trust:* Blockchain has been regarded as a trustless system, meaning that you do not have to trust specific participants in a transaction for the transaction to occur. A transaction will occur because of specific set rules and algorithms – protocol – of a blockchain platform. The trustless paradigm scatters the role of transaction approval across multiple actors in a network. It makes trust irrelevant. But trust does not just end with this characteristic; it is one of the most basic and popular features of blockchains. Transparency characteristics, especially in the supply chain, are also part of building trust through blockchain technology.
- *Transparency:* The transport industry values transparency, and blockchain technology provides companies and clients clarity. Blockchain technology can provide transparency and speedy delivery, making it a plus for customers. It also gives companies the latest updates on a trip, route, or the state of specific vehicles or drivers on the road. This way, they can provide the support their drivers or clients need. Traceability can build trust and transparency by meeting stakeholder needs, curbing illicit business practices, improving sustainability performance, increasing operational efficiencies, enhancing supply chain relationships and information flow, and providing better information about market forces and trends.
- *Data Privacy:* Balancing transparency with data privacy is crucial. While transparency is essential, some data must remain confidential. Hybrid solutions that balance transparency and privacy are emerging.
- *Data Security:* Freight management involves the exchange of sensitive information, including invoices, bills of lading, and customs documents. Blockchain's cryptographic algorithms and decentralized architecture provide robust data security. By encrypting data and distributing it across multiple nodes, blockchain minimizes the risk of unauthorized access. This aspect enhances trust and ensures the integrity of critical information.
- *Traceability*: Blockchain technology enables end-to-end traceability of goods throughout the supply chain. Each transaction and movement is recorded on the blockchain, creating an auditable trail. This traceability feature enhances accountability by providing a comprehensive view of the entire journey, from origin to destination.

CHALLENGES

While blockchain technology holds promise for the transportation industry, it faces numerous challenges**.** Major challenges such as scalability, regulatory uncertainty, and integration with legacy systems must be addressed before blockchain can be widely adopted in the transportation industry. The applications of blockchain can be obscure and difficult to understand. From technical limitations to regulatory uncertainties, these obstacles present both risks and opportunities for innovation. Other challenges include the following [16,17]:

- *Scalability:* Scalability remains a primary concern; as more transactions are added to the blockchain, processing times can slow down. This issue needs to be resolved for blockchain to handle the volume of transactions in global transportation networks. Although blockchain has a lot of promise, the transportation sector is concerned about scalability. With millions of transactions taking place every day, global supply networks can generate massive amounts of data. Blockchain needs to be able to handle a lot of transactions quickly in order to be a practical option for extensive logistical operations.
- *Regulation:* Blockchain solutions must comply with local regulations. Regulatory hurdles present a significant challenge. Lack of regulation can create risks for the users. Government agencies are still grappling with how to regulate blockchain technology effectively. The lack of

clear, uniform regulations creates uncertainty and could hinder adoption. If organizations like BiTA (Blockchain in Trucking Alliance), in conjunction with government agencies like the FMCSA (Federal Motor Carrier Safety Administration) and DOT (Department of Transportation), can create a regulatory infrastructure geared towards helping drivers, all will benefit.

- *Legacy System Integration:* The integration of blockchain with existing financial infrastructures and regulatory frameworks presents significant challenges. Many transportation and logistics companies rely on older, established systems. Integrating blockchain technology with these legacy systems could be complex and costly.
- *Integration with Other Technologies:* Blockchain is one of the emerging technologies. There is no doubt that our future society will be increasingly interconnected digitally. Therefore, integration with other technologies including Internet of things (IoTs), artificial intelligence (AI), machine learning (ML), big data, deep learning (DL), edge computing, cloud computing, 5G, and quantum computing are paramount. These technology integrations are applicable across fields.
- *Adoption:* The need for industry-wide adoption presents its own set of challenges. The network effect of blockchain means that its benefits are maximized when widely adopted. Convincing all stakeholders in the transportation ecosystem to adopt the technology is no small feat. Investing in education and research is crucial to understand blockchain technology and its potential applications.
- *Energy Consumption:* Energy consumption is a concern for some blockchain networks, particularly those using proof-of-work consensus mechanisms. This could conflict with companies' sustainability goals.
- *Standards*: The absence of industry-wide implementation standards presents another obstacle to the use of blockchain technology in transportation. Blockchain technology requires appropriate standardization and governance for it to operate. Many of the required standards are currently in early stages of development, representing few established and agreed-upon standards; and thus limited structured governance. IEEE and ISO represent industry, governmental, and other stakeholder bodies; private industry associations have also sought to set standards. The Blockchain in Transport Alliance (BiTA) has its own standards group for transportation and logistics. As organizations like BiTA continue to grow in membership and influence, it will become increasingly important for universal standards to be both created and adopted by member organizations.
- *Ethics:* There are various ethical concerns with blockchain technology. Open information, building consensus, access and inequity, security, and governance each have aspects that influence ethical concerns. Supporting ethical conduct can also be a goal of blockchains. Another ethical aspect is that blockchains may also be subject to accessibility concerns.
- *Sustainability:* Sustainability is a major cross-cutting theme in future mobility in transport and logistics. One major sustainability concern with blockchain and most digital technologies is the amount of energy needed to operate them. Although there may be efficiencies and optimization in energy trading and other efficient mechanisms offered by blockchain; a major concern is the amount of energy required to manage the distributed ledger system and proof-of-stake and proof-of-work.
- *Expertise/Skills*: Blockchain expertise is not easy to find. Once promising use cases have been validated, organizations should strive to educate or hire tech-savvy and quick-to-learn individuals who can understand new applications in context, instead of only trying to recruit blockchain experts. In addition, organizations should seek collaboration with academic and specialist technical institutions in order to help shape the technology research and development agenda and gain access to key expertise.

CONCLUSION

While still in its early stages of adoption, blockchain is drawing attention for its possible applications in an industry ripe for digital transformation. While the potential of blockchain in transportation is significant, it is important to approach it with measured expectations. Its true impact will only be realized through careful testing, gradual implementation, and industry-wide collaboration. Blockchain's influence on the transportation industry is going to keep growing.

Although the blockchain technology is still in an early stage, it is an absolute game changer. Its future in the world of transportation is bright, with the potential for higher revenue, efficient operations, and better fleet management. We still have several years to go before it becomes an integral part of our daily operations. However, once the technology is adopted and

standardized, it will affect the transportation industry in various ways. More information on the integration of blockchain technology into the transportation industry is available from the books in [18-21] and the following related journals:

- *IEEE Blockchain*
- *Transportation Research Procedia*

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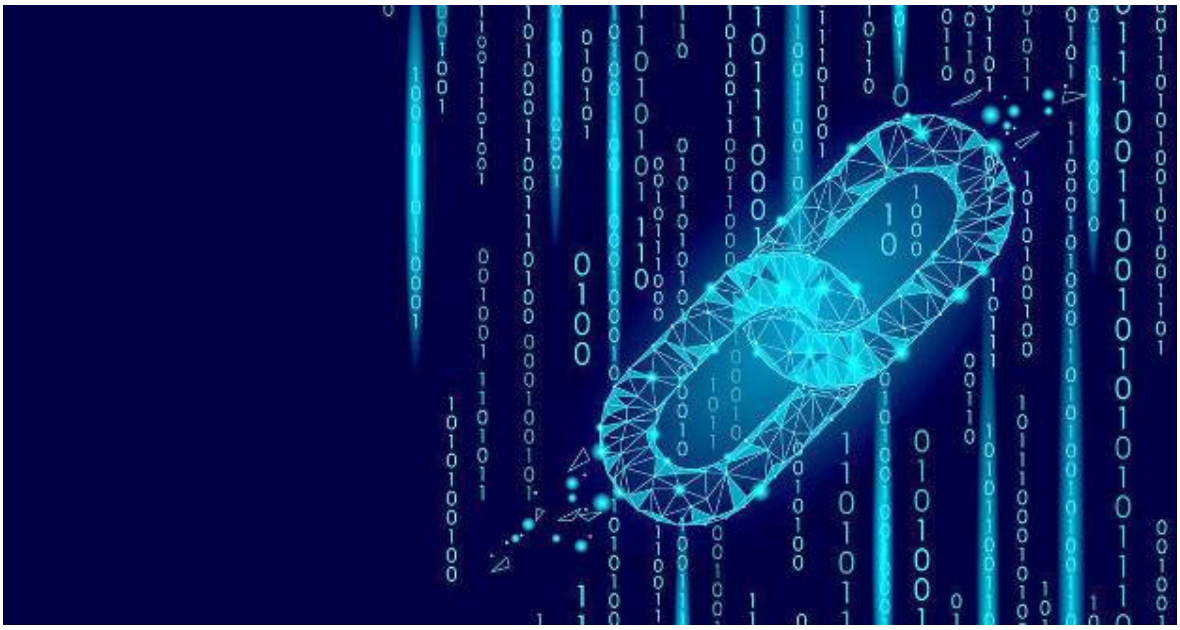

Figure 1 The symbol of blockchain [2].

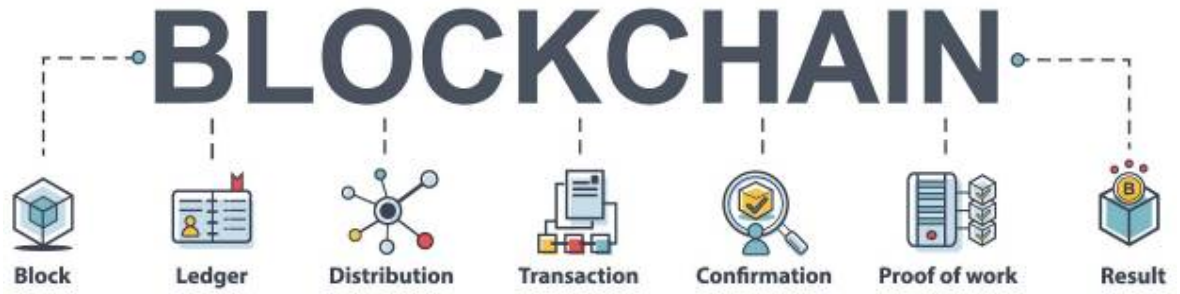

Figure 2 Different components of blockchain [6].

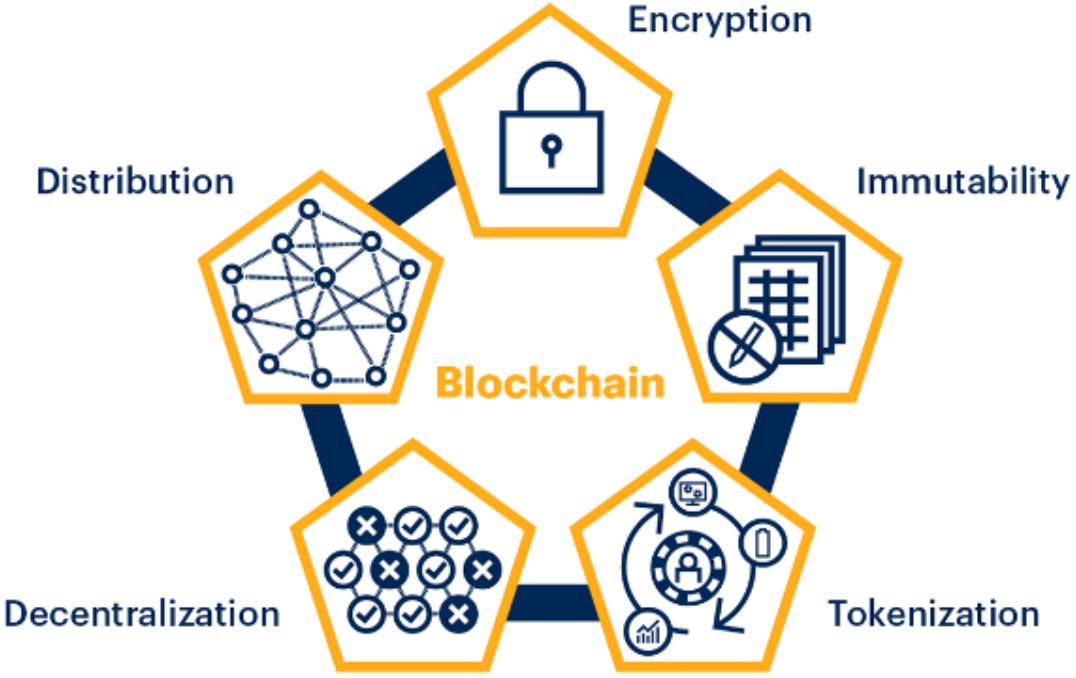

Figure 3 Five key elements of Blockchain [7].

Figure 4 Bitcoin [8].

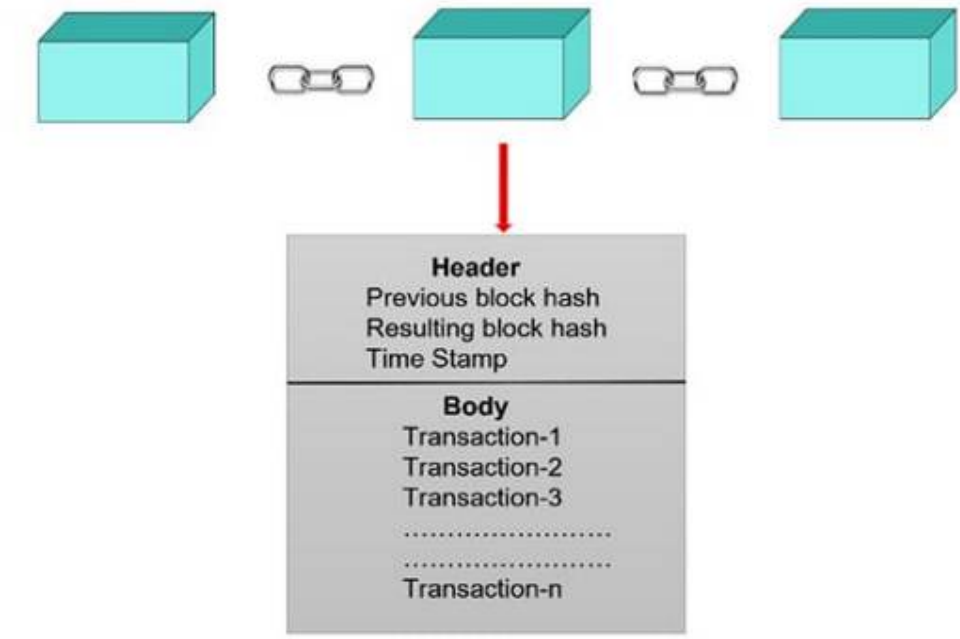

Figure 5 How blockchain works [9].

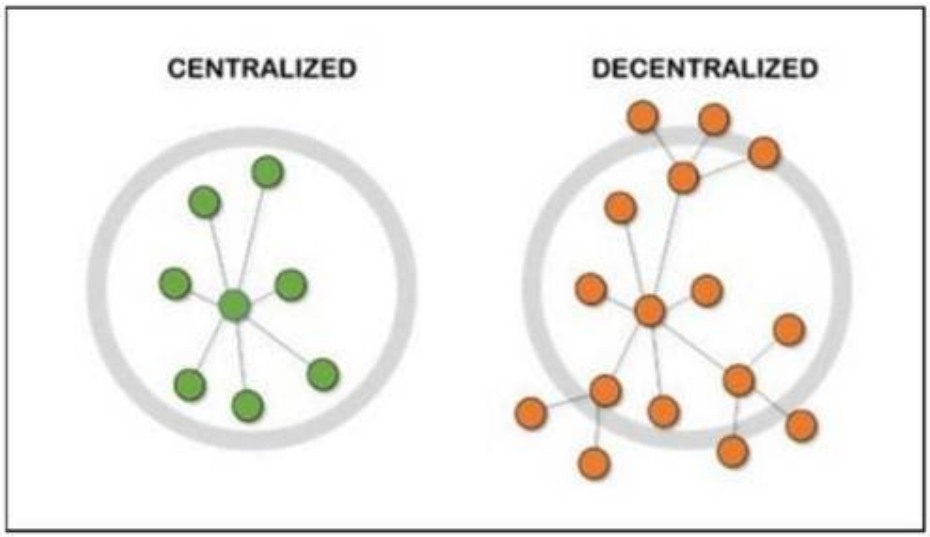

Figure 6 The decentralized property of blockchain [9].

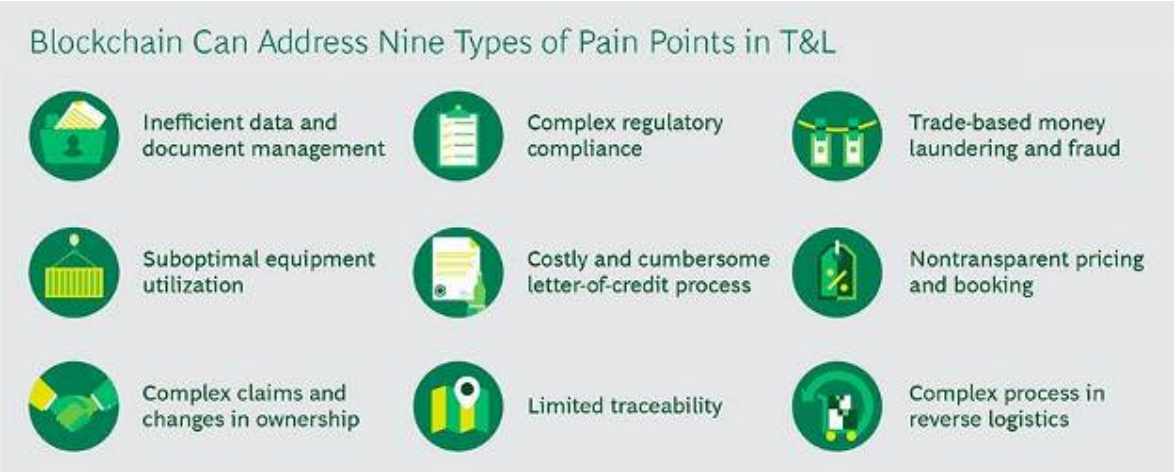

Figure 7 Blockchain can address some pain points in transportation and logistics [10].

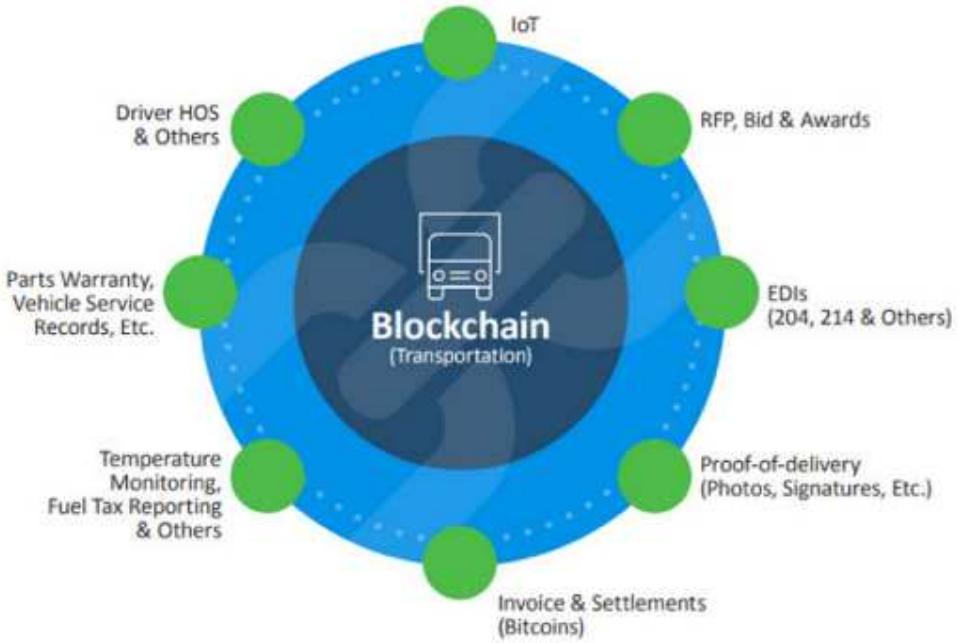

Figure 8 Transportation applications of blockchain [11].

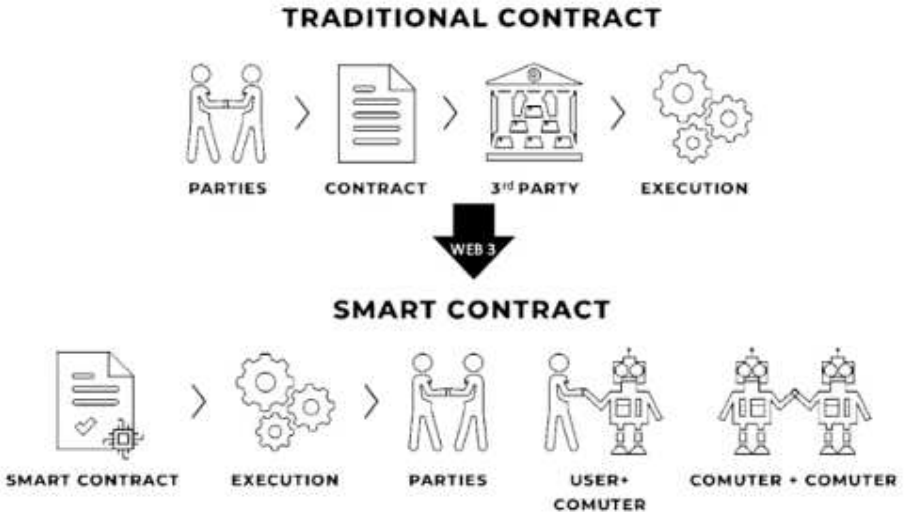

Figure 9 Comparison of traditional contracts with smart contracts [15].