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Using Blockchain Technology to Foster Collaboration among Shippers and Carriers in the Trucking Industry: A Design Science Research Approach

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Abstract: In the global trucking industry, vertical collaboration between shippers and carriers is attained by intermediaries, called brokers. Brokers organize carriers for a shipper in accordance with its quality and price requirements, and support carriers to collaborate horizontally by sharing a large distribution order from a shipper. Brokers also act as trustees, preventing the passing of private information of any party to the others. Despite these benefits, intermediaries in the trucking industry are involved in several sustainability problems, including high costs, high levels of carbon emissions, high percentages of empty miles, low-capacity utilizations, and driver shortages. Several studies have acknowledged the importance of improving collaboration to address these problems. Obviously, the major concern of brokers is not collaboration, but rather to optimize their own gains. This paper investigates the potential of blockchain technology to improve collaboration in the trucking industry, by eliminating brokers while preserving their responsibilities as organizers and trustees. This paper extends the transportation control tower concept from the logistics literature, and presents a system architecture for its implementation through smart contracts on a blockchain network. In the proposed system, the scalability and privacy of trucking operations are ensured through integration with privacy-preserving off-chain computation and storage solutions (running outside of the blockchain). The potential of this design artifact for fostering collaboration in the trucking industry was evaluated by both blockchain technology experts and trucking industry professionals.

Keywords: blockchain; trucking; collaboration; trustee; transportation control towers

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1. Introduction

Despite its significant contributions to the economic growth and social welfare of all nations around the world, the global trucking industry suffers from many problems, mainly due to the heavily fragmented nature of the industry, as well as the poor level of collaboration among its involved parties.

Traditionally, trucking operations between shippers and carriers have been orchestrated by freight brokers acting as organizers and trustees in the industry. Brokers organize carriers for a shipper in accordance with its quality and price requirements, and support carriers to collaborate horizontally through sharing large distribution orders from shippers. Brokers also act as trustees, preventing the passing of private information of any party to the others. Considering the fragmented structure of the carrier market, with its high degree of competition, brokers currently play an important role in bringing shippers and carriers together in the industry. However, this business model, centralized around freight brokers, also limits collaboration opportunities among shippers and carriers and further aggravates the problems in the trucking industry.

The global trucking industry has been undergoing a digital transformation in recent years, thanks to the adoption of GPS, Internet of Things (IoT), mobile and Internet technologies, and data analytics. However, more innovative information and communication technology (ICT) solutions are still needed to encourage collaborative business models in the industry, by addressing the trust problems among the involved parties.

As an emerging technology intrinsically supporting decentralized and trustless business models, the blockchain has the potential to disrupt the trucking industry by eliminating the need for intermediaries between shippers and carriers. However, despite the potential that blockchain technology offers, there is a gap in the literature around understanding the application areas of this new technology in the logistics industry. In a recent study, blockchain application areas (BAAs) in supply chain transactions, their likelihood of being implemented, and their impact were investigated through a multimethod approach, combining an extant literature review, a Delphi study, and surveys completed by 151 business managers [1]. According to the findings of that study, even though the "logistics and delivery systems" BAA was initially not identified in the literature search, it surfaced during the Delphi study, and it ranked among the top three BAAs in terms of application likelihood. The results of that study clearly indicate the gap in the literature on the potential of blockchain technology for logistics and delivery systems. Our study aimed to help fill that gap in the literature by exploring a potential application area of blockchain technology in the trucking industry.

More specifically, this research aimed to achieve the objective of utilizing blockchain technology and other relevant technologies to improve collaboration among shippers and carriers in the trucking industry. To achieve this objective, this study investigated the following specific research questions:

1. Can the transportation control tower concept from the logistics literature be extended by operationalizing it in a decentralized fashion on a blockchain network, where the need for a neutral and independent trustee is eliminated?
2. How can we address the scalability and privacy issues of transactions of trucking operations managed on the blockchain?

This paper contributes to the literature in several ways. Firstly, to the best of our knowledge, this is the first study addressing the collaboration problem in the trucking industry from an information systems perspective, even though the importance of ICT solutions in improving collaboration has been acknowledged in a variety of EU, WEF, and OECD reports. Secondly, our work presents a unique use case for blockchain technology in the logistics industry: a decentralized transportation control tower, designed to achieve the same functionality as traditional trustee models without the need for a trusted intermediary. Finally, this study presents a solid business case, where integration with privacy-preserving off-chain (storage and computation) approaches addresses the privacy and scalability issues of blockchain applications.

The rest of this paper is structured as follows. In Section 2, the literature on the economic, social, and environmental impacts of the global trucking industry; the collaboration types in the trucking industry; the transportation control tower concept; and the use of ICT and blockchain solutions in the trucking industry is reviewed. In Section 3, the design science research (DSR) method, the main methodology in this study, is explained; the research relevance is presented by investigating the structure and leading problems of the trucking industry; and the design artifact, together with its system architecture, is generated based on the findings in the literature and the research relevance. In Section 4, the opinions of blockchain technology experts and trucking industry professionals are shared in order to evaluate the proposed design artifact in terms of its contribution to the knowledge base, as well as its technical viability and application in the trucking industry. In Section 5, the managerial implications of the proposed design artifact are discussed in detail. Finally, the concluding remarks and future research directions are provided in Section 6.

2. Literature Review

2.1. Impact of the Trucking Industry on Economy, Society, and the Environment

Road freight transportation, or trucking, is the primary form of shipping for domestic, trans-border, and international cargo, representing over 70% of the global freight bill, and an even higher percentage of cargo value around the world. Generating a significant proportion of the GDP in many nations, road freight transport is the backbone of the global economy and is vital to production, distribution, reverse logistics, and any type of mobilization of goods [2–5].

From a social perspective, road freight transportation touches every individual in society by employing millions of people and providing access to jobs, housing, and goods and services. A complete halt of trucking operations for a single week would result in serious disruptions in meeting the most basic needs of a society, such as food supply, waste collection, and medical services [6,7]. This fact became painfully clear during the COVID-19 pandemic, where employees in the logistics sector had to work relentlessly to provide for the basic needs of people under lockdown. During this period, Amazon Prime deliveries took as long as a month for some items that would usually arrive in two days, as the e-commerce giant struggled to keep up with the surge in demand for hygiene products. However, although trucking has a major social impact on the well-being of a population, the trucking industry is currently suffering from low social value and comparably heavy work conditions, due to fierce competition in global markets [8]. Drivers complain about long working hours (traveling 120 K miles annually, with 240 days away from home on average [9]), and low/delayed payments. Carriers suffer from driver shortages and low rates of driver retention. Shippers are challenged by high transportation costs, resulting from empty miles and the low level of load factors.

On the other hand, despite growing attention to green energy in recent years, global freight transport is still heavily dependent on fossil fuels (mostly oil), and produces a significant fraction of the greenhouse gases released into atmosphere globally. In fact, air pollution, high noise levels, and congestion/accidents—due to increased traffic from heavy-duty trucks—are major threats to the environment, especially in metropolitan areas [10,11]. Since trucking demand is expected to increase in the coming years, in parallel to the growth of e-commerce, these problems will only increase in significance in the future [12].

Due to the aforementioned economic, social, and environmental impacts of road freight transportation, policy makers and organizations in the trucking industry around the world are seeking innovative business models and technology solutions for mitigating the risks and threats of road freight transportation.

The main difficulty in generating solutions is the fact that road freight transportation is a complex operation, involving many parties in the process, including shippers, carriers, freight brokers, regulators, insurance companies, and financial companies (banks or factoring companies). Bringing so many different parties together, and resolving conflicts as they arise, are significant challenges for the trucking industry, which is more or less still operating based on 30-year-old business models in most parts of the world [13]. Unfortunately, traditional business models, where shippers and carriers maintain an indirect relationship with each other through middlemen (brokers), are not helping to resolve these highly complex, multi-faceted problems. In fact, these problems have already been addressed in numerous industry reports generated by the European Union (EU), the World Economic Forum (WEF), the Organization for Economic Co-operation and Development (OECD), and various research organizations [14–16]. In these reports, improved collaboration among the parties involved is repeatedly highlighted as a key concept. Moreover, the development of innovative information and communication technology (ICT) solutions for collaboration is recommended as the key solution for addressing the current problems of the trucking industry.

2.2. Collaboration Types and the Transportation Control Tower Concept

Collaboration in logistics is achieved when two or more parties (shippers, customers, carriers, or 3PLs) exchange or share resources (tangible or intangible) such as trucks, or demand information with the goal of generating benefits that cannot be achieved individually. The intensity of collaboration among partners can range from information exchange, to joint planning, to joint execution, to a strategic alliance [17].

Collaboration in logistics can be realized in two forms: vertical collaboration and horizontal collaboration [18]. In vertical collaboration, partners at different levels of a supply chain (such as a shipper and a carrier) share or exchange resources [19]. In horizontal collaboration, competing organizations operating at the same level of a supply chain (such as two shippers or two carriers) build a partnership to increase the value gain and to better utilize their resources [20].

The supply chain management literature has an abundance of studies on vertical logistics collaborations [21,22]. A large number of studies have examined vertical collaboration models between manufacturers and retailers. Among the vertical collaboration models, Vendor-Managed Inventory (VMI) and Collaborative Planning, Forecasting, and Replenishment (CPFR) have generated great interest among researchers and practitioners in the supply chain domain [23–25].

In recent years, there has been an increasing interest among researchers around analyzing concepts, methods, and mathematical models related to horizontal collaboration in logistics and transportation domains [26–29]. The focus on those studies has been generally on the application of game theory to coalition formation and gain sharing issues, the mechanism of design for exchanging requests, and developing optimization models for collaborative transportation planning. However, surprisingly, ICT issues and opportunities have received less attention in the literature, despite the importance of real-time information exchange in horizontal collaboration [26].

Both vertical and horizontal collaboration practices are limited today in the trucking industry, where transactions are heavily orchestrated by freight brokers. However, considering the size and fragmented structure of the carrier market, horizontal collaboration among carriers will be particularly important in addressing the sustainability problems of the trucking industry at the strategic level. With horizontal collaboration, carriers can increase productivity for core activities (implementing joint route plans, decreasing empty hauling, increasing load factors, reducing nights away from home, etc.), and reduce costs related to non-core activities (vehicle purchasing, fuel, training, etc.). Furthermore, horizontal collaboration also enables small-or medium-sized carriers to tender with large shippers on larger contracts that they would not be able to fulfill individually due to capacity constraints. Scaled up carriers can offer a better quality of service at lower costs to their customers, for example, in terms of speed, frequency of deliveries, geographical coverage, and reliability of delivery times.

Information sharing among collaborating parties (for example, operational plans, existing orders, current and future capacity levels, etc.), alignment of individual and joint goals of collaborating parties, existence of rapid dispute resolution mechanisms, and availability of ICT infrastructure for faster and secure data exchanges among partners are facilitating factors for horizontal collaboration in the trucking industry. On the other hand, difficulties in finding a reliable business partner, risks related to the misuse of sensitive information by malicious partners, challenges in sharing costs and gains fairly among partners, and the lack of ICT solutions are impediments to horizontal collaboration in the trucking industry [30–34].

It should be noted that information sharing among involved parties is both a facilitator and an obstacle to the success of horizontal collaboration in the trucking industry. A carrier's ability to earn the trust of its competitors is one of the most important factors for achieving collaboration among carriers. The problem is further complicated due to the increasing competition in the trucking market, as well as the lack of effective coordination between the key parties involved [35]. Transparently sharing business plans and other relevant business information with partners contributes to the growth of trust among partners, and reinforces the alignment of the individual and joint goals of partners. However, misuse of that information by a malicious partner might have serious consequences for the other partner. Depending on the initial strengths and weaknesses of the partners and how these strengths and weaknesses change over time, smaller companies in a partnership might lose clients or be pushed out of the market completely over time.

Transportation control towers or trustee organizations are fairly new concepts being discussed in the logistics literature, to eliminate the trust issues among involved parties when practicing horizontal collaboration in the trucking industry. Basically, a trustee is an independent, neutral, and reliable third party that collects data from collaborating parties, keeps the shared data strictly confidential, and processes the data with the goal of maximizing gains for all partners [36–38].

The trustee—a central independent third party—concept sounds promising in theory; however, a mechanism is still needed to ensure the neutrality and fairness of the trustee in its decisions when consolidating loads from different shippers, delegating the loads to carriers, and distributing the gain to participants. In addition, this tight-coupling business model with an independent trusted organization bears the single point of failure risk for the industry. If the trustee loses its neutrality or cannot function any longer for whatever reason, the financial impact would be a huge burden for the involved shippers and carriers, considering the sizable economic activity of the trucking industry. For this reason, the trustee concept needs to be bolstered by an innovative ICT solution for ensuring the neutrality of the trustee, while also allowing shippers and carriers to validate the trustee's decisions without compromising the privacy of shared data.

2.3. Use of ICT Solutions and Blockchain in the Trucking Industry

Cloud computing, big data, advanced data analytics, and Internet of Things (IoT) technologies have impacted the trucking industry in recent years [16]. These ICT innovations are transforming businesses by providing better connections through mobile and web technologies, and generating smarter decisions with data analytics. While these solutions are improving the efficiency of the daily operations of carriers, they have not been successful so far in promoting horizontal collaboration among carriers in the trucking industry.

In addition, online freight matching platforms have gained popularity recently in the trucking industry. Acting as centralized electronic marketplaces, these platforms match shipper demand for carrier/trucking capacity using mobile or web-based technology applications. In a nutshell, shippers/freight brokers post their load requests for the spot market on these electronic marketplaces, and carriers offer their rates digitally for these loads. Once a load is matched with a carrier, the status of the cargo is tracked on the platform during its entire journey. However, these platforms mainly rely on the reputation of participants, and they suffer from entry barriers for new participants [39]. In fact, it becomes extremely difficult for a party to switch to another platform once it adapts to the technology and establishes a reputation on a particular platform [40,41]. In addition, dispute resolutions with a trusted third party take too long in centralized electronic marketplaces [39,42]. Finally, shut-down of the platform in extreme cases, and misuse of confidential data collected from all stakeholders, are other potential risks associated with these centralized marketplaces [39]. Hence, online freight matching platforms are not satisfactorily overcoming the weaknesses in regards to practicing horizontal collaboration in the trucking industry at present. In addition, the impact of these platforms on the overall trucking industry has been quite limited, since they are mainly used for spot market transactions, which are a considerably smaller proportion of the industry compared to contract market transactions (10% vs. 90%) [43].

Finally, blockchain technology has emerged in recent years, and has already disrupted many industries. Businesses that could previously run only through a trusted intermediary can now operate in a decentralized fashion, without the need for a central authority, and achieve the same functionality with the same amount of certainty. This was simply not possible before. The absence of a trusted intermediary means faster reconciliation between the transacting parties [44]. Even though it initially gained popularity in the finance industry by allowing the transfer of cryptocurrencies (for example, Bitcoin and Etehereum) between parties, it has found use cases in other industries as well.

A blockchain is essentially a distributed database of records, or a public ledger of all transactions and digital events that have been carried out and shared among all participants in a network. Each transaction is verified by consensus of a majority of the participants in the network before being recorded into the ledger with cryptographic functions [45,46]. The records, once entered into the public ledger, can never be erased, and they cannot be altered retroactively without alteration of all subsequent blocks and the consensus of the network functions [45]. Smart contracts are one of the most important applications of blockchain technology. A smart contract is an executable code that runs on the blockchain to facilitate, execute, and enforce the terms of an agreement between untrusted parties, once the pre-defined rules have been met [46].

There are two main types of blockchain: public and private. The sole distinction between them is related to who is allowed to participate in the network, execute the consensus protocol, and maintain the shared ledger. A public blockchain network is completely open and anyone can join and participate in the network, to conduct transactions or validate the transactions of others (for example, bitcoin miners). One of the drawbacks of a public blockchain is the lack of privacy of transactions, since they are broadcast to every single participant (node), and every node thus keeps a complete record of the entire transaction history. On the other hand, a private blockchain is a permissioned blockchain which is hosted on private computing networks, and uses an access control layer to govern who has access to the network. Participants need to obtain an invitation or permission to join the network. In contrast to public blockchains, transactions are validated by a pre-selected set of participants who have been vetted by the network owner, and only the entities participating in a transaction will have knowledge of it; others will not be able to access it. One of the biggest drawbacks of a private blockchain is the inherent centralization that they use to offset the scalability and privacy problems of public blockchains. When you are part of a private blockchain, by design you are placing your trust in a central source.

Due to data protection (privacy) concerns, most commonly organizations have preferred deploying private solutions in lieu of using public blockchains in the supply chain industry. For example, TradeLens—a global commercial blockchain platform developed by the joint venture of IBM (Armonk, NY, USA) and Maersk (Copenhagen, Denmark) in 2018—reduced paperwork and improved the workflow and visibility of containers in international maritime transport [47]. Participants of the platform are able to track the progress of cargo during its entire journey, and can access to customs documents, bills of landing, and any other details of the transactions recorded in the blocks. Furthermore, using IBM's blockchain solution based on Hyperledger Fabric, Walmart has successfully completed blockchain pilots for tracking the provenance of pork in China and mangoes in the Americas. At the end of the pilot, the time for tracking mango origins was reduced from seven days to 2.2 s [48]. Similarly, Chinese retailer Jingdong (Bejing, China) actively uses blockchain technology to track the entire process of food production, processing, and sales over its food supply chain systems [49].

Private blockchains enable secure and real-time exchange of supply-chain data and paperwork for an organization or a group of organizations where the entities are known and trust each other or the network owner. However, due to the fragmented structure of the trucking industry (for example, 920 K carriers in the USA [50]), with participants who do not necessarily trust each other, private blockchains would not sufficiently eliminate the trust problems and promote collaborative business models in the trucking industry. Instead, a public blockchain solution with support for privacy-preserving transactions is needed to encourage both vertical and horizontal collaboration among shippers and carriers, without the need for a trusted intermediary. To the best of our knowledge, no such blockchain solution has emerged yet in the trucking industry.

This study aimed to fill this gap in the literature, by proposing the design artifact and the system architect of a transportation control tower concept implemented in a decentralized fashion on a public blockchain network. The confidentiality of trucking transactions was ensured through off-chain privacy-preserving computation and storage solutions integrated with the blockchain.

3. Materials and Methods

We adopted design science research (DSR) methodology in this study to create a blockchain-based design artifact for improving collaboration in the trucking industry. In a nutshell, design science is a research paradigm aimed at creating scientific knowledge by designing and building useful artifacts to address business problems. In information systems research, the design–science paradigm seeks to extend the boundaries of human and organizational capabilities by creating innovative artifacts that solve either a hitherto unsolved problem, or a known problem, in a more effective or efficient manner [51].

A DSR is represented by three cycles between the environment that the research problem originates from and the knowledge base that includes the solution approaches (see Figure 1). Quoting from Hevner, "*the Relevance Cycle connects the contextual environment of the research project with the design science activities. The Rigor Cycle connects the design science activities with the knowledge base of scientific foundations, experience, and expertise that informs the research project. The central Design Cycle iterates between the core activities of building and evaluating the design artifacts and processes of the research*" [52].

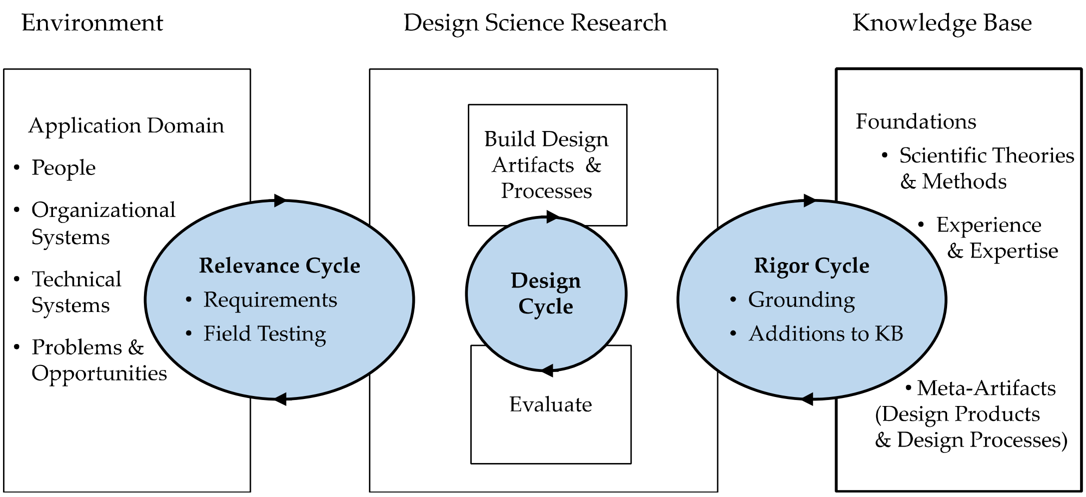

Figure 1. Design Science Research (DSR) cycles adapted from Hevner's study [52].

The theoretical rigor for this study has already been provided in the literature section above, where the literature was reviewed to investigate the impact of the trucking industry on the economy, society, and the environment, the critical success factors for collaboration in the trucking industry, the transportation control tower concept, and the use of ICT and blockchain in the trucking industry. In the rest of this section, the relevance cycle and design cycle will be presented in detail.

3.1. Establishing the Research Relevance

In this section, a snapshot of the trucking industry is taken to obtain a deeper understanding of the involved parties, existing business models, and the major problems, through industry reports and a semi-structured interview conducted with executives at a non-profit trucking industry organization in Turkey.

3.1.1. Structure of the Trucking Industry

According to the American Trucking Association (ATA), the trucking industry generated $796.7 billion in gross freight revenue (primary shipments only), employing 3.5 million drivers in the USA, which represents 80.3% of the nation's freight bill, in 2018 [50]. Being such a major economic activity and having strong ties to all other industries, the trucking industry is one of the leading indicators for the direction of the overall economy around the world.

Freight transportation simply involves the movement of raw materials, components, and finished products from one location to another within a supply chain network. The shipper, carrier, freight broker, and consignee are the four main parties involved in road freight transportation. A shipper is the person or company who is usually the supplier or owner of the commodities being shipped. The shipper physically tenders the goods to the carrier at the origin. A carrier is a person or company that transports goods for any person or company, and who is responsible for any possible loss of the goods during transport. A consignee is the person or company who is designated to receive the shipment. The consignee and shipper could be same party if the shipper ships the cargo from the origin to one of its related branches or locations. Finally, a freight broker is an individual or a company who brings together a shipper, who has goods to transport, with an authorized motor carrier, who wants to provide that service. Without taking possession of the freight, the broker facilitates communication between the shipper and the carrier (see Figure 2).

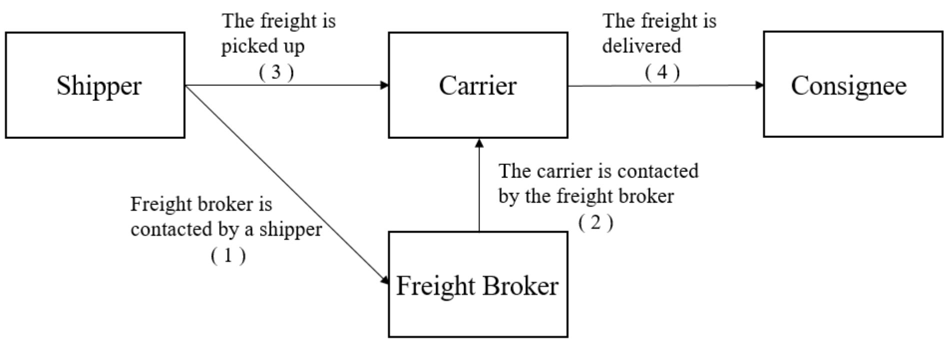

Figure 2. Life of a brokered freight load.

Today, the trucking industry is heavily orchestrated by freight brokers, and shippers and carriers depend on them for different reasons. Shippers want to do business with trusted carriers who have more than the legal minimum insurance, with drivers with stellar safety records, with those who have expertise in special areas—like hazmat or refrigerated shipping—and those who can be counted on to deliver reliably. Managing freight transportation in-house requires complex processes for shippers, such as finding reliable carriers, preparing paperwork and contracts, scheduling and synchronizing pick-ups, tracking cargo, and managing insurance, damage claims, and payments. Rather than dealing with these complexities on their own, shippers typically prefer working with freight brokers or third-party logistics service providers (3PL) to manage freight transportation activities. According to a 2017 industry report by Armstrong & Associates (a market research company, Milwaukee, WI, USA), 90% of Fortune 500 companies rely on 3PLs to control their logistic costs, and to increase supply chain efficiency [53]. Therefore, shippers rely on freight brokers to find trusted carriers for their freight shipments.

On the other hand, the carrier market is extremely fragmented, such that 90% of carriers have fewer than six trucks in their fleet in the USA [50]. Under such a competitive market, carriers desire to have consistent loads and minimize their idle times and empty miles on the road, to reduce their costs. Carriers have different preferences in regards to the types of lanes on which they operate. Some carriers prefer working with dedicated lanes, where they serve the same customer on regular routes and schedules, while others prefer long hauls where they spend a couple of weeks on the road, working with different customers throughout the entire haul. Nevertheless, they all want to do business only with trusted shippers, who respect the detention times during loading and unloading and who make payments on time. For these reasons, carriers rely on freight brokers to find profitable loads from trusted shippers in a highly competitive and fragmented market.

Freight brokers establish their own network of trusted shippers and carriers over time, and using that network, they act as a trusted intermediary in matching load requests from shippers with the transportation capacity of carriers, in exchange for a commission charged to both parties. Unfortunately, this centralized business model, controlled by freight brokers, limits the level of collaboration among shippers and carriers in the industry. Furthermore, considering the fact that freight brokers want to maximize their own profits, their objectives may not always align with those of shippers, carriers, and sustainable freight transportation efforts. For example, a freight broker might be inclined to match a certain load request with a certain carrier, regardless of concerns about efficient and sustainable trucking operations, as long as higher revenues can be achieved by matching them [54,55]. Inefficiencies and non-optimized business operations due to the match maker role of freight brokers and the lack of collaboration among carriers in the trucking industry have led to a number of serious problems for the economy, society, and the environment. We will elaborate more on those problems in the next sub-section.

3.1.2. Problems of the Trucking Industry

Below is a summary of the leading problems of the trucking industry based on industry reports and the logistics literature.

- High levels of carbon emissions: According to the OECD, globally, more than one-third of transport-related CO_2 emissions, and 7% of total energy-related CO_2, come from road freight transport [56].
- High percentage of empty-miles: Truckers drive between 20% and 50% of their miles empty in the US and Europe, mainly due to the unavailability of nearby loads headed in that direction [14,15,36]. These empty miles mean that more fuel is consumed, more carbon is emitted, drivers spend more hours sitting idle, and customers end up paying more.
- Low level of load factors: The load factor in trucking is defined as the ratio of the average load to total vehicle freight capacity. For non-empty running trucks in the USA and Europe, the average load factor is estimated to be around 60% [14,36,57].
- Poor work conditions (wellness) of drivers: In a survey of the National Institute for Occupational Safety and Health (NIOSH), it was found that obesity (69% vs. 31%), morbid obesity (17% vs. 7%), diabetes (14% vs. 7%), and cigarette smoking (51% vs. 19%) were considerably more prevalent among long haul drivers compared to the national working population in the USA [58].
- Driver shortage: In 2018, the trucking industry in the US was short by roughly 60,800 drivers, which was up nearly 20% from the 2017 figure of 50,700. If the current trend continues, the shortage is expected to grow over 100,000 in the next five years [59].
- Detention/delay at customer facilities: Detentions over two hours typically impact drivers' ability to comply with the hour-of-service (HOS) rules, and force drivers to park in unauthorized or undesignated parking areas if they run out of available on-duty hours before reaching a safe parking location. Moreover, only 29.3% of carriers report that they are able to collect all of the detention fees they bill to customers [12,60].
- Extended payment wait-times: 30 days after proof-of-delivery/invoice is the industry average in contracts for receiving payments, i.e., brokers being paid by shippers and carriers being paid brokers. Faster payments come with additional commission cuts via Quick Pay or Factoring services [61].

In addition to reviewing the industry reports, an initial semi-structured interview was conducted with executives from the International Freight Forwarder Association (UND)—a non-profit organization founded in 1974 to address the problems of the logistics industry in Turkey—to better understand the problems from the perspective of the implicated parties.

Confirming the aforementioned problems for the trucking industry, they emphasized the importance of collaborative business models for addressing these issues in the long term. However, they also noted that even though the industry has been going through a digital transformation in recent years, it is still far from a being collaborative one, mainly due to trust issues among industry players. They reiterated that more innovative ICT solutions are needed to address the trust problems, and facilitate collaboration among shippers and carriers in the trucking industry.

3.2. Generating the Design Artifact

Based on our findings from the relevance and rigor cycles of the DSR, here we present the design cycle where the design artifact was generated. We argue that this is an innovative approach to extend the transportation control tower concept from the collaboration literature, by operationalizing it digitally in a decentralized fashion on a public blockchain. The proposed system should eliminate the concerns related to the neutrality of the trustee, and the single point of failure risks intrinsic to centralized trustee models.

3.2.1. Overview of the Blockchain-Based Transportation Control Tower Concept

The digital transportation control tower brings together all stakeholders in the trucking industry, including shippers, carriers, insurance companies, regulators, and other parties, on a blockchain platform that supports smart contract functionality. In essence, each user of the platform has a unique account on the blockchain, and a smart contract is created for executing the terms of every single workflow of a shipment on the platform, such as loading the cargo, detention/delay conditions, unloading cargo, auditing, post-delivery payments, and conflict resolution. For example, the arrival time of the carrier at the origin location and the pick-up time of the cargo can be recorded on the blockchain. If the carrier faces an excessive delay upon arrival for the pick-up of the cargo, the related smart contract terms are executed automatically to charge detention fees to the shipper. Similarly, every state update during the shipment, such as the hours-of-service status, the status of the cargo, delays due to traffic, etc., is verified and validated on the platform, and then recorded into the immutable ledger. The design of a blockchain-based transportation control tower for the trucking industry is represented below in Figure 3.

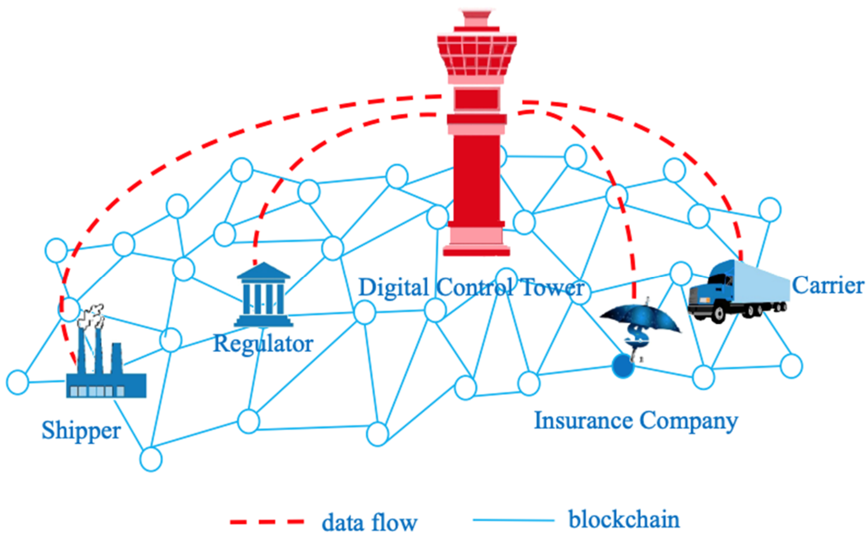

Figure 3. A transportation control tower running on a blockchain network.

While the platform could be used for executing an individual shipment contract between a shipper and a carrier without the need for a broker, its full potential is achieved when all shippers and carriers start sharing their business plans with a privacy-preserving decision algorithm (digital trustee) “integrated” within the blockchain network. Here, we use the word "integrated" purposefully: the decision algorithm, which is basically a recommendation engine to match shippers and carriers, stores large amounts of private input data and runs complex computations off-chain (outside the blockchain), and its decisions are verified and validated collectively by everybody on the blockchain.

Based on the requirements of platform users (shippers and carriers), any collaborative models from the logistics literature can be included in the recommendation engine, such as the relay trucking model, bundling shipments, backhauling, roundtrips, etc. However, the modeling details of the decision algorithm and its performance evaluation are outside the scope of this conceptual research. Further studies are needed to adapt the collaborative models and other relevant approaches from the logistics literature into the decision algorithm of the design artifact during the implementation phase. For example, Path Choice Problem (PCP) and Vehicle Routing Problem (VRP) paradigms can be studied to optimize the routes for the trucks once the matching between shipper and carrier has been finalized on the blockchain platform [62]. Transportation System Models (TSMs) and multiple-criteria decision methods can be instrumental for simulating the system behavior, to measure the performances and evaluate conflicting interests among the involved parties [63,64].

There are two main reasons the decision algorithm does not directly run on the blockchain network. First, from a scalability perspective, storing large data sets and executing complex computations directly on the blockchain is very expensive and not allowed in public blockchains; otherwise, every node on the blockchain would have to have high computational power and storage capacity to undertake the same computations for verification and validation purposes, as well as to replicate the ledger locally for data integrity purposes. Second, from a privacy perspective, storing the original data or the inputs off-chain and keeping corresponding hash values on-chain ensures that the sensitive information collected from collaborating partners will not be publicly visible on the blockchain. Therefore, moving complex computations and large data storage needs to off-chain systems, and verifying and validating their results on the blockchain enhances the capability of public blockchain applications in terms of scalability and privacy concerns.

In a nutshell, shippers and carriers send their input (load requirements, capacity availabilities, and other potentially sensitive information) to the privacy-preserving decision algorithm running outside the blockchain. The business rules or codes of the decision engine are visible to everybody on the blockchain network, but the input is not accessible to anybody on the blockchain. This ensures the confidentiality of the data collected from collaborating parties. The decision engine processes the collected data and produces load orders by matching shippers and carriers according to previously agreed business rules. Finally, the results of the decision engine, together with its digital signature, are verified and validated by users on the blockchain, without compromising the confidentiality of the input data sent to the decision engine earlier. This workflow ensures that the decisions are not generated by any malicious party or system, and they are in line with the previously agreed business rules. Eventually, the decision algorithm acts as a neutral trustee to maximize the gains for collaborative parties, while minimizing waste and negative impacts on the environment. Finally, the platform is free from the single point of failure risk because the decision algorithm can be run anywhere, and the ledger of transactions is replicated, shared, and synchronized across the entire network.

Off-chain storage (for example, IPFS and Swarm) and off-chain computation (for example, zkSNARKs) are promising approaches for addressing the privacy and scalability problems of standard blockchain architecture [65]; however, a more detailed discussion on these approaches should be the topic of another study, as it is outside the scope of the current one.

The system architecture of the proposed design artifact is presented in the next subsection.

3.2.2. System Architecture of the Blockchain-Based Transportation Control Tower

The system architecture (see Figure 4, adapted from [66]) has five layers: the infrastructure layer, blockchain layer, data analytics layer, applications layer, and users layer.

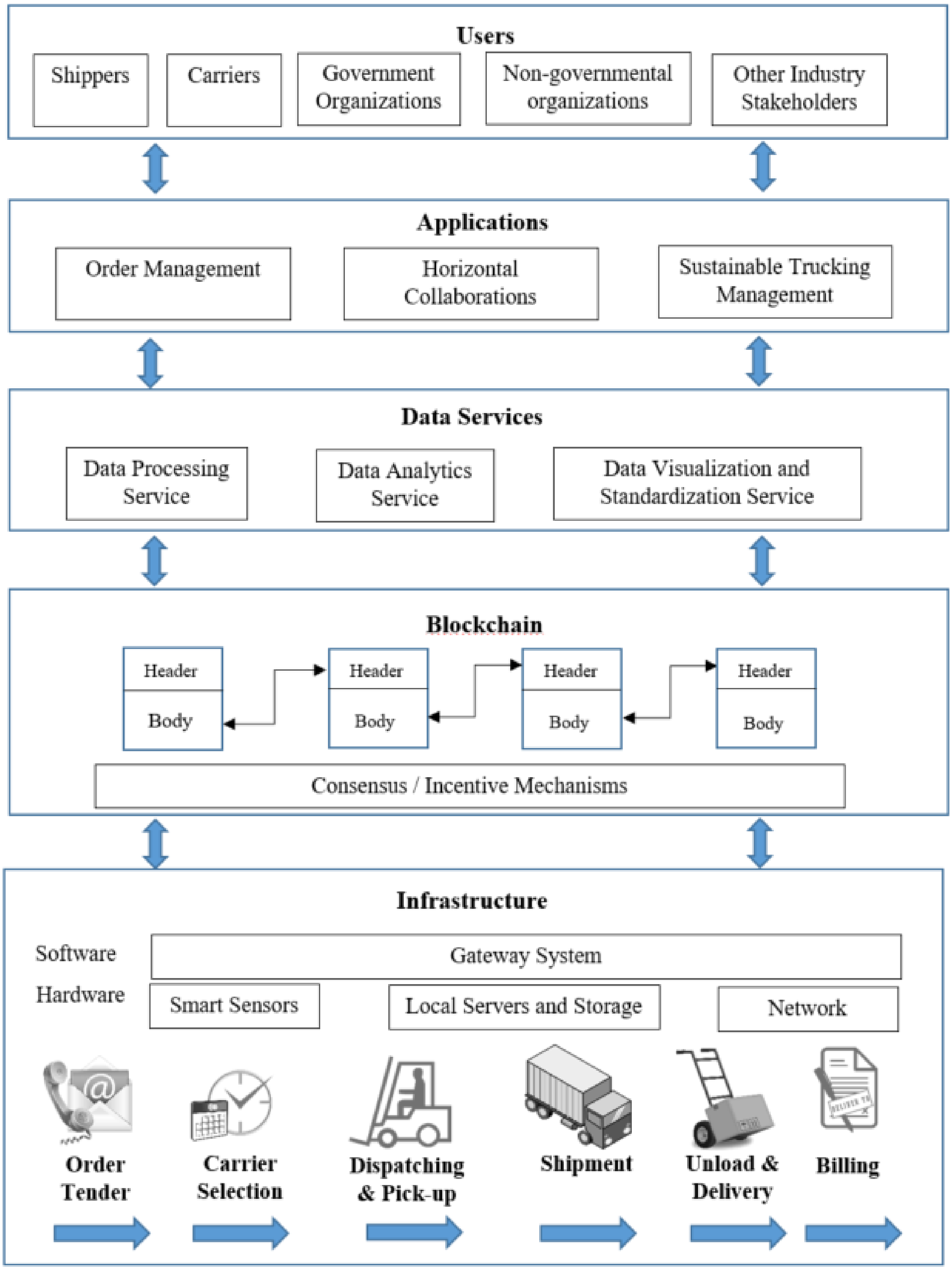

Figure 4. System architecture of the blockchain-based transportation control tower platform.

A generic lifecycle of a trucking order is presented at the bottom of the infrastructure layer. During its life cycle, a trucking order goes through the phases of order tendering, freight scheduling, dispatching, loading, transition, unloading, and billing. At each phase, the data from the trucking operations are generated, transmitted, and recorded into local storage or networks, to be utilized in the upper layers. The blockchain layer processes and records the data transmitted from IoT devices into chained blocks on the network. The data analytics layer connects the blockchain layer and the applications layer through cleansing, processing, analyzing, and visualizing the transactional data from the network. In the application layer, critical trucking applications use the data in decision-making processes. Finally, at the top of the architecture, trucking industry actors utilize the system through the users layer.

It should be noted that the proposed blockchain-based system architecture is powered by two other major technologies, namely IoT and big data analytics. IoT sensors play a critical role in collecting data and pushing the transactions to the blockchain network automatically, with minimal human involvement during the life cycle of a trucking order. On the other hand, big data tools are equally important in processing the large volumes of data produced by IoT devices, and extracting insights from the data, such as CO_2 emissions, empty hauling, etc.

From the bottom-up, the infrastructure layer consists of the hardware layer and software layer. In the hardware layer, IoT devices such as QR codes, RFID tags and readers, sensors, and GPS are used to collect the data automatically at each stage as the trucking order progresses through its life cycle. At the software layer, an IoT gateway software is used to transfer the collected data at each stage of the order life cycle to local databases, and/or cloud databases. After the operations through the gateways, the data and information from the infrastructure layer become available to the blockchain layer. For example, RFID tags and readers can be used to mark the arrival and departure times of the driver at the pickup location of the cargo. Once that information has been verified (consensus) and recorded into the blockchain, later it can be used for detention charge calculations for the shipper in the case of excessive waiting at the pickup location.

The blockchain layer is responsible for processing and recording the data transmitted from IoT gateways during activities in all stages of the trucking order life cycle. In a nutshell, the transactional data generated from trucking operations are verified, secured, and placed into a block in the blockchain network by miners, who share their computational powers in order to validate the legitimacy of a block of transactions. Anybody on a blockchain network can become a miner by installing and running special mining software that enables their computers to communicate securely with one another. A consensus mechanism is required to ensure that all the nodes in the network agree on a single state of the blockchain network, while multiple miners continuously add new blocks into the chain. Furthermore, a reward mechanism is also required to motivate the participants of the blockchain to act as miners and share their computational power, in order to keep the blockchain network up and running. Finally, it should be noted that only limited data is recorded on the blockchain network, in order to honor the privacy of transactions and minimize the computational power and data storage requirements for the miners. For that reason, once transactions are approved by the consensus algorithm, the hash values corresponding to transaction details are stored in the blockchain network, while the original object data are stored off-chain in the cloud storage environment servers, or in a distributed file system such as IPFS or Swarm.

The data services layer provides three key services to be used by applications in the upper layer: a data processing service, data analytics service, and data visualization service. The data processing service provides necessary tools to clean, classify, and sort the data, as well as run calculations on the extracted data. For example, CO_2 emissions from trucking operations can be calculated in this service. The data analytics service is used to conduct more sophisticated analyses on the processed data, by running techniques from machine learning, statistics, and data mining disciplines. For example, backhaul optimization can be fulfilled in this service in order to minimize the empty miles on the road. In the data visualization and standardization service, the processed and analyzed data are presented graphically to users, and formatted in common formats (XML, JSON etc.), to be shared by other systems.

The applications and user layers of the system architecture will be discussed in Section 5, along with the managerial implications for the trucking industry.

4. Results

Design science research is completed by assessing the contribution of the final design artifact to the knowledge base, as well as its application in the environment, to address the business requirements or problems. In this section, the proposed design artifact is evaluated based on the expert opinions of blockchain technology experts and trucking industry professionals. Please see Tables A1 and A2 in Appendix A for more information about the interviewees, and the questions asked to them.

4.1. Contribution to the Knowledge Base

The proposed design artifact itself is our contribution to the knowledge base, because to our best knowledge, it is the first blockchain application designed for enabling collaborative business models in the logistics industry.

In addition, the proposed system contributes to the knowledge base by extending the transportation control tower concept from the logistics literature. More specifically, running the transportation control tower concept in a decentralized fashion on a blockchain network eliminates the risks intrinsic to centralized trustee models, such as the loss of neutrality of the trustee, or the single point of failure in the system due to the inability of the trustee to function for any reason. The proposed system ensures the confidentiality of sensitive data on the platform through privacy-preserving off-chain computation and storage solutions. A decision algorithm processes the confidential data off-chain on behalf of the participants, maximizing the gains for them. Even though the inputs to the decision algorithm are confidential and not visible to anybody, the logic of the decision algorithm is known to participants, and transactions can still be validated by participants on the blockchain without compromising confidentiality, before being recorded into the distributed ledger. Once a decision algorithm is designed and agreed upon by participants, no transactions can happen on the blockchain against the rules of that algorithm. This ensures the neutrality of the decisions on the platform, and it is expected to encourage both shippers and carriers to engage more in horizontal collaboration practices.

4.2. Contribution to the Application Environment

In order to assess the viability of the design artifact and its potential impacts in the logistics industry, we asked for expert opinions from professionals in blockchain technology, and experts from the transportation industry.

The viability of the proposed design artifact was evaluated by two blockchain technology advocates, both with 20+ years of experience on the development of large-scale information systems in Turkey. The first interviewee, who is also a founder of a blockchain start-up company, confirmed that blockchain technology offers many opportunities for the logistics industry. In fact, he evaluated the technology as revolutionary for all industries because of its support for decentralized business models, and the immutability of the transactions on the network. Pointing to the fact that domestic and international supply chain operations involve too many parties, too much paperwork, and complex processes, he argued that by managing those transactions and processes via smart contracts on a blockchain network, the logistics industry might benefit from reduced paperwork, improved payment and pricing processes, faster invoice reconciliation and dispute resolution, and improved compliance with regulations, improving the provenance of goods, and reducing the risk of fraud in transactions. For the trucking industry, he considered that blockchain technology could simply be used to track the progress of a particular cargo during its journey (for example, load, unload, detention, location, etc.), and facilitate the fund exchanges between the shipper and the carrier upon delivery. In that sense, existing online freight matching platforms might be interested in utilizing the technology to offer a better experience to their users (for example, shippers and carriers). On the other hand, he also confirmed that a more holistic solution to enable horizontal collaboration in the industry, as suggested in our design artifact, requires complex computations (for example, bringing multiple carriers together for a single load order, splitting gains, sharing costs, etc.), and this would be very expensive to handle on a blockchain network. In addition, he also noted that current smart contracts are designed to be executed by all miner nodes, and transaction details are visible entirely on-chain. In order to improve the scalability and privacy on the blockchain, he was supportive of the idea of moving complex computations and private data off-chain, while validating the outputs of those computations on-chain. In fact, he considered our design artifact as a good use case of this. However, he also underlined that off-chaining approaches are still in their infancy in the blockchain community, and there are not many mature applications yet. Therefore, it might take some time for off-chaining solutions to gain maturity to the extent that our design artifact could go live in production. Nevertheless, he provided examples of ongoing initiatives of off-chaining computation approaches (for example, zkSNARKs, Bulletproofs, zkSTARKs, Enclave Systems, and TrueBit), as well as off-chaining storage approaches (for example, IPFS, StorJ, and SWARM), which might be useful for implementing our design artifact. The second interviewee, who was also a columnist at an international weekly business journal, shared similar perspectives with the first interviewee in regards to the potential of blockchain technology for the overall logistics industry. He found our design artifact innovative, and considered it a good example of the integration between decision support systems and blockchain technology. He argued that computing and storing state updates completely on-chain considerably limits the application areas of blockchain technology. He affirmed that, as off-chaining solutions mature, similar systems could be designed for different business problems requiring complex and privacy-preserving computations in other industries as well. Finally, the third interviewee, who was the co-founder of a blockchain discussion platform, stated that there is a great interest within the logistics industry to utilize blockchain technology, mainly in order to improve their daily processes and reduce paperwork, wasted resources, and time. In that sense, he evaluated our design artifact as an innovative solution to address many problems in the logistics industry. However, he also shared his concern regarding the fact that the trucking industry lags a bit behind technological advancements, and any innovative solution might face technology adaption challenges in the industry. Finally, he considered the lack of regulatory clarity, governance issues, integration with legacy systems, and interoperability issues between different blockchains as being among the other challenges for blockchain technology.

The application of our design artifact to the trucking industry was assessed through a number of interviews conducted with industry experts in Turkey and the USA. Initially, we conducted interviews with professionals from different sized carriers in Turkey. One common observation from these interviews was that none of the interviewees had previous experience with blockchain technology. The transportation planning manager at a large-sized asset owner carrier company (5000+ trucks) and the business development manager at a medium-sized asset owner carrier company (200+ trucks) in Turkey stated that they already have a direct relationship with most of their customers, and they also provide freight brokerage services in the industry by sub-contracting certain loads to smaller carriers. Therefore, they were not interested in a system design where the freight broker role is replaced with a decision algorithm powered by a blockchain. In addition, they both claimed that the reputation of the carrier is very important for shippers, and even though the terms of business are enforced through smart contracts on the blockchain, the proposed design artifact would not be able to convince shippers to do business with a group of unknown small carriers brought together by a decision algorithm to fulfill a load request. That being said, they also stated that blockchain technology could still be useful for reducing complex paperwork, especially for international shipments (for example, customs clearance), faster conflict resolution, and faster payment management. On the other hand, an owner operator of a small carrier shared that he is too dependent on freight brokers in order to find loads in the market, and he is not happy with the commissions paid to those brokers. In fact, he reported being excited with the idea of eliminating brokers and being able to engage in direct business with shippers. As long as his sensitive data remains confidential, he was interested in collaborating with other carriers on a blockchain-based transportation control tower platform. In securing the terms of business via smart contracts, he was even interested in monetizing his trailer by sharing it with other carriers and gaining commission from its operations on the platform. However, the owner operator also shared his concerns around the cost of the platform for him, the required technology literacy, and the technical support requirements. From the interviews with carriers, it is clear that even though the proposed design artifact has not received much support from large and medium size carriers with freight brokerage services, considering the fragmented structure of the trucking industry (90% of carriers have less than six trucks in the USA), the proposed design artifact offers unique opportunities for the majority of the carriers market, despite the technology acceptance challenges.

Next, we conducted interviews with the vice president of engineering and director of transportation operations at a leading beverage company in the USA. Sharing his vision on the potential of blockchain technology for overall supply chain operations, the vice president stated that the company is investing in the technology to increase the transparency and traceability of items along the entire supply chain, as well as to reduce the carbon footprint of their operations. He evaluated our design artifact as an innovative approach for a paradigm change towards decentralized business models in the logistics industry, and he expressed his support for implementation of a proof-of-concept (POC) solution in order to assess the performance of the proposed system. On the other hand, the director of transportation operations stated that currently they are highly dependent on freight brokers in order to secure transportation capacity from reliable carriers when needed, especially during peak seasons, and depending on the availability of alternative freight brokers in a region, the company might have to pay high commissions to those brokers at times. The director noted that they need to trust freight brokers at the end of the day to assess the eligibility of assigned carriers for their cargo delivery. However, he considered that the proposed design artifact could offer several benefits to them. First, the platform would bring them together with a pool of carriers beyond the reach of their own freight brokers. Moreover, since the records are immutable on the blockchain, they would also have the opportunity to check the past activities of carriers transparently on the platform, to make sure they were eligible to pick up their cargo. The director noted that those records would be critical for evaluating the performance of carriers, as well as ensuring the proper execution of regulations. He provided an example: a trailer which was used to deliver poultry products cannot be used for delivering beverage products, due to the risks of salmonella bacteria. The director also commented that the proposed design artifact or platform could also be used for monetizing the excess capacity of his private fleet (trucks or trailers) during the off season. Finally, as long as the sensitive data remained confidential, the director also shared his interest in collaborating with other shippers on joint shipment plans to reduce costs and carbon emissions from empty miles. Both the vice president and director at the beverage company agreed that the proposed design artifact has the potential to streamline inefficient processes, improve visibility of cargo movements, improve compliance with regulations, and reduce costs and waste via direct connection with reliable carriers.

Finally, we conducted a focused group interview at the International Freight Forwarders Association (UND)—an industry organization founded in 1974 to address the problems of road freight transportation companies in Turkey. The participants included government officials from transportation and customs administration, an executive of a software company, a customs and trade consultant, and high-level executives at the UND. The purpose of the interview was to understand the current blockchain initiatives for the logistics industry in Turkey, and discuss the potential of our proposed design artifact for the industry. In general, the participants agreed that blockchain technology has the potential to solve many pain points in road freight transportation, and they considered customs clearance as one of the initial application areas that blockchain could be instrumental for, in terms of reducing the time and resources wasted. However, the executive of the software company noted that even though the industry is ready to adopt this emerging technology, there are a few sets of challenges that have been responsible for the slow adoption of blockchain technology, such as scalability, privacy and regulatory issues, interoperability issues, high energy consumption, lack of standardization among blockchain networks, and a lack of talent to develop and maintain blockchain platforms. On the other hand, regarding our design artifact, even though it has a more complex implementation compared to completely on-chain use cases, the government officials and UND executives confirmed that it has the potential to improve the level of collaboration in the overall logistics industry, and eventually reduce carbon emissions from operations, and they shared their interest in contributing to our research in the future.

5. Discussion

In this section, the managerial implications of the proposed design artifact for the trucking industry are discussed in detail based on the system architecture provided earlier, in Section 3.

All parties involved in trucking operations can benefit from the proposed design artifact. Shippers can create load tenders, search reliable carriers, prepare smart contracts for the terms of agreement, and execute the contract on the blockchain without the need for a trusted intermediary or a freight broker. Similarly, carriers can directly make themselves visible to shippers on the blockchain network, and build their reputation by delivering excellent service to shippers. In addition, government and non-government organizations (NGOs) can monitor trucking activities on the blockchain network using data services. For example, the related government organization can check the transactions on the blockchain network to see if the hours of service regulation have been violated for shipments. Similarly, NGOs can analyze the vertical and horizontal collaboration opportunities for shippers and carriers in the industry, in order to reduce CO_2 emissions and empty driven miles from trucking operations. Governments and NGOs can together promote sustainable trucking activities in the industry based on the snapshot of the industry from the blockchain transactions. Furthermore, other industry stakeholders can also use the system. For example, the insurance details of carriers and shippers can be recorded on the blockchain network, and the terms of insurance can be coded into a smart contract to be executed by insurance companies when the need arises. Finally, freight brokers can still exist as users of the system, by providing technology consultancy to their clients. For example, they can manage the transactions of client carriers who lack the necessary technology skills to utilize the system.

The application layer provides at least three key application areas for the trucking industry; namely, order management, horizontal collaboration, and sustainable trucking management.

Trucking orders in contract (long term) or spot (one time) markets are traditionally managed by freight brokers. This indirect relationship between shippers and carriers leads to prolonged reconciliation processes, and it also limits the level of vertical collaboration between shippers and carriers. In a nutshell, freight brokers secure the capacity of reliable and available carriers (holding the necessary insurance, good driver records, etc.) on behalf of reliable shippers (respectful of detention times, make payments on time, etc.). Once a load is tendered to a carrier, the freight broker monitors the progress of the cargo throughout the order lifecycle, and provides updates to the shipper on the status of the cargo. In addition, the freight broker provides an escrow service for the shipper and carrier by holding the billed amount on their behalf until both parties have met their obligations for the shipping agreement. On the other hand, in our proposed system architecture, a privacy-preserving decision algorithm, whose decisions are verified and validated by miners on the blockchain, replaces the match maker role of freight brokers. Once a shipper and carrier match each other on the platform, a smart contract automatically executes the terms of the load order (including the escrow services) on a contract (long-term) or spot market agreement. In addition, immutable, traceable, and transparent records are added to the distributed ledger for every single state update of the shipment, and those records are available to everybody on the platform. On the platform, both shippers and carriers build their reputation over time based on their performance records on the network (for example, safe driving records, delivery on time, respect of detention hours, payments are on time, etc.). With this level of transparency, supported by smart contract technology, shippers and carriers have the opportunity to engage in direct business with each other (vertical collaboration), and have access to wider markets beyond the reach of their freight brokers.

In addition to improving the vertical relationship between shippers and carriers, the proposed architecture based on blockchain and smart contract technology promotes horizontal collaboration in the trucking industry as well. For example, the decision algorithm on the platform can bring multiple carriers with a good reputation together to fulfill a single large load order of a shipper, which they cannot tender individually. This allows small carriers to increase their market share by doing business with large shippers, and it also helps large shippers reduce their dependency on large carriers through receiving more competitive offers from smaller carriers for their load requests. Furthermore, smart contracts can be designed on the platform to support relay trucking models, where two truck drivers swap trailers at a meeting point, and head to their home terminals with the new loads, taking them closer to their final destinations. Enabling truck drivers to spend more nights at home, relay trucking is considered one of the main solutions to driver shortages/retention issues and excessive empty mile in the trucking industry. In fact, relay trucking has been widely examined in operations research and in the transportation literature [67–69]. However, it has not been widely practiced in the trucking industry so far, due to the complexities of transactions and the high level of trust needed among partners.

As discussed earlier in Section 3, the trucking industry suffers from important sustainability problems, such as poor working conditions for workers, CO_2 emissions from truck operations, high level of empty miles of trucks on the roads, and a low level of load factors. The availability of immutable data generated from trucking operations in the industry and data analytic services can be used to find the root cause of these problems at a granular level based on historical transactions, and can help to promote the necessary solutions or policy changes accordingly.

6. Conclusions

Employing millions of people, and generating a significant portion of GDP in economies around the world, the trucking industry has significant impacts on the three pillars of sustainability: the economy, society, and the environment. However, the global trucking industry has also been suffering from serious problems for long time, such as poor working conditions of drivers, driver shortages and retention issues, extended payment times, and increased costs as a result of a low level of load factors and high percentage of empty miles. Any improvement in these issues would result in higher productivity and lower costs for the economy, improved working conditions and a reduced risks of accidents for society, and reduced carbon emissions and pollution for the environment. That being said, old business models and existing ICT solutions are not helping much in addressing these problems. In their industry reports, the EU, the WEF, and the OECD acknowledge the importance of collaboration among shippers and carriers in order to establish a sustainable freight transportation system, and call for more innovative technology solutions to foster collaboration in the trucking industry.

In this paper, we presented the overall structure and leading problems of the trucking industry based on a literature review, industry reports, and interviews. Following that, we discussed the role of horizontal collaboration in achieving sustainable trucking, as well as the barriers and facilitators for achieving collaboration.

Even though information sharing is essential to a successful collaboration experience, carriers perceive sharing sensitive business plans with their competitors as a threat to their future market positions. The transportation control tower concept was proposed in the logistics literature for solving this, such that a neutral and independent trustee would collect sensitive information from collaborating parties, keep it confidential, and process it for the maximum benefit of all collaborating parties. However, the trustee concept itself also suffers from trust-related concerns due to the risk of a trustee losing its neutral position and favoring a particular carrier in its decisions when confidentially processing collaboration data.

We extended the trustee concept from the literature by operationalizing it digitally, in a decentralized fashion, on a public blockchain network. In contrary to traditional trustee concepts, the proposed design artifact ensures the neutrality of the digital trustee in its decisions, as well as preventing the single point of failure problem intrinsic to centralized trustee models. In addition, the design artifact safeguards the confidential information of shippers and carriers on the public blockchain via integration with privacy-preserving off-chain computation and storage solutions.

We evaluated the viability of the proposed system, and its potential for the logistics industry, through expert opinions. Interviews with blockchain experts revealed that our design artifact is an innovative use case for the logistics industry, wherein the scalability and privacy issues of blockchain technology can be addressed through integration with off-chain computation and storage solutions. However, as blockchain is still an emerging technology, off-chaining approaches are still in their infancy, and further research is needed in that domain in order to develop a mature implementation of our design artifact. Even though the proposed system was not welcomed in the interviews with professionals from large and medium-sized carriers providing freight brokerage services in the industry, it received support from small carriers, which constitute the largest percentage of the carriers market, along with shippers and policy makers. In fact, interviewees at a large beverage company in the USA, and UND executives in Turkey, found the proposed system quite disruptive to the industry, and offered their support for a proof-of-concept implementation in the future stages of our research.

There are ample research opportunities to explore the potential application areas of blockchain technology in the logistics industry. Firstly, further investigation is needed to understand the attitudes of large and medium carriers against decentralized business models, as suggested in our design artifact, as well as to develop business models where they could also benefit through monetizing their excess resources, or providing technology consultancy to other carriers less competent with the technology. More studies are needed to investigate existing off-chaining approaches, to evaluate their advantages and disadvantages in implementing our design artifact. In addition, a prototype solution needs to be developed to measure its performance and understand the technology acceptance issues in the trucking industry. Furthermore, the proposed design artifact can be adapted for solving similar problems in other industries where collaboration matters. Finally, similar to any other research in the blockchain domain, further studies are needed to address the problems of wider adoption of the technology in the logistics industry, such as regulatory clarity, high energy consumption, governance issues, GDPR-related concerns, lack of standardization, and a lack of technical talent.

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Appendix A

Tables A1 and A2 present more information regarding the interviewees, and the semi-structured questions asked during those interviews.

Table A1. Interviews with transportation industry experts.

Company	Interviewee Title/Role
1. A large carrier in Turkey (≥5000 trucks)	Transportation Planning Manager: Coordinating with customers to schedule cargo pick-ups and developing strategies to minimize the empty miles of truck fleet
2. A medium carrier in Turkey (≥200 trucks)	Business Development Manager: Establishing relationships with shippers and sub-contracting for freight brokering operations
	General Manager: Driving the growth strategies and investment decisions for the company
3. A small carrier in Turkey	Owner Operator and Driver: Transporting farm products (potatoes and onions) for a grocery chain
4. Focus group interview at International Freight Forwarders Association (UND) in Turkey	Customs Administration Manager: Ensuring the proper execution of customs laws and regulations, as well as, where applicable, policies and means Researcher at Ministry of Transportation: Developing strategies for reducing the traffic of heavy trucks in urban areas
	VP at a Software Company: An executive at a leading software company providing blockchain-based software solutions in the international trade and supply chain management domains Blockchain Engineer: Developing decentralized applications using smart contracts
	Customs and Trade Consultant: Providing consultancy services in customs compliance, corporate governance, project management and implementation, supply chain security, trade facilitation, and minimizing administrative inefficiencies
	Strategy Development Manager at UND: Conducting sector and market research for seeking new business opportunities and projects, establishing sustainable customer relationships, and carrying out process improvements in the industry Executive Committee Member at UND: Coordinating with stakeholders in Turkey and foreign counterparts in Russia and the European Union to address the problems of Turkish carriers transporting international freight Technology Relations Member at UND: Managing relationships with industry and technology consultants for accelerating the digital transformation in the industry
5. A leading beverage company in the US	Director of Transportation Operations: Establishing relationships with freight brokers and planning the shipments with carriers
	Vice President of Engineering: Managing R&D activities in the organization

Semi-structured interview questions for industry experts from the transportation area

1. What is the structure of the road freight industry in your country?
    a. How many people are working in the industry?
    b. What is the contribution to the economy?
    c. What are the key players in the industry (i.e., carriers, shippers, brokers etc.)?
2. What are the most common business models executed in the industry?

   a. How do shippers and carriers match each other?
   b. What is the split of contract business vs spot market business?
   c. What is the role of brokers?
   d. What is the level of direct collaboration among carriers or among shippers?

3. What are the most important problems of the industry?
4. What are the factors aggravating (weaknesses) those problems?
5. What could be done to help with those problems?
6. What do you think about horizontal collaboration with another carrier?
7. What is the level of technology usage in the industry?
   a. Cloud technologies, data analytics, mobile applications
   b. Do you use electronic load marketplaces?
      i. What are the pros and cons of those platforms?
8. What is your experience with blockchain technology?
9. (After explaining blockchain technology and our design artifact)
   a. What do you think about collaborating with other carriers on a platform similar to our design artifact?
   b. What could be the potential problems with such a system?
   c. What else would you desire to see in that system?

Table A2. Interviews with blockchain technology experts.

Company	Interviewee Title
6. An international weekly business journal in Turkey	Blockchain and Cryptocurrency Expert: Contributing writer on new media, digital transformation, and cryptocurrencies with ≥20 years of experience as an executive manager in the telecommunication and software industry
7. Blockchain start-up in Turkey	Blockchain Entrepreneur: Founder of a software start-up companies in Turkey with ≥20 years of experience in software engineering and development of a decentralized system, and a well-respected speaker, educator, and consultant on blockchain technology in Turkey
8. Blockchain Turkey platform	Co-founder: Coordinating with stakeholders from different industries for establishing a sustainable blockchain ecosystem in Turkey to foster innovative business models in those industries

Semi-structured interview questions for blockchain technology experts

1. What is blockchain technology?
2. What makes that technology a disruptive one exactly?
3. Where is blockchain technology on the hype cycle?
4. How mature is the technology at the moment?
5. How could that technology be useful for the transportation industry?
6. (After explaining current business models in road freight transportation industry)
   a. Can we use this technology to reduce or eliminate trust-related concerns among carriers and foster collaboration among them?
7. Can we integrate complex optimization and data storage systems with blockchain technology?
   a. How can we push complex calculations and data storage requirements to off-chain, but still benefit from the advantages of blockchain technology?
8. What are the other challenges for organizations when they want to use blockchain technology for their businesses?

References

1. Durach, C.F.; Blesik, T.; von Düring, M.; Bick, M. Blockchain Applications in Supply Chain Transactions. *J. Bus. Logist.* **2021**, *42*, 7–24. [CrossRef]
2. Aditjandra, P.T. Europe's freight transport policy: Analysis, synthesis and evaluation. In *Advances in Transport Policy and Planning*; Academic Press: New York, NY, USA, 2018; Volume 1, pp. 197–243.
3. EUROSTAT (2019). Energy, transport and environment statistics. Available online: https://ec.europa.eu/eurostat/documents/3217494/10165279/KS-DK-19-001-EN-N.pdf/76651a29-b817-eed4-f9f2-92bf692e1ed9 (accessed on 30 September 2020).
4. Kent, P.L. *Freight Transport for Development Toolkit: Road Freight*; World Bank: Washington, DC, USA, 2009; Available online: http://documents.worldbank.org/curated/en/649241468155983939/Freight-transport-for-development-toolkit-road-freight (accessed on 30 September 2020).
5. Sprung, M.J. *Freight Facts and Figures 2017*; Technical Report; Bureau of Transportation Statistics: Washington, DC, USA, 2018. Available online: https://rosap.ntl.bts.gov/view/dot/34923 (accessed on 30 September 2020).
6. Åkeriföretag, S. A week without Truck Transport: Four Regions in Sweden. The International Road Transport Union. 2009. Available online: https://www.iru.org/apps/cms-filesystem-action?file=mix-publications/A-Week-without-Truck_full.pdf (accessed on 30 September 2020).
7. McKinnon, A. Life without trucks: The impact of a temporary disruption of road freight transport on a national economy. *J. Bus. Logist.* **2006**, *27*, 227–250. [CrossRef]
8. Apostolopoulos, Y.; Sönmez, S.; Hege, A.; Lemke, M. Work Strain, Social Isolation and Mental Health of Long-Haul Truckers. *Occup. Ther. Ment. Healing* **2016**, *32*, 50–69. [CrossRef]
9. Lillegren, J.; Rietzler, J. Infographic: 9 Impressive Facts about Trucking. HNI Risk Asvisors. Available online: https://www.hni.com/blog/9-impressive-trucking-facts (accessed on 30 September 2020).
10. Allen, J.; Bektas, T.; Cherrett, T.; Friday, A.; McLeod, F.; Piecyk, M.; Austwick, M.Z. Enabling a freight traffic controller for collaborative multidrop urban logistics: Practical and theoretical challenges. *Transp. Res. Rec.* **2017**, *2609*, 77–84. [CrossRef]
11. Demir, E.; Huang, Y.; Scholts, S.; Van Woensel, T. A selected review on the negative externalities of the freight transportation: Modeling and pricing. *Transp. Res. Part E Logist. Transp. Rev.* **2015**, *77*, 95–114. [CrossRef]
12. American Transportation Research Institute (ATRI) (2019). Critical Issues in the Trucking Industry-2019. Available online: https://truckingresearch.org/wp-content/uploads/2019/10/ATRI-Top-Industry-Issues-2019-FINAL.pdf (accessed on 30 September 2020).
13. Londsale, J. How to Reboot the Trucking Industry? Medium Blog. 2019. Available online: https://medium.com/8vc-news/how-to-reboot-the-trucking-industry-60757dac3968 (accessed on 30 September 2020).
14. Doherty, S.; Hoyle, S. *Supply Chain Decarbonization: The Role of Logistics and Transport in Reducing Supply Chain Carbon Emissions*; World Economic Forum: Geneva, Switzerland, 2009.
15. European Commission (EC). *An Overview of the EU Road Transport Market in 2015*; European Commission, Directorate-General Mobility and Transport: Brussels, Belgium, 2017.
16. Tavasszy, L. Innovation and Technology in Multimodal Supply Chains. In *International Transport Forum Discussion Papers*; OECD Publishing: Paris, France, 2018.
17. Audy, J.F.; D'Amours, S.; Lehoux, N.; Rönnqvist, M. Coordination in collaborative logistics. In Proceedings of the International Workshop on Supply Chain Models for Shared Resource Management, Brussels, Belgium, 21–22 January 2010.
18. Simatupang, T.M.; Sridharan, R. The Collaborative Supply Chain. *Int. J. Logist. Manag.* **2002**, *13*, 15–30. [CrossRef]
19. Chopra, S.; Meindl, P. Supply Chain Management. Strategy, Planning & Operation. In *Das Summa Summarum des Management*; Springer Science and Business Media LLC: Berlin/Heidelberg, Germany, 2007; pp. 265–275.
20. Barratt, M. Understanding the meaning of collaboration in the supply chain. *Supply Chain Manag. Int. J.* **2004**, *9*, 30–42. [CrossRef]
21. Soosay, C.A.; Hyland, P. A decade of supply chain collaboration and directions for future research. *Supply Chain Manag. Int. J.* **2015**, *20*, 613–630. [CrossRef]
22. Stadtler, H. A framework for collaborative planning and state-of-the-art. *OR Spectr.* **2009**, *31*, 5–30. [CrossRef]
23. Gharaei, A.; Karimi, M.; Shekarabi, S.A.H. An integrated multi-product, multi-buyer supply chain under penalty, green, and quality control polices and a vendor managed inventory with consignment stock agreement: The outer approximation with equality relaxation and augmented penalty algorithm. *Appl. Math. Model.* **2019**, *69*, 223–254. [CrossRef]
24. Yang, Y.; Pan, S.; Ballot, E. Innovative vendor-managed inventory strategy exploiting interconnected logistics services in the Physical Internet. *Int. J. Prod. Res.* **2017**, *55*, 2685–2702. [CrossRef]
25. Sari, K. Exploring the impacts of radio frequency identification (RFID) technology on supply chain performance. *Eur. J. Oper. Res.* **2010**, *207*, 174–183. [CrossRef]
26. Pan, S.; Trentesaux, D.; Ballot, E.; Huang, G.Q. Horizontal collaborative transport: Survey of solutions and practical implementation issues. *Int. J. Prod. Res.* **2019**, *57*, 5340–5361. [CrossRef]
27. Guajardo, M.; Rönnqvist, M. A review on cost allocation methods in collaborative transportation. *Int. Trans. Oper. Res.* **2016**, *23*, 371–392. [CrossRef]
28. Nagarajan, M.; Greys, S. Game-theoretic analysis of cooperation among supply chain agents: Review and extensions. *Eur. J. Oper. Res.* **2008**, *187*, 719–745. [CrossRef]

29. Serrano-Hernández, A.; Juan, A.A.; Faulin, J.; Perez-Bernabeu, E. Horizontal collaboration in freight transport: Concepts, benefits and environmental challenges. *SORT* **2017**, *1*, 393–414.
30. Basso, F.; D'Amours, S.; Rönnqvist, M.; Weintraub, A. A survey on obstacles and difficulties of practical implementation of horizontal collaboration in logistics. *Int. Trans. Oper. Res.* **2019**, *26*, 775–793. [CrossRef]
31. Cao, M.; Zhang, Q. Supply chain collaboration: Impact on collaborative advantage and firm performance. *J. Oper. Manag.* **2010**, *29*, 163–180. [CrossRef]
32. Chen, J.V.; Wang, C.-L.; Yen, D.C. A causal model for supply chain partner's commitment. *Prod. Plan. Control.* **2014**, *25*, 800–813. [CrossRef]
33. Cruijssen, F.; Cools, M.; Dullaert, W. Horizontal cooperation in logistics: Opportunities and impediments. *Transp. Res. Part E Logist. Transp. Rev.* **2007**, *43*, 129–142. [CrossRef]
34. Muir, M. *European Supply Chain Horizontal Collaboration—A Brief Analysis of Eyefortransport's Recent Survey*; Eye for Transport: London, UK, 2010.
35. Islam, S.; Shi, Y.; Ahmed, J.U.; Uddin, M.J. Minimization of empty container truck trips: Insights into truck-sharing constraints. *Int. J. Logist. Manag.* **2019**, *30*, 641–662. [CrossRef]
36. Cruijssen, F. CO3 Position Paper: Framework for Collaboration. Tilburg University. 2012. Available online: https://pure.uvt.nl/ws/portalfiles/portal/45898351/CO_framework_for_collaboration_full_report_February_2012.pdf (accessed on 30 September 2020).
37. Frisk, M.; Göthe-Lundgren, M.; Jörnsten, K.; Rönnqvist, M. Cost allocation in collaborative forest transportation. *Eur. J. Oper. Res.* **2010**, *205*, 448–458. [CrossRef]
38. Pedersen, J.T. One common framework for information and communication systems in transport and logistics: Facilitating interoperability. In *Sustainable Transport*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 165–196.
39. Klems, M.; Eberhardt, J.; Tai, S.; Härtlein, S.; Buchholz, S.; Tidjani, A. Trustless intermediation in blockchain-based decentralized service marketplaces. In *International Conference on Service-Oriented Computing*; Springer: Cham, Switzerland, 2017; pp. 731–739.
40. Einav, L.; Farronato, C.; Levin, J. Peer-to-Peer Markets. *Annu. Rev. Econ.* **2016**, *8*, 615–635. [CrossRef]
41. Schlauderer, S.; Overhage, S. How perfect are markets for software services? An economic perspective on market deficiencies and desirable market features. In Proceedings of the European Conference on Information Systems, Helsinki, Finland, 9–11 June 2011.
42. Ast, F.; Lesaege, C. 'Kleros: A Protocol for Decentralized Justice' in Dispute Revolution: The Kleros Handbook of Decentralized Justice. 2019. Available online: https://ipfs.kleros.io/ipfs/QmZeV32S2VoyUnqJsRRCh75F1fP2AeomVq2Ury2fTt9V4z/Dispute-Resolution-Kleros.pdf (accessed on 30 September 2020).
43. Caplice, C. Electronic Markets for Truckload Transportation. *Prod. Oper. Manag.* **2009**, *16*, 423–436. [CrossRef]
44. Christidis, K.; Devetsikiotis, M. Blockchains and Smart Contracts for the Internet of Things. *IEEE Access* **2016**, *4*, 2292–2303. [CrossRef]
45. Alharby, M.; Van Moorsel, A. Blockchain-based smart contracts: A systematic mapping study. *arXiv* **2017**, arXiv:1710.06372.
46. Crosby, M.; Pattanayak, P.; Verma, S.; Kalyanaraman, V. Blockchain technology: Beyond bitcoin. *Appl. Innov.* **2016**, *2*, 71.
47. IBM. Maersk and ibm Introduce Tradelens Blockchain Shipping Solution. 2018. Available online: https://newsroom.ibm.com/2018-08-09-Maersk-and-IBM-Introduce-TradeLens-Blockchain-Shipping-Solution (accessed on 30 September 2020).
48. Kamath, R. Food Traceability on Blockchain: Walmart's Pork and Mango Pilots with IBM. *J. Br. Blockchain Assoc.* **2018**, *1*, 1–12. [CrossRef]
49. Kshetri, N. Blockchain and the Economics of Food Safety. *IT Prof.* **2019**, *21*, 63–66. [CrossRef]
50. American Trucking Associations. Reports, Trends & Statistics: Industry Data. Available online: https://www.trucking.org/economics-and-industry-data (accessed on 30 September 2020).
51. Hevner, A.; Chatterjee, S. Design Science Research in Information Systems. In *Design Research in Information Systems*; Springer: Boston, MA, USA, 2010; pp. 9–22.
52. Hevner, A.R. A three cycle view of design science research. *Scand. J. Inf. Syst.* **2007**, *19*, 4.
53. Armstrong & Associates. Trends in 3PL and Customer Relationships 2017 (Sample). 2017. Available online: https://theloadstar.com/wp-content/uploads/Trends-in-3PL-Customer-Relationships-SAMPLE-First5Pages.pdf (accessed on 30 September 2020).
54. Hagiu, A.; Jullien, B. Why do intermediaries divert search? *RAND J. Econ.* **2011**, *42*, 337–362. [CrossRef]
55. Armstrong, M.; Zhou, J. Paying for Prominence. *Econ. J.* **2011**, *121*, F368–F395. [CrossRef]
56. International Energy Agency. *The Future of Trucks: Implications for Energy and the Environment*; IEA: Paris, France, 2017. [CrossRef]
57. Chottani, A.; Hastings, G.; Murnane, J.; Neuhaus, F. *Distraction or Disruption? Autonomous Trucks Gain Ground in US Logistics*; McKinsey&Company: New York, NY, USA, 2018; Available online: https://www.mckinsey.com/industries/travel-transport-and-logistics/our-insights/distraction-or-disruption-autonomous-trucks-gain-ground-in-us-logistics (accessed on 30 September 2020).
58. Sieber, W.K.; Robinson, C.F.; Birdsey, J.; Chen, G.X.; Hitchcock, E.M.; Lincoln, J.E.; Nakata, A.; Sweeney, M.H. Obesity and other risk factors: The National Survey of U.S. Long-Haul Truck Driver Health and Injury. *Am. J. Ind. Med.* **2014**, *57*, 615–620. [CrossRef]
59. Costello, B.; Karickhoff, A. *Truck Driver Shortage Analysis*; The American Trucking Associations: Arlington, VA, USA, 2019; Available online: https://www.trucking.org/sites/default/files/2020-01/ATAs%20Driver%20Shortage%20Report%202019%20with%20cover.pdf (accessed on 30 September 2020).

60. Speltz, E.; Murray, D. *Driver Detention Impacts on Safety and Productivity*; American Transportation Research Institute: New York, NY, USA, 2019.
61. Kaplan, D. *Four Strategies to Help Freight Brokerages Get Paid*; Material Handling & Logistics: Independence, OH, USA, 2019; Available online: https://www.mhlnews.com/transportation-distribution/four-strategies-help-freight-brokerages-get-paid (accessed on 30 September 2020).
62. Croce, A.; Musolino, G.; Rindone, C.; Vitetta, A. Route and Path Choices of Freight Vehicles: A Case Study with Floating Car Data. *Sustainability* **2020**, *12*, 8557. [CrossRef]
63. Croce, A.; Musolino, G.; Rindone, C.; Vitetta, A. Sustainable mobility and energy resources: A quantitative assessment of transport services with electrical vehicles. *Renew. Sustain. Energy Rev.* **2019**, *113*, 109236. [CrossRef]
64. Musolino, G.; Rindone, C.; Vitetta, A. Evaluation in transport planning: A comparison between data envelopment analysis and multi criteria decision making methods. In Proceedings of the 31st Annual European Simulation and Modelling Conference, Lisbon, Portugal, 25–27 October 2017.
65. Eberhardt, J.; Tai, S. On or Off the Blockchain? Insights on Off-Chaining Computation and Data. In *European Conference on Service-Oriented and Cloud Computing*; Springer: Cham, Switzerland, 2017; pp. 3–15.
66. Wang, B.; Luo, W.; Zhang, A.; Tian, Z.; Li, Z. Blockchain-enabled circular supply chain management: A system architecture for fast fashion. *Comput. Ind.* **2020**, *123*, 103324. [CrossRef]
67. Campbell, J.F. Strategic network design for motor carriers. In *Logistics Systems: Design and Optimization*; Springer: Boston, MA, USA, 2005; pp. 245–278.
68. Vergara, H.A.; Root, S. Mixed fleet dispatching in truckload relay network design optimization. *Transp. Res. Part E Logist. Transp. Rev.* **2013**, *54*, 32–49. [CrossRef]
69. Uster, H.; Kewcharoenwong, P. Strategic Design and Analysis of a Relay Network in Truckload Transportation. *Transp. Sci.* **2011**, *45*, 505–523. [CrossRef]