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Overcoming the Technological Barriers in the Blockchain Supply Chain for Small Carriers

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Abstract: The current trend in supply chain development requires the application of new knowledge to meet the challenges posed by new technologies. One such technology is blockchain, which facilitates supply chain solutions through the use of innovative data transfer, storage and verification systems. However, the use of blockchain can be challenging for certain stakeholders, such as small carriers, who may lack the necessary technical expertise or access to the technology. In this paper, we explore the potential for engaging small carriers that provide services within the blockchain supply chain but face technological barriers. We identify the technological barriers and opportunities for these carriers to participate, focusing on a case study of a small carrier that transports temperature-sensitive cargo. As one of the innovations, we proposed a classification according to 3 types of control levels, which are of fundamental importance in blockchain applications. In addition, we tested in-vehicle temperature measurement for use in cold chains and stored the transaction in a distributive ledger application in blockchain.

Keywords: blockchain; supply chain; technological barriers; small carriers; technology

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1. Introduction

In 'today's globalised and digitised world, we rely heavily on third-party entities to make decisions, act, and interact. Trust is crucial in such interactions. While the Internet was about digitising information and social media was about digitising communities, blockchain technology was developed to digitise value and create a decentralised network for transferring value without depending on trusted third parties. In the absence of blockchain technology, digital continuity cannot be guaranteed without the involvement of a trusted third party. Anyone could easily copy and paste data, making it difficult to track changes. However, with the advent of blockchain technology, it is now possible to ensure data authenticity and continuity without relying on trusted third parties. [1]. Blockchain is thus suitable in such cases where users need trusted record keeping (the necessity of keeping a complete history of data) without the involvement of a centralised authority. Instead of this authority, a P2P network takes control of the shared data [2]. Blockchain technology became the most famous mainly because of cryptocurrencies, which brought an alternative way of financial operations or applications to a greater extent. The typical representatives are financial operations based on cryptocurrencies such as Bitcoin, Ethereum, and similar products [3]. Cryptocurrencies play a significant role in the blockchain. Cryptocurrency is a virtual currency that, like real-world currency, is used as a medium of exchange between users. However, the main distinction is that cryptocurrencies are not controlled and regulated by any central authority [4].

The exchange of financial assets (finance) through cryptocurrencies is not the only application area of Blockchain technology. Many blockchain platforms allow decentralised financing, which is more flexible than conventional centralised financing, bringing benefits but also limitations [5]. Currently, other non-financial applications that can be operated on this technology are also interesting [6]. Blockchain technology can also work on the principle of tokens. A digital token is a tool that allows users to exchange verifiable data in different ways. Tokens within the Blockchain allow for a programmable representation of digital assets. Token units are meant to serve as digital coins. Transferring token units means removing or debiting funds from the sending account balance and adding or crediting them to the receiving account balance [7]. Blockchain has gained a lot of attention with its architecture, specific features (immutability of data once stored, real-time data sharing, distribution, decentralised, etc.) and especially the ability to store, keep and share any data (not just finance). Many researchers have researched the areas in which this technology can be applied. Several authors have conducted a review of Blockchain applications [8–12]. They have demonstrated that the range of applications is extensive. For example, healthcare (health records, verification of 'doctors' qualifications, telemedicine), government (smart city, voting, education, property management), area of autonomous vehicles, AI, machine learning, big data, maintenance (together with digital twin), and supply chain.The energy sector could be one of the industries most affected shortly [13]. However, as this technology is based on data sharing, we must point out that each area must be entirely digital and operate based on the Internet. Therefore, one of the main areas of implementation is the Internet of Things (IoT).

Our paper focuses on the area that can benefit the most from Blockchain implementation: the supply chain. Several stakeholder groups are somehow involved in the supply chain process. There are the manufacturers who supply the original product. There are the carriers who transport the product, the warehouses that store the product and the final points of sale, where the product reaches the customer. Specially for a specific type of carriers that are not equipped with a technological background, however, getting involved in blockchain may pose a problem. Therefore, it is important that the ecosystem itself is created universally for all potential stakeholders. Hence, various parties in a supply chain need to trust each other, even if they 'don't know each other. However, the interactions between these parties can often result in high costs, loss of trust, long delivery times, excess consumption, environmental pollution, etc. This is where blockchain can be beneficial. The main aim of the supply chain is to ensure that the original product reaches the end customer in the best possible quality. Achieving this is a challenge for all intermediate links in the supply chain, especially for a cold supply chain. In 'today's fast-paced world, faster dissemination and storage of information is required in the transport sector of perishable foodstuffs. It is essential to monitor the temperature in every part of the foodstuff supply chain to maintain the health and safety of humans and animals consuming it. However, currently, there is no system to keep the information so that it is possible to go back and check it after a certain period. Therefore, there is a worldwide effort to verify food or sources so that their original origin can be identified clearly. Some authors have presented a theoretical way of applying blockchain in tracking food or other goods. Traceability in the food industry has become increasingly important as we strive to improve climatic conditions and health. [14]. One of the crucial features of blockchain in the supply chain might also be the ability to store data from geospacers [15] and simultaneously enable the information flow from various sensors or peripheral devices, e.g., IoT. Our study has made three main contributions. Firstly, we have identified challenges for small carriers (carriers with a limited vehicle fleet, without the ability to send online data from the vehicles, without connecting to an advanced network or system) when transporting temperature-sensitive goods. Secondly, we have identified the different levels of control required in such situations. Finally, we have proposed a universal ecosystem and requirements for storing data on a distributed ledger platform, such as blockchain or similar platforms.

The structure of the paper is divided as follows:

Section 2 discusses the related work focused on the analysis of blockchain technology studies, devices for data acquisitions, and supply chain applications linked to Blockchain; Section 3 presents the materials and methodology we applied to the case study described in Section 4; Section 4 presents the case study of measurement of the temperature of a vehicle intended for the transport of temperature-sensitive goods. Section 5 discusses the outcomes and future work.

2. Related Work

2.1. Blockchain Technology

Blockchain technology is not a single concept. It combines several concepts, such as cryptography, mathematics, networks, consensus principles, and algorithms [16]. The idea was first mentioned in the context of the cryptocurrency Bitcoin. Satoshi Nakamoto [17] proposed the concept of a decentralised digital currency, Bitcoin, supported by a decentralised payment system. This concept allows peer-to-peer (P2P) transactions without a centralised authority. Bitcoin and all other current cryptocurrencies are based on Blockchain technology. Blockchain is a fully distributed system for cryptographic recording and storing a consistent, immutable, linear record of transactions between network participants. Functionally, it resembles a distributed ledger consensually managed, updated, verified, and validated by individual participants of all transactions executed [18]. Komalavalli et al. [19] consider blockchain a digital data storage concept. Where data can be, for example, a list of transactions, documents, or other valuable data that can be recorded, this data is stored in blocks. Blockchain is thus the concatenation of consecutive blocks of transactions. Further, the authors [20] defined blockchain as follows: a distributed database shared and agreed upon in a peer-to-peer network. It consists of a linked sequence of blocks that store time-stamped transactions encrypted with public-key cryptography and verified by the network community. Once a block is added to the blockchain, it cannot be changed, turning it into an immutable record of past activity.

As mentioned above, the basis of blockchain technology is distributed ledger technology [21]. This provides a mechanism for verifying consensus through a network of computers. Such a network can also be referred to as a blockchain network. It is an interconnection of many computers, each with a copy of the ledger. A network formed in this way allows transactions to be carried out more easily and quickly without needing an intermediary or centralised authority [19]. Blockchain consists of blocks with a growing list of executed records (transactions). It is thus a continuously emerging chain of blocks. The blocks are linked using cryptography and hashing functions to prevent data tampering. Since all the blocks are decentralised and distributed, it is impossible to change any block without affecting all the others [22]. After successfully executing the data transactions, the valid transactions are encrypted and encoded into the Merkle tree in the block. New blocks are added to the chain so they do not overwrite the old ones already added but are appended to them [23]. The system works by distributing a copy of the database, or a partial copy, to each party. That party can then change the database according to mutually agreed rules. The changes made by each party are collected and stored in the database in blocks at regular periods [24]. If some participant wants to add a transaction to the ledger, the transaction must be shared on a peer-to-peer (P2P) blockchain network. All members keep a copy of the ledger. It is verified because participants sign transactions using public and private key cryptography before sharing them on the network. Therefore, only the owner of the private key can initiate them. Participants can be transparent while remaining anonymous because keys are not associated with real-world identities [25].

Blockchain technology presents the following advantages: anonymity - the blockchain is anonymous and can be freely connected, which means that individual parties can communicate freely. Data immutability - once data has been sent, it cannot be changed. At the same time, guarantees of integrity are not provided by a centralised party (authority, entity, etc.) but by the consensus of the entire network. Non-censorship - since the stored data cannot be changed, removed, or replaced, censorship (as in a centralised system) cannot be applied [26]. Real-time records - the blockchain is updated whenever a transaction (adding a block to the chain) is executed. This process is automated. Transparency - every participant of the blockchain network has access to the same data, providing a single source of truth [21].

Many blockchain platforms are trending right now, e.g. Ethereum (ETH), Binance Smart Chain (BSC), Cardano (ADA), Polkadot (DOT), Solana (SOL), Chainlink (LINK), Tezos (XTZ), Avalanche (AVAX), Algorand (ALGO), etc. In addition, there are various distributed ledger technologies similar to the blockchain (such as Hedera based on the hash graph [27], which differ in their consensus mechanisms, structure, scalability approaches, fairness, security models or other characteristics [28,29].

Many blockchain platforms with different features can be used in the supply chain. There are also significant differences in transaction per second (TPS)—currently, Ethereum processes around 15 transactions per second. Meanwhile, Solana processes more than 2,600 transactions per second due to its unique consensus mechanism. This is comparable to Bitcoin, which can make about 7 TPS. Polygon achieves up to 7,000 TPS speeds while still being fully compatible with the Ethereum ecosystem. However, the Hedera network can process up to 10,000 TPS, which makes it one of the fastest blockchain platforms in the market. In blockchain technology, the primary method of ensuring the integrity and security of transactions is through cryptographic proofs [30]. The main types of proofs used in Blockchain are Proof of Work (PoW) [31] and Proof of Stake (PoS). There is also the alternative PoS consensus. Proof of History (PoH) is a concept associated with the Solana blockchain [32]. It is not a typical consensus algorithm but works with the primary consensus mechanism, Proof of Stake (PoS).

From our perspective, we see the problem that new blockchain platforms are constantly emerging with specific characteristics. Most of the academic work focuses on their description, but applications, but there is little work that addresses the integration of multiple distributed ledger platforms, which will be critical for the supply chain space.

2.2. Devices for Data Acquisition

Currently, several devices are enabled to collect various data with the help of sensors [33,34]. The trend is to create a sensor network and use different end devices that will be connected, e.g. IoT. The Internet of Things is generally related to scenarios in which network connectivity and computing capabilities are extended to objects, sensors, and other items that are not considered computers, allowing these devices to generate, exchange, and consume data with minimal human intervention [35]. Connecting physical things to the Internet enables remote sensors to access data and control the physical world remotely. Combining recorded data with data obtained from other sources (e.g., on the web or other devices) creates a new synergistic service-providing approach. Such a system does not work only with isolated data; this is the essence of the Internet of Things. The basis of IoT is a bright object (it can be any device that records data), also called an Internet-connected built-in system [36]. A significant requirement of IoT is that things (intelligent objects) on the network must be interconnected. The IoT system must bridge the gap between the physical and virtual worlds. System extensibility, interoperability, and scalability should be considered in the design of the IoT architecture. As things (intelligent objects) can move geographically and need to interact with other devices in real-time, the IoT architecture must also be adaptive. Moreover, IoT should be decentralised and heterogeneous [37].

Some current processes, which are implemented within the framework of closed business systems, already produce data with which they monitor the development of process production and thus have an overview of the state of the process itself. Therefore, the use of sensor networks is not unusual, and the advance of the industry to INDUSTRY 4.0 will also depend on them [38]. Such a created sensor network has the prerequisites for further expansion with a blockchain element. Any sensor network also relies on data transmission, storage and processing security. From this perspective, blockchain can be a suitable technology for processing and storing secure data. In reality, there are many systems that collect data, but they are closed, don't share it anywhere, and usually only have a function for a specific stakeholder who uses it for decision making. This is also the case for transport companies, which collect transport data internally, but it is not publicly available.

Current research tends to focus only on data automatisation, transmission and linking. Still, there is a lack of studies looking at data from devices that are not connected to the network, do not allow data transmission, etc. This is in line with the fact that some data collection devices only work offline or only in a mode where the user collects the data and does not share it anywhere, which remains a problem. This data also has value, and it is essential that it can become part of different processes.

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2.3. Applications in the Supply Chain

One of the most exciting challenges in the field of blockchain application is the supply chain. There can be separate technology already in production, shipment tracking, quality control or other parameters, and payment. In theory, blockchain technology can have various applications in the supply chain. Successful integration of blockchain technology in supply chain management necessitates cooperation among all involved parties and the establishment of suitable legal and regulatory structures [39]. Azzi et al. [40] presented the benefits of blockchain in the supply chain. The literature review from the management integration perspective is given [41].

Several authors presented theoretical models. Helo a Hao [42] developed a Blockchain-based Logistics Monitoring System (BLMS) prototype. The purpose of the BLMS was to provide a solution to track packages and give an open and immutable history record for each transaction within the supply chain. Caro et al. [43] proposed AgriBlockIoT, a decentralised Blockchain-based traceability solution for agri-food supply chain management that can integrate IoT devices. The proposed system could give consumers a complete overview of their food from farm to consumption. The system can be integrated into existing systems (ERP, CRM, etc.). An interesting concept has been proposed by Amin et al. [44]. It is about Blockchain-based supply chain management and smart contracts for e-agro business systems. The basis of the proposal is an open platform for suppliers and buyers where they can negotiate prices for goods. In addition, tracking and tracing of goods is possible by deploying IoT sensors and devices and the smart contracts used. There are already supply chain traceability systems based on blockchain [45,46]. However, these do not account for the change (transformation) of goods in the production processes. This significantly complicates the traceability of the origin of the goods unless the change in the structure of the original goods is assumed. Therefore, the authors [47] proposed a Blockchain-based supply chain management system that enables tracking and tracing goods, including their transformation (change) in the production process using smart contracts. In smart contracts, manufacturers define the composition of products in the form of recipes. Some studies deal with real-world use cases of Blockchain technology in the supply chain. Varavallo et al. [48] proposed a platform based on Algorand Blockchain [49] designed to track and trace the supply chain of Fontina DOP cheese. Supply chain operators record all transactions but send data in JSON format to the Alogrand platform only at the packaging stage. This reduces energy consumption, resulting in minimal environmental impact and cost reduction. The platform has been tested and validated in dairies in the Aosta Valley in Italy. The authors claim that the proposed architecture and design can be applied this platform to any other dairy supply chain. Another study [50] describes another actual use case for blockchain. This pilot project aims to track and trace eggs from the farm to the consumer. Consumers can scan a QR code and gain access to information about the entire supply chain. The system is based on IoT technology. They are already proven business solutions linked to companies such as IBM [51] or AMAZON [52]. An essential part of the supply chain is the shipping process. Especially in the cold supply chain, monitoring the required temperature during transport is necessary. SkyCell has created air freight containers based on IoT and Blockchain technology to transport goods under controlled temperatures. The solution is that an IoT device is placed in each container, which allows real-time data to be captured. This data is then stored in blockchain and visible to all participants in the supply chain. Supply chain actors can react to temperature changes in a short time and thus prevent the goods being transported from spoiling [53].

In conclusion, there are many studies on different applications, models and areas where blockchain can be used. Reviewing the research papers, we encountered a shortage of peer-reviewed studies that addressed small carriers regarding the barriers preventing them from using blockchain technology. The research gap we have noticed pertains to the following facts. Multiple blockchain technology platforms have developed applications for the supply chain. Nevertheless, authors frequently prioritise theoretical possibilities while neglecting to address real challenges and impediments that potential stakeholders are likely to encounter. Our primary emphasis was on technological obstacles, which were not thoroughly elucidated in the examined studies and were predominantly addressed only superficially. Hence, our research primarily concentrated on the matter of small carriers, which we believe to be a significant subset of stakeholders who could be impacted by prospective engagement with blockchain technology.

3. Methodology and Materials

The approach comprises the subsequent steps. Initially, we examine both public and private networks with regard to supply chains and small carriers. Next, we address the issue of varying control requirements for different types of supply chains. Finally, we provide an illustrative case study in the last phase. This section presents the differences in control that result from the availability of different technological systems in the supply chain. This is linked to the issue of private and public networks, which has implications for the way in which actors or stakeholders in these networks cooperate together. Therefore, we discuss the differences from the perspective of different data control levels for various stakeholders. The last section presents a case study of measurement in an isothermal vehicle and data verification in a blockchain-based platform.

An essential question in the supply chain is whether to prioritise a private or public network [54]. Private and public blockchains differ primarily in their accessibility, governance, and level of decentralisation, which are key factors influencing their use in the supply chain.

Regarding accessibility, public blockchains are open and permissionless networks, meaning anyone can participate, transact, and validate transactions without needing approval. Private blockchains are permissioned (a network with restricted access for authorised entities) networks that restrict access and participation to specific entities or members. Governance in public blockchains is typically decentralised, with decisions made through consensus mechanisms involving many participants. Changes to the protocol or network require agreement among most of the network. Governance in private blockchains is centralised or semi-centralised, with a governing authority or a consortium of entities controlling decision-making processes [55]. Changes can be implemented more swiftly and are subject to the rules established by the governing entity or entities.

In summary, public blockchains are open and decentralised networks accessible to anyone. In contrast, private blockchains are permissioned, centrally governed networks with restricted access tailored to specific use cases and 'participants' needs. Therefore, a private network is meaningful within a closed chain, where there is no need for the interaction of external stakeholders. Such a private network can set its own rules, representing, for example, the current quality standards of a specific product or process. Therefore, they are more suitable for the supply chain. From this perspective, private companies will find it easier to create private networks with their own rules or standards to follow.

Traditional supply chain management (SCM) is based on classical product ordering and control through people (see Figure 1). On the other hand, decentralised SCM makes decisions based on data stored in the ledger.

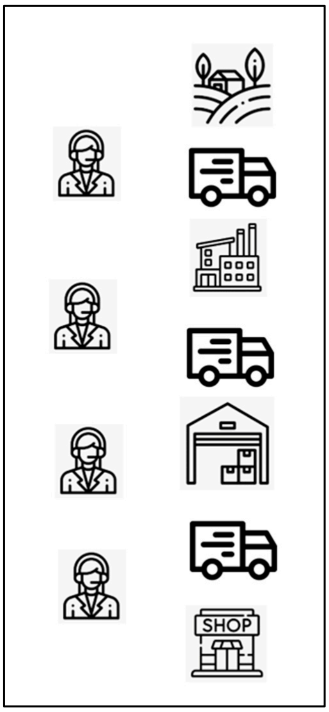

Figure 1. Human control within the process of transport or delivery.

In contrast, blockchain technology can save time, increase credibility, and protect data, all automatically, to minimise human intervention in processes such as ordering, issuing a bill of lading, invoicing, etc. Human interaction and intervention will only be kept to a minimum; see Figure 2.

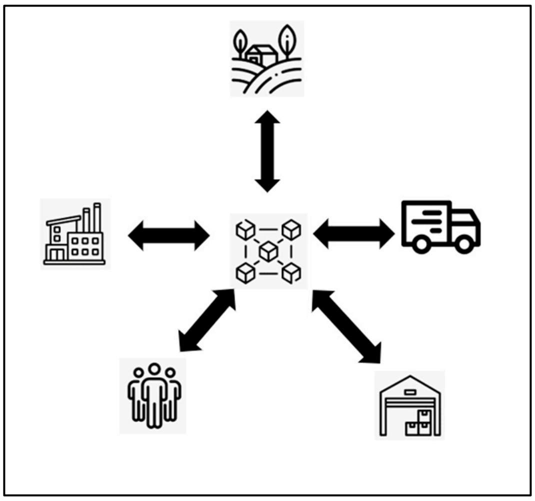

Figure 2. The decentralised supply chain based on the blockchain.

With the deepening of globalisation, the supply chain of modern enterprises has become fragmented, complicated, and diversified. This also brings great challenges to supply chain management. The most significant example is the food safety problem. Once food pollution occurs, tracing back to the source takes a week or even longer. Food producers or retailers are likely to pay a heavy price. This situation leads to the opacity of the supply chain, which is more likely to drive up operating costs [56].

If it were possible to create blocks for individual activities in the supply chain that could be checked in real-time, this would make it easier to control and find the culprit of spoilage. Also, if the goods were not perishable but, for example, high-value goods that must be transported at a specific temperature and humidity, it would be possible to store and control these records continuously. The blockchain application would also be very suitable for transporting pharmaceuticals, which must be transported under controlled temperature and humidity [57].

If a stakeholder is interested in applying blockchain within their supply chain processes, the process must be set up correctly. First, it must prepare the methods for transferring data from the sensor network (e.g. IoT or private network) to the blockchain. He also needs to know what platform and authentication he will use. A consensus must be reached between the various stakeholders. It is quite likely that different types of platforms will be used in the future, so it will be necessary to ensure compatibility between them.

Levels of Controls

The logistics and supply chain industry faces a challenge due to the involvement of numerous companies, each with different roles, services, and levels of technology and information management. This results in variations in quality control and data collection processes. We have proposed the primary levels of controls.

1. Manual control

The first level of goods transportation involves manual measurement and control of the temperature and other conditions during transportation. This information is only accessible to the responsible organisation or the carrier itself (Figure 3). A responsible person publishes the report. Small carriers usually provide such a level of control with limited budgets and access to technology.

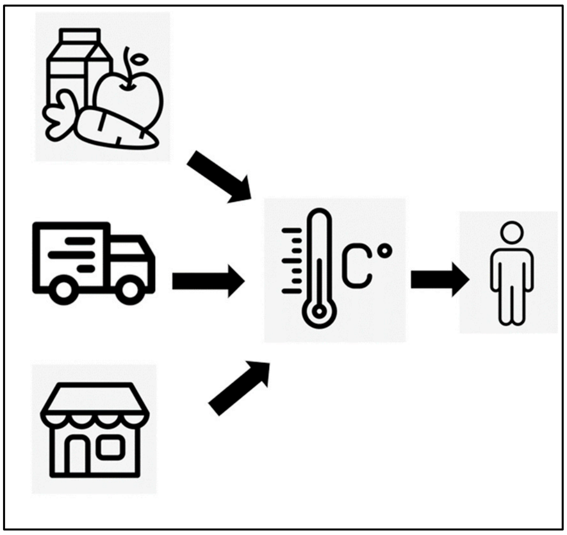

Figure 3. Manual temperature control of goods.

2. Semi-manual control

The second level involves creating a comprehensive system that can automatically collect temperature data, transmit it to relevant parties or store it in a central database. The system can also monitor the temperature within the vehicle as per the requirement, track its location, or monitor other parameters (Figure 4). However, human intervention is still required to check the database and enter instructions.

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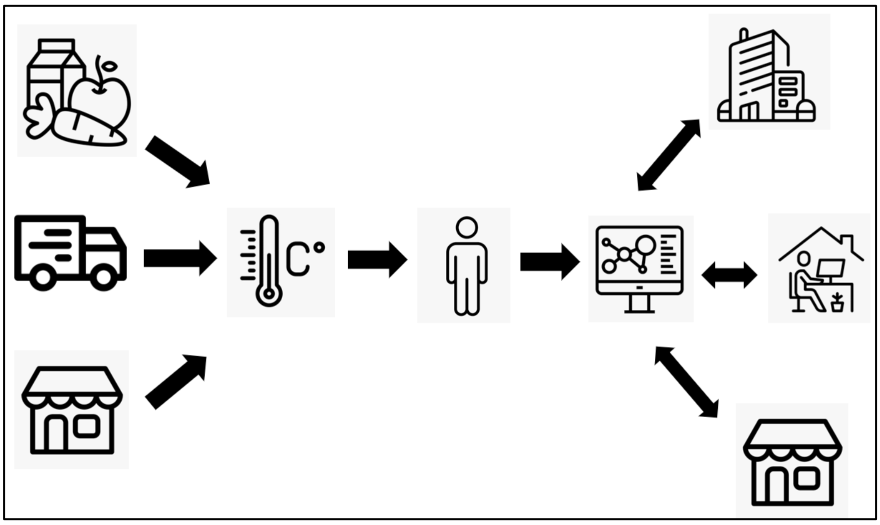

Figure 4 Semi - Manual temperature control of goods

3. Automatic control

The third level of automation allows for temperature control without any human intervention (Figure 5). Creating a sensor architecture that can automatically evaluate and provide instructions based on the data collected is possible. This data can be securely stored using blockchain technology, providing stakeholders with trustworthy data on which to base their actions. Companies with well-established systems of automation and sensor networks typically use this type of control.

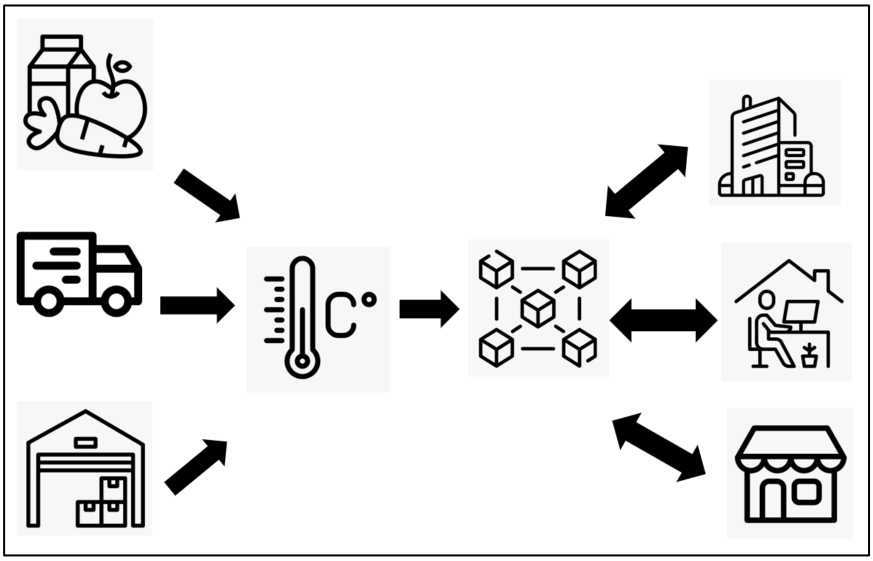

Figure 5 Automatic control within the blockchain

The following table compares the key aspects of control. Manual control will have lower operational costs than semi-automatic control, which results from the fact that there is no need to create an operational and capital-cost-intensive sensor architecture. Stakeholders who do not need to share temperature data will only prefer manual control. On the other hand, automatic control is more relevant for stakeholders involved in a supply chain where data sharing is required and meets other criteria.

Table 1. Comparison of various aspects of control.

Factors	Manual	Semi-manual	Automatic
Operation cost	Low	Medium	High
Human intervention	High	Medium	Low
Technology dependence	Low	Medium	High
Data Sharing	Low	Medium	High

It is essential to acknowledge that many transport operators still do not use modern technologies to ensure online data accuracy and control of transport conditions. This is due to various barriers that prevent them from utilising new technologies or existing sensor networks. For small carries, the following are identified as the main barriers:

- lack of access to technology,
- motivation to use new technologies,
- insufficient financial resources to upgrade equipment or technology,
- ignorance and mistrust of new technologies,
- lack of transport standards.

4. Case Study: Measurement of the Temperature of a Vehicle Intended for the Transport of Temperature-Sensitive Good

Sequencing all activities is vital during the transportation of perishable food items. In areas where refrigeration or freezing is necessary, constant monitoring is crucial. Hence, temperature monitoring is the most accurate method, and subsequent traceability data storage is easy to maintain in this part of the supply chain. However, measuring the temperature of goods directly loaded onto a transport vehicle from the point of production or manufacturing (e.g., orchards) where pre-cooling of the area is not required may cause a problem. Additionally, there may be issues during transportation or unloading from the vehicle. Strict adherence to honesty, trust, and quality standards is necessary throughout the supply chain process. Several regulatory bodies have established rules and regulations to increase the openness, safety, and quality of the traceability system of the supply chain. The system uses barcodes to identify the 'products' country of origin [58].

The current practice is to use telematics systems installed in vehicles during manufacture to monitor the temperature during transport. However, this is not always possible for all goods that are transported. Semi-trailers used for road transport must have temperature control devices to ensure the temperature progression is minimally affected after transport. Unfortunately, this data is not permanently stored online, making it challenging to identify the cause of spoilage or contamination. Most warehouses and loading bays are designed for loading and unloading goods. The Figure 6 below shows the activities performed throughout the supply chain, with the left column displaying the activities and the right column showing how temperature monitoring is performed at each point.

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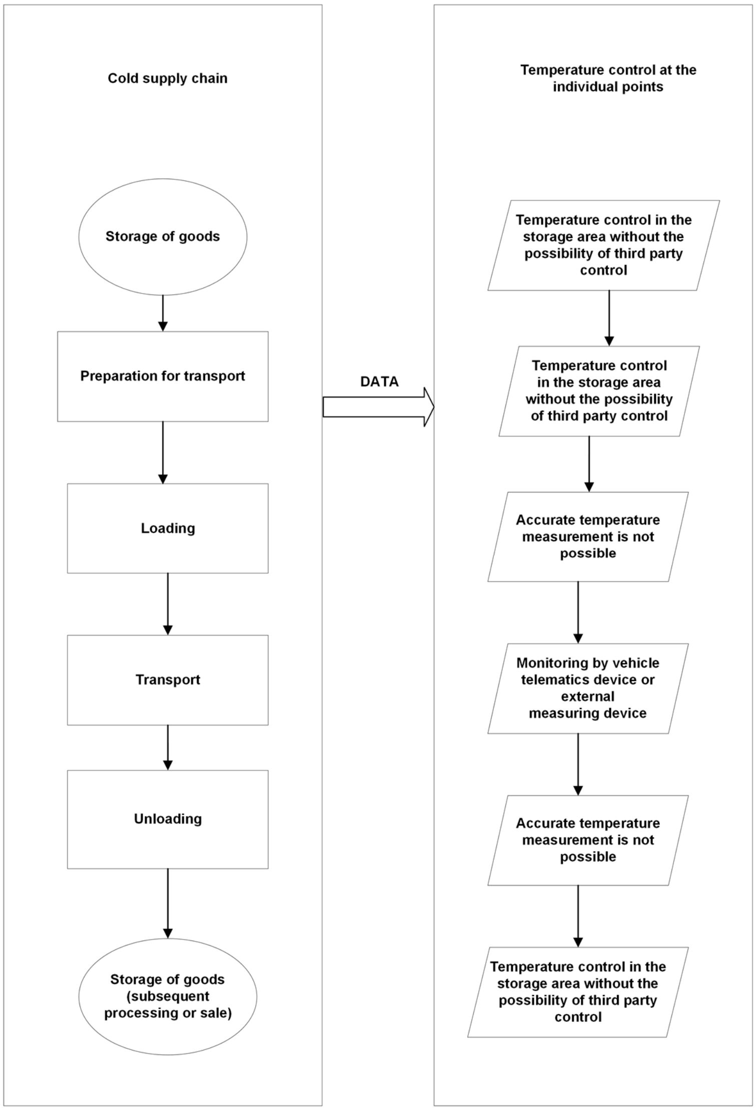

Figure 6 Automatic control within the blockchain

Perishable goods pose a challenge in the supply chain as the loading and unloading process generates significant heat transfer. Additionally, accurately recording temperatures at these points is nearly impossible. While semi-trailer storage areas are equipped to isolate the outside environment from the vehicle and warehouse area, the same cannot be said for delivery vans. A datalogger must be placed directly on the goods or pallet to ensure temperature control.

Temperature measurement in transport differs between semi-trailer combinations and smaller vans. Maintaining the desired temperature in vehicles with frequently opened and closed cargo doors is challenging. Therefore, it is advisable to equip cars with online monitoring systems that continuously record temperatures. The system should be designed to record temperatures near the doors, the centre of the vehicle, and the refrigeration unit where the temperature is most stable.

When goods are sold or reused in production, the same temperature control measures employed during storage should be applied. For instance, goods that require temperature regulation during transport, handling, or preparation (see Table 2) should have their temperatures measured. This is where blockchain technology can be beneficial.

Table 2. Comparison of supply chain activities and monitoring of temperature during various events.

Supply Chain Activities	Monitoring of temperature	Application of Blockchain
Storage of goods	Full-surface measurement in the warehouse or destructive measurement	Online monitoring and recording in the ""storage of goods"" block
Storage at production sites	Without measurement, e.g. orchard	Temperature measurement and recording when goods are loaded
Preparation for transport	Goods wrapped in the required packaging material previously temperature-measured non-contact or destructively	Temperature measurement and recording when inspecting goods before loading
Loading into the vehicle	During loading, a temperature change occurs in the space between the storage area and the cargo area.	Placing the measuring device on the goods at loading and automatic recording in the ""loading"" block
Transport of goods	Monitoring the temperature of the items being transported in the vehicle	Placing multiple measuring devices and sending the current temperature information to the ""transport"" block
Unloading from the vehicle	Heat transfer occurs between the cargo and storage areas during unloading.	Placing the measuring device on the goods at loading and automatic recording in the ""unloading"" block
Final storage and sale to the consumer or use of the transported raw material to produce other goods	Temperature recording is also required in these areas	Online monitoring and recording in the ""storage of goods"" block

Many transport companies now offer transport services using isothermal vehicles, ensuring that goods are transported under specific conditions. However, a significant issue is the sharing of transport data, as it is often only available to the transport company and not the end customer. This means the data is usually only stored within the organisation or published as reports or certifications for the company that ordered the transport. In this case study, we consider a small carrier that uses an isothermal vehicle to transport perishable foods, particularly dairy products, and milk. The car does not have technology for transmitting data, only industrial temperature gauges. This example of transporting perishable goods is essential in various ways. It is about delivering the goods and ensuring that they maintain the required characteristics. For instance, the quality characteristics of food can deteriorate at high temperatures. Although other parameters, such as spatial tracking, can still be monitored, we have not focused on this aspect in this study.

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4.1. Vehicle and Measuring Devices

In our case, we will model a case where an existing small carrier offers services for transporting perishable goods. It has an isothermal truck and temperature gauges. Control measurements were also carried out to demonstrate the need for more comprehensive and accurate measurements during transport. These measurements were carried out during the transport of chilled foodstuffs. The transport was carried out in a Fiat Ducato Professional van. The refrigeration equipment installed in the vehicle is ALEX Original, Model TRE324. The critical fact is that equipment does not operate independently; it only operates when the engine runs. According to the ATP agreement [59], the 'vehicle's distinguishing mark is FNA - X/ 3-2027. This sign indicates that the vehicle is classified as a mechanically refrigerated means of transport with regular Class A insulation. In this case, the letter X in the distinguishing mark indicates that the vehicle engine drives the refrigeration equipment. The temperature commodity standard requires a temperature range of 3-8 °C.

The following figures show the vehicle in which the food was transported. This vehicle has a dependent refrigeration unit. This means that the refrigeration unit cannot operate independently without the 'vehicle's engine running. It is, therefore, essential to provide a car that can give independent refrigeration for more temperature-intensive transports. Figure 7 shows the TESTO and Hadex control measuring devices we used to control the temperature in the transport compartment. Figure 8 shows the 'driver's monitor, which monitors the temperature in the load compartment (Figure 9).

Figure 7. The control measuring equipment Hadex and Testo H2D.

Figure 8 Adjusting the ALEX Original TRE24 vehicle-mounted refrigeration unit.

Figure 9 Adjusting the ALEX Original TRE24 vehicle-mounted refrigeration unit.

It follows from the above that the small carrier fulfils the primary conditions laid down by the legislation [60] for the carriage of perishable goods. In the case of guaranteeing the required temperature standard, it assumes all the risks that it carries out the transport according to the 'customer's requirements. The disadvantage of this system is that the transport data is not objectively verified and not sent to a central database where it would be available to the customer. This case represents a stakeholder that does not have technology equipment that works with web or cloud-based services to enable data sharing and control by customers.

The Figure 10 shows the temperature trend recorded by the probes installed in the vehicle. The probes were installed in the vehicle at 6:05. From then on, temperature monitoring began. At 6:45, the vehicle started cooling the transport compartment by switching on the refrigeration unit. As seen in the graph, from this point on, the curve had a decreasing character. This zone is marked on the graph as No. 1. In zone No. 2, a concrete transport was performed until 11:47, when the refrigeration unit was switched off. In this part of the graph, we can see the temperature fluctuation. This is because the refrigeration unit is set in the required range from 3°C to 8 °C. However, as we can see in the graph, the measured values are sometimes outside the interval. This is due to the cold air being drawn into this space from the generator set. At points where the data curve approaches or exceeds the maximum set value, the door was observed to open as the unloading operations were being carried out. If a blockchain system were applied in the vehicle, temperature recording would be more accurate as any temperature fluctuations and exceedances would be immediately recorded and evaluated. In Zone No. 3, the refrigeration unit was noted to shut down again at 11:47 a.m. after the transport and arrival to the 'company's headquarters were completed.

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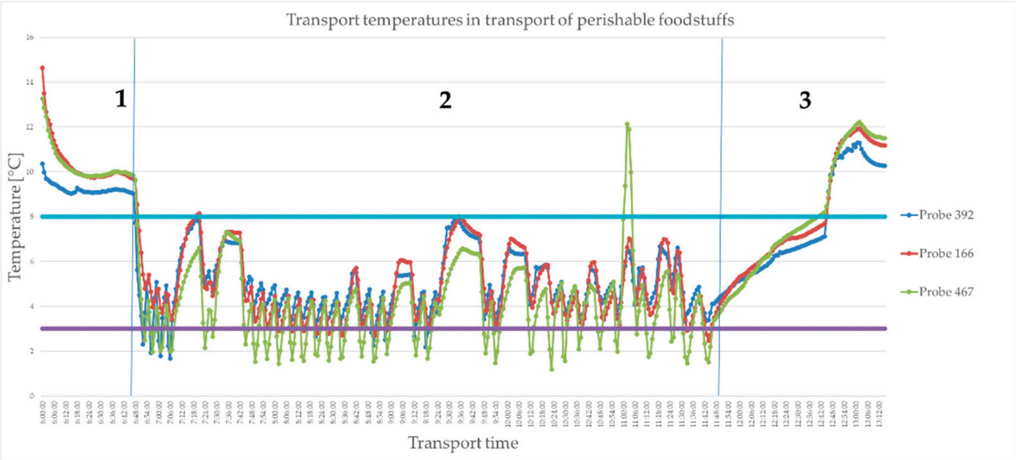

Figure 10 Overview of temperature during the transport process

4.2. The Proposed Ecosystem of Engagement in the Blockchain Platform

From the previous example, it can be seen the biggest hurdle in temperature-sensitive transport lies in the following:

- lack of verification of transport conditions,
- the level of objectivity,
- insufficient technological equipment,
- Processing is based only on traditional procedures and minimum legislative requirements.

To solve this issue, the ecosystem itself will need to agree on all usable and verifiable resources that each group can use. For example, small carriers should use certified gauges. These also can be non-IoT devices that operate outside of online applications.

Large carriers representing the semi-control group, which has built its information technology structure based on multiple sensors and IoT, will also need to certify the resources it uses to perform control and collect data. This means that the authorities responsible for the blockchain network will have to set standards regarding certified inputs, i.e. devices and technology that will be recognised as verified data loggers. Blockchain technology will provide the verification and logic process (see Figure 11).

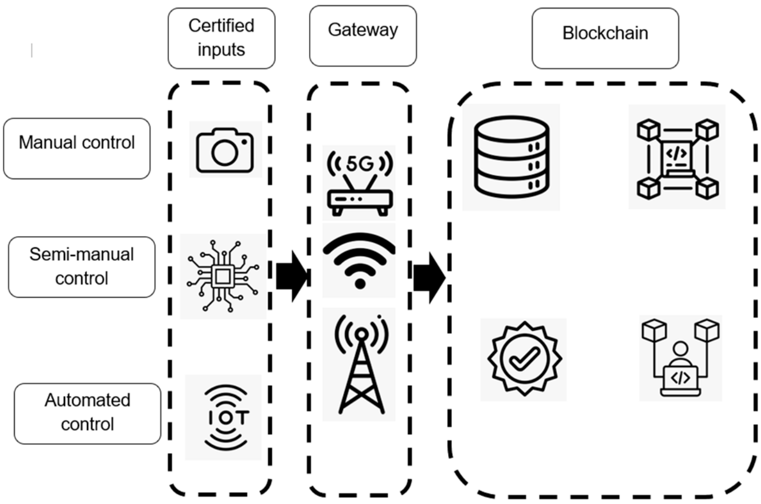

Figure 11 Principe of the data flow from various types of control

The universal ecosystem for the transport of temperature-sensitive goods should consist of the following components:

- Legal requirements set by standards, regulations, etc., for the transportation of temperature-sensitive goods.
- Standards for entry devices and communication gateways that certify entries, considering the level of control available between the different stakeholders. Insufficient technological equipment should also be considered.
- Standards for secure verification in a distributed ledger, such as blockchain platforms and similar systems.
- Establishing process logic and collaboration within the supply chain to ensure effective communication and coordination among the various stakeholders involved.

Various standards, regulations, and international treaties establish legal requirements for transporting temperature-sensitive goods. Entry devices and communication gates for entry certification are subject to minimum requirements, considering the level of control among different stakeholders. Therefore, carriers must ensure they possess the appropriate equipment to transmit data online and measure how they deliver the measured data to demonstrate compliance with the requirements for maintaining the quality of perishable foodstuffs. Standards must be set by professional organisations, self-governing consortia, or specified in ISO standards and new requirements that arise from the characteristics of the blockchain. The idea is that the data cannot be modified, for example, it must have a time stamp or some form of encryption. Finally, we can expect similar devices that the industry will accept as the current IP standard (Ingress Protection), which could be marked as "blockchain ready".

Moreover, standards for secure verification in distributed ledgers outline how verification should occur in blockchain platforms and similar systems. Establishing process logic and collaboration within the supply chain will help facilitate efficient data-driven processes between stakeholders.

This transport ecosystem is open to all potential stakeholders interested in participating. The crucial point is that control through entry facilities standards should be established in advance. This means that requirements will be set from a simple instrument to a sensor network to allow stakeholders from different business groups to collaborate within the supply chain. Similarly, this will apply to the information gateways used to transmit data. The blockchain will be used to verify, store, and execute data. The advantage of this system is that various companies can participate in the supply chain within this ecosystem, even those whose technical conditions do not allow them to procure expensive IoT information systems. The benefit of this ecosystem will be that small carriers who do not have a connection to online data transmission can enter or report the required data via certified devices (e.g. traditional upload via a web interface or a smartphone app). The standards and recommendations will thus guide them to participate in the supply chain using distributed ledgers, such as blockchain.

The ecosystem offers potential benefits to all stakeholders. For small carriers, the opportunity to participate in the interconnected network and attract new customers.

Supply chain consortium authorities need to increase the openness of the supply process as I attract new carriers. Regulatory authorities can exercise regulatory oversight of companies more efficiently and quickly. The tangible supply chain will be more open, unified and frictionless if it is not limited to a single blockchain platform or similar distributed ledger, which may have interesting applications on a global scale.

Multiple options exist for verifying data on the blockchain or similar distributed ledger technology. One option involves storing data while the technology stores it at a specific time interval. In this scenario, the system verifies all data received from the devices. The disadvantages are system overload and the need to confirm all data. The second option will only store the important predefined data based on the required standards. Each data verification and transaction incurs a fee to the system, which can be significant for large transactions. Also, data have to be verified by the consensus mechanism.

The consensus mechanism in blockchain is based on meeting specific criteria, such as maintaining the correct temperature during food transportation. Once this data is confirmed, it is

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stored in a block and can trigger other actions like payment or offering pre-packaged food to customers. The consensus can also be used to create a loyalty program, where companies that meet the transport requirements are favoured for future transport and promoted for their reliability and quality of service. This collective of mirror node operators and users use an application that deals with private or proprietary data but can benefit from the fast processing, decentralised trust, and immutable record provided by a public ordering service.

The blockchain-based consensus may consist of the following steps:

- the client app submits the smart contract/transaction,
- the main net node is checking the necessary information,
- the node provides information to the network,
- the network determines the order and consensus time-stamp of the event,
- the node produces a transaction record that includes a payload, topic, and order,
- the mirror node listens for records,
- the mirror node or nodes analyse transaction details,
- the client app communicates with the mirror node to execute the transaction.

The application process (see Figure 12) consists of two steps: the actual measurement of the vehicle's temperature and a record of the temperature progress, with data on whether the temperature met the requirements or not. Subsequently, the temperature was loaded into the blockchain application and sent for verification in the Hedera platform. The application itself consists of three parts. The first part is the database where the data from the temperature meters are stored. The second part is creating a program in a Linux environment (Ubuntu) where the Hedera program is installed and interfaced with the Hedera testnet. The third part is the official online node of the Hedera network, where the transaction of the sent file is verified.

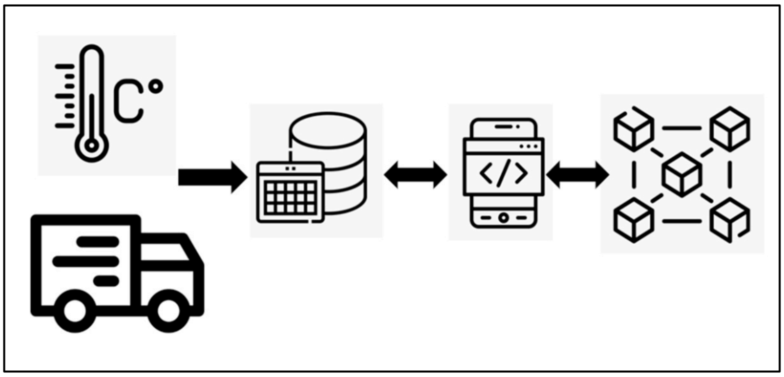

Figure 12 Principle of measuring data processing to transaction into blockchain

4.3. Testing the Blockchain

In our case, this ecosystem is not dependent on only one platform; the aim is to make it universal and usable for multiple platforms. Therefore, the final consensus may differ. The challenge will be enabling data sharing and validation across multiple blockchain-based platforms. In our case study, we have used the Hedera platform with own account. A Hedera account is a discrete entity, a specific sort of item, maintained in the ledger, which is responsible for holding tokens. Accounts have the ability to store three types of tokens on the Hedera network: the native Hedera fungible token (HBAR), custom fungible tokens, and custom non-fungible tokens (NFTs). Stakeholders engage with the network by submitting transactions to alter the state of the ledger or query requests to retrieve data from the ledger. The majority of transactions and inquiries incur a transaction fee, which is denominated in HBAR or another cryptocurrency. While users can generate custom tokens on the Hedera network, the native HBAR token does not have a corresponding token ID. To be able to confirm the transaction each stakeholder should also have an electronic wallet. A basic requirement for the implementation and use of this network is the creation of a user account. The Hedera platform itself enables testing of its network within the so-called testnet. Each stakeholder or player in the

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supply chain should have an account in a distributed ledger platform with a unique Account ID. This ID together with HEX and DER keys are crucial during the processing of the transaction, see Figure 13.

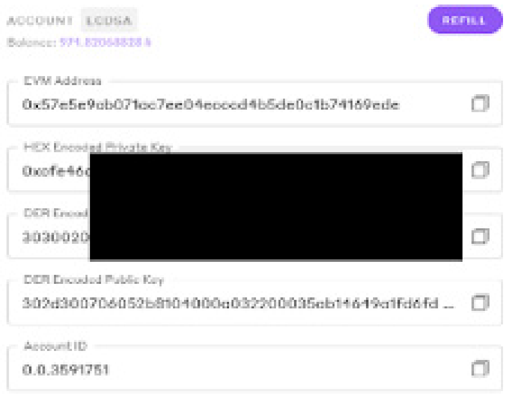

Figure 13 The account information with private and public keys

The transfer information was subsequently verified in the Hedera network, and this information is already stored there and unchanged, see figure.

Since no consortium network was created for supply chain and blockchain in our case, we used the test network of the Hedera testnet platform, where we tested the transaction of the outputs of a file containing information about the required temperature from a vehicle transporting perishable food or temperature-sensitive goods.

The client application will generate a transaction, enabling it to incorporate a message and subject. The message may encompass a particular operation, solely consisting of a hash, or be any other byte array pertinent to the client program. Every application must utilise one or more subjects. The transaction can be delivered to one or more mainnet nodes like other services. The mainnet node will verify that the transaction contains the required information, such as signature(s), payment, and inputs. It will then confirm to the client application that the transaction has passed the precheck stage.

The example output of the file creation in the Hedera network:

- Account Id: 0.0.3994950
- fileCreateTxId: 0.0.3591751@1712681776.049011113
- txExplorerUrl:https://hashscan.io/testnet/transaction/0.0.3591751@1712681776.049011113
- localFileContents: The required temperature during transport was 5.2 Celsius. This is to the requirements.
- networkFileContents: The required temperature during transport was 5.2 Celsius. This is to the requirements.

The transaction is possibly verified in the ledger explorer (see Figure 13); in this case, we have used Hashscan.io.

This example has shown that technologically it is not a problem to apply blockchain technology, rather we see the problem in the necessity to create such an ecosystem also for technologically limited stakeholders (e.g. small carriers), which could be called e.g. blockchain ready after meeting the requirements that will be imposed in terms of the aforementioned standardisation.

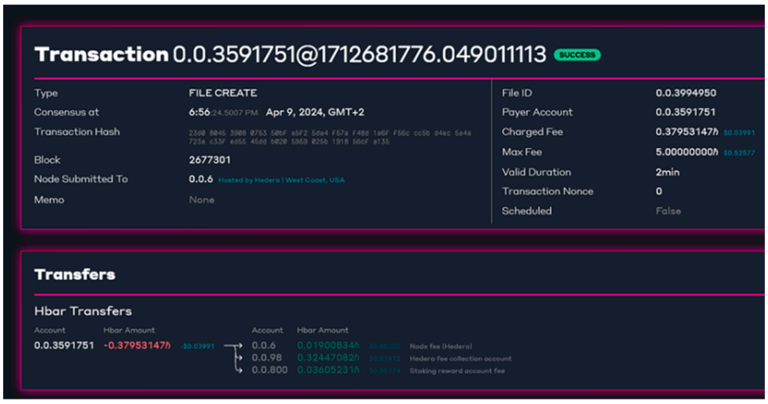

Figure 13 The verification of transaction in Hashscan.io

5. Discussion and Further Work

In our paper, we addressed the challenge of small carriers being responsible for transporting perishable goods and explored the potential of using blockchain technology in the supply chain.

One of the main issues with smaller vehicles performing shorter delivery tasks is measuring and maintaining temperatures in the transport space. We suggest implementing an online monitoring system to retain records for temperature compliance checks to address this. Temperature monitoring equipment directly onto vehicles with a minimum of three checkpoints (at the refrigeration unit, centre of the vehicle, and doors) would allow monitoring of the required temperatures.

Continuous temperature measurement is carried out in the semi-trailer for semi-trailers if the vehicle is equipped with a refrigeration unit and temperature recorder. Telematics devices are also installed in semi-trailers, allowing temperature recording and online monitoring and control throughout the entire transport period. This is the only part of the transport chain where online temperature monitoring is enabled and is accessible to third parties by agreement. Transparency, quick data verification, and decentralised features are desirable attributes for various applications. For example, in addition to managing data quickly, the pharmaceutical industry also evaluates and verifies data from different sensors. Assessing your reasons for developing decentralised applications before choosing an innovative contract platform is essential. Differences in platform features and capabilities could affect the functionality of an app and the tasks that users can perform with it.

We did not focus on security but examined the 'blockchain's applicability in the supply chain. So, what will attract potential stakeholders to use this technology in the supply chain? There is still a gap between scientific and research fields, where blockchain is seen as having potential for the future. However, there is still some distrust among business stakeholders regarding adopting blockchain technology. There are still many areas that will need to be explored in terms of the relationship between blockchain and the supply chain:

Challenges for small carriers:

The specific challenges for small carriers in adopting blockchain technology are:

- Transformation and adaptation to market needs,
- Modernising the fleet,
- Testing new equipment,
- Automatisation of processes,
- Introducing the new approach to meet the industry criteria,
- Provide feedback to supply chain consortia to enable efficient data verification.

Small carriers can also be incentivised to participate in the blockchain supply chain through financial and non-financial incentives and benefits, offering participation in a larger market.

Integration with existing systems and Interoperability: To effectively integrate blockchain technology into existing supply chain systems with small carriers, it is necessary to ensure seamless interoperability with other technologies such as ERP, CRM, and IoT. In addition, through decentralised applications built on Smart contracts, it is possible to create automated processes, e.g.

data verification, execution of tasks, thus eliminating the need for manual data evaluation, task assignment, etc. This can greatly speed up and simplify the supply chain process, for example.

Regulatory Compliance: Compliance with relevant regulations and industry standards governing data privacy, security, and consumer protection. Some of them are mandatory in terms of legislation, but some will be indispensable from the point of view of using the blockchain platform. Compliance with regulations such as GDPR (General Data Protection Regulation) or HIPAA (Health Insurance Portability and Accountability Act) may be necessary depending on the industry and geographic location.

Public or private: We expect there to be concerns regarding whether the platform should be public or private. In some cases, small carriers will be able to operate in both. On the other hand, companies will need to develop themselves on public platforms and adapt to exchanging data. Private platforms may be implemented more quickly than public ones because they can develop own specific rules.[62] Additionally, hybrid networks may be used. That means, in the private network, they will be able to provide transport on the basis of the consortium's internal rules. In the case of a public network, they will in turn be able to offer their services to other companies as they will already be 'blockchain ready'.

Collaboration and Participation: Successful implementation often requires collaboration among multiple stakeholders involved in the supply chain. All stakeholders must be willing to participate and share data on the blockchain network.

Security: Although blockchain is considered a secure technology for processing and storing data as immutability and cryptographic verification, there may be attempts to test its vulnerabilities. Pennekamp et al. [63] discussed various scenarios from a security perspective. Organisations must implement appropriate measures to protect confidential information and comply with data protection regulations. From the perspective of small carriers, the data protection process must be secured by the blockchain ecosystem itself and through standardised appliances. The future research challenges will represent the modelling of . [64] potential risks and weak scenarios of blockchain usage.

Data and input certification standardisation: Establish standardised data formats and protocols to ensure compatibility and interoperability across the supply chain network. Consistency in data formats enhances the efficiency of data sharing and processing.

The primary challenge is to identify the system in which the technology can be presented to ensure its reliability. [65].

Cost: Implementing blockchain technology can be expensive, especially for small and medium-sized enterprises (SMEs). Costs may include investment in technology, training, and ongoing maintenance. Additionally, there may be costs associated with data storage and transaction fees on the blockchain network.

Environmental impact: Due to the nature of some platforms, including cryptocurrency mining, the current issue of sustainability and the 'environment's future is essential. Specially, this fields in the supply chain, where some consortia place demands on the ecological aspect of the supply chain.Therefore, there is room for more sustainable forms of blockchain that potential users will consider [66].

Incompatibility of blockchain platforms: Several platforms currently have specific characteristics [67]. The problem is what will happen if different consortia have incompatible platforms. This will allow small carriers to offer multi-platform services.

So here are many aspects that should be considered. When applying new technologies, the carrier explores these options from a number of perspectives. Especially when it comes to a carrier with a smaller fleet and a smaller budget to invest in change. However, for these types of transport, safety is a major concern and the recovery of the costs associated with the creation of risks can often be higher than the cost of implementing a new system. In this case, the carrier is mainly analysing how the technology will improve safety, i.e. whether it is necessary to invest in innovation. It then mainly considers the cost of the upfront investment and whether the small carrier is able to make this investment. Furthermore, one of the main conditions is whether the technology is capable of storing

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data and whether the carrier can show it to third parties on request. If the carrier already decides to apply the system, it still considers the time required to implement the system and the time required to apply the system to individual transports

6. Conclusions

Integrating blockchain technology into the supply chain is challenging and poses several obstacles to different stakeholders. Despite the significant amount of scientific research conducted in this area, identifying the supply chain as an attractive area to use multiple blockchain platforms, some concerns and barriers hinder the adoption of this technology. Apart from the barriers in technology and security, the existing systems and ease of penetration are major obstacles that prevent the wider adoption of blockchain technology in the supply chain. Many supply chain organisations already have established systems to track and manage their operations. Integrating blockchain technology with these existing systems can be complex and may require significant changes to infrastructure and processes. Another important factor that hinders adoption is the cost of implementation. Users and stakeholders expect blockchain technology to add value to facilitate the processes themselves and to add value that, in collaboration with artificial intelligence and IoT, can bring tangible benefits to the supply chain. We conducted a test on temperature measurement methods during transportation. We have developed an ecosystem approach to help stakeholders determine if this technology is suitable for their supply chain. The ecosystem will consist of certified input devices that enable data collection for each stakeholder group. The same applies to all communication channels and gateways through which data will be transmitted. We believe that storing this data on the blockchain is the simplest solution. In fact, there are currently a number of viable approaches to operating a blockchain that supply chain stakeholders can use. However, the main challenge is creating an attractive ecosystem that can be used by all supply chain stakeholders, allowing stakeholders with traditional manual or low-tech data control to participate.

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