blockchains

MDPI

Article

Blockchain Solutions for Logistic Management

Veneta Aleksieva *, Hristo Valchanov, Venelin Maleshkov and Aydan Haka

Faculty of Computer Sciences and Automation, Technical University of Varna, 9010 Varna, Bulgaria; hristo@tu-varna.bg (H.V.); v.maleshkov@tu-varna.bg (V.M.); aydin.mehmed@tu-varna.bg (A.H.)
* Correspondence: valeksieva@tu-varna.bg

Abstract: Blockchain technologies have the potential to fundamentally change logistics and supply chain management. By leveraging the capabilities of blockchain technology, businesses can increase efficiency, reduce costs, and improve security and trust in operations. However, there are still difficulties to overcome in terms of uptake and implementation. This article examines the various blockchain technologies applicable in the field of logistics, presents the benefits and limitations of blockchain technologies in this aspect, and offers a summary of the existing technologies used in the logistics sector. According to this, blockchain-based models applicable both to a specific stage of the logistics process (e.g., transportation of goods, materials, and feedstocks; management of warehouse operations; cargo tracking; etc.) and related insurance services have been proposed. The proposed models have been tested in a lab environment on the HyperLedger Fabric platform, and the results show that they are fully functional.

Keywords: blockchain; HyperLedger Fabric; logistics; hierarchical model; blockchain-based logistic model

check for updates

Citation: Aleksieva, V.; Valchanov, H.; Maleshkov, V.; Haka, A. Blockchain Solutions for Logistic Management. *Blockchains* **2024**, 2, 445–457. https://doi.org/10.3390/blockchains2040019

Academic Editors: Keke Gai and Liehuang Zhu

Received: 24 July 2024
Revised: 16 October 2024
Accepted: 28 October 2024
Published: 31 October 2024

1. Introduction

With the appearance of smart contracts in blockchain technologies and the first regulations with standards in Ethereum (ERC20, ERC223, ERC777, ERC1820, and ERC721) [1–5] guaranteeing the correct operation of the smart contract code, applications of blockchain technology for various business solutions are beginning. This goes beyond the previously imposed notion that blockchain technologies are only suitable for cryptocurrencies and challenges both science and business to find solutions based on blockchains and smart contracts that improve existing solutions in various aspects: security of transactions, anonymity of participants in the network, accessibility of the information, transparency of processes for all participants, irreversibility of recorded events/data, possibility to record different type and format of data, encryption of data, time-stamped transactions, and impossibility of tampering with already recorded data.

The blockchain-based solutions offer workflow with trusted data, end-to-end visibility, and automation to multiple organizations and industries. The solutions change the flow of data from centrally designed and resource-intensive products to knowledge-intensive decentralized services designed and produced with strong support from advanced analytics and artificial intelligence. The techniques of collective intelligence, artificial intelligence, advanced analytics, big data, digital transformation, and service design are good examples of innovative technologies applied from global business leaders. The blockchain-based solutions are also innovative direction to change the business toward new horizons. But not every business is suitable for implementing blockchain-based solutions. At different adoption stages like research, pilot, development, and production, companies are setting their footprints with this burgeoning technology, but more than 30 solutions are fully functional. According to 2021 statistics [6] for 100 companies, 81 of them are ready to try blockchain-based solutions. If we read a popular statistic on [7], 30 examples of blockchain solutions are presented.

The crypto API platform, Node as a Service (NaaS), has been launched as Blockchain as a Service (BaaS) on Microsoft Azure since 2018, offering paid applications (crypto APIs) for it based on Ethereum [8]. Thus, with the help of the hybrid cloud capabilities of Microsoft Azure, customers are provided with new blockchain services that can simplify their complex business processes. The daily emergence of cryptocurrencies and the introduction of blockchain-based pilot solutions require society to establish a legal framework to protect the participants of blockchain-based solutions. The EU Parliament published in 2023 the first EU rules to trace crypto-asset transfers for customer protection [9]. Since 2018, the first public sector blockchain infrastructure in Europe has been created, European Blockchain Services Infrastructure (EBSI) [10]. In 2023, the European Commission launched the European Regulatory Sandbox for Blockchain for the period 2023–2026, where up to 20 projects per year of business companies or scientific organizations will be able to test their products and services [11]. All these capabilities provide developers and scientists with a stable environment in which to create, test, and prototype various blockchain-based business solutions.

Websites have appeared where applications using smart contracts on different blockchains are divided into categories. One such current classification for blockchain-based applications in the logistics sector [12] shows that there are currently 12 active cryptocurrency blockchains running smart contracts for solutions in this sector, while many times, more cryptocurrencies (1483) are actively used for entertainment, such as memes. According to [13], the cryptocurrency market is valued at $2.6 trillion with an average increase of 0.77% over the last day (21 July 2024). The total market cap for stablecoins is $164.6 billion. The total crypto market volume over the last 24 h is $59.3 billion, and the number of confirmed transactions per day is 680,330 on 20 July 2024. That's a huge amount of data per day that needs to be stored and protected but accessible for retrieval 24/7 to be used for reference, comparison, analysis, and trend prediction. What's more, duplicate, forged, and incorrect data can lead to lost revenue and compliance issues. Blockchain and big data analytics together can ensure the authenticity of data records in larger volumes, such as terra and zettabytes, but designers of such systems must carefully consider which data to store, where to store it, and in what format for timely and accurate processing that would lead to correct management decisions for the respective business. In addition, with blockchain-based solutions, all participants in the process can make inquiries about the status and location of the product at any time, which ensures the product's originality and non-substitutability along the manufacturer-to-customer chain, proving compliance violations and delivery delays, enables immediate action to be taken during emergencies (e.g., in the event of a product recall from the market) and is proven to ensure compliance with regulatory requirements. In addition, by combining blockchain with Internet of Things (IoT) technology, supply chains can automate the tracking of manufacturing, transportation, and quality control conditions.

A reason for the slower penetration of blockchain-based solutions in the logistics sector is that logistics is a complex and multifaceted business process in which the management and optimization of information, material, and financial flows are carried out at all levels and subsystems, depending on the management needs: operational, tactical, strategic, integration, and collaboration layers. Existing automated solutions mainly focus on a single process (e.g., only on warehouse management, transport management, open area management, or material requirements planning) to ensure the continuity of the production process, management of forwarding, and so forth. Automated solutions require the use of technologies for automatic identification of units: commercial, logistical, and locations. Practice has proven barcodes (or QR codes) and RFID to be the most suitable data carriers for fast processing with minimal human error. Nowadays, a common approach is to use different software for different subsystems. Such systems facilitate a limited type and number of transactions, process large volumes of data that are uniform, and allow the output of management inquiries for the relevant subsystem. Adding automation to another subsystem necessitates a review and redesign of existing processes to "straighten" them into consistent flow and avoid process duplication, delays, and lack of connectivity between processes. The correct structuring of information, goods, and financial flows when introducing a unified information system will lead to acceleration and optimization of the work process, a reduction of operating costs, improved traceability of goods, improved control of task performance, and even an increase in the quality of customer service and work with counterparties. These are precisely the advantages that blockchain technology itself provides and is the basis of the idea of seeking blockchain-based solutions in logistics.

The proven advantages of blockchain solutions raise the question of where in automated logistics management systems they can be applied and what model is appropriate in order to increase efficiency, reduce operational costs, enhance security and trust, and automate the tracking of production, transportation, and quality control conditions, not only by the manufacturing company but also by its partners (insurers, forwarding companies, and customers), allowing them to share tracking data as a means to verify product authenticity and ensure ethical supply chain practices.

Like any new technology, blockchain is coming in smoothly and raises doubts about whether it is cost-effective to transit from an established working solution to a blockchain-based solution. For functions such as real-time data analysis and traceability, blockchain creates a huge impact when combined with big data analytics and is here to assure that the infrastructure will become more cost-effective in the near future. Blockchain technology brings trust, transparency, security, and visibility to all participants in the business network. These benefits outweigh skepticism about the perceived high cost of transitioning to blockchain-based solutions.

Based on the review of existing solutions in the logistics sector and the supply chain, this paper proposes an abstract layered model for managing logistics processes, analyzing the possibilities of applying blockchain solutions according to this model. To prove the applicability of the proposed hierarchical management model in blockchain-based logistics, the authors present a management model for a logistics subsystem. This use case is experimentally implemented on a private blockchain, HyperLedger Fabric.

The paper is organized as follows: Section 2 discusses earlier work in this area. Section 3 describes the proposed hierarchical logistic management model and presents solutions of related works and previous authors' works on which layer in this logistic management model belong. Section 4 presents one example of application of the proposed hierarchical model through authors' blockchain-based model of one subsystem, namely subsystem "Process for delivery of production to a distribution warehouse". This solution works on HyperLedger fabric blockchain, and the results are presented and discussed. Finally, Section 5 concludes the work and outlines some promising directions for further research.

2. Related Works

A number of critical reviews of existing blockchain-based solutions in this sector have been conducted. In [14], which is from the dawn of the emergence of smart contracts, the problem with the lack of clear regulations and uniform standards for the use of these technologies is addressed. As explained above, this problem has been solved for established blockchains, such as Ethereum and HyperLedger Fabric, and in the last two years, the European Parliament has been actively filling the legal gap. In [15,16], attempts are made for the first time to analyze the applicability of blockchains in the logistics sector. At the same time, only the advantages of blockchain technologies for any business application are pointed out, and how they would optimize a process with many interconnected functions and a large number of participants, without focusing on specific logistics processes or analyzing possible patterns, are presented.

In [17–38], the already mentioned advantages of integrating blockchain technologies into logistics processes are explained, and some key risks and challenges are indicated, such as scalability problems due to high energy consumption, lack of standardization, and increased costs of implementing the technology. Moreover, they analyze the changes in the roles and functions of the different actors in supply chains and reverse logistics when transitioning to blockchain-based solutions and integration with existing systems.

For the first time, models applicable to any subsystem of a logistics process or supply chain appeared in 2018. The first attempts are aimed at the operational level of logistics, reverse logistics or warehouse inventory management [39–42]. Most of them are only at the conceptual level—architecture, analytical/mathematical model, interaction model, and distribution of roles and functions in a separate subsystem or specific business—without a test, prototype, or pilot proof of their workability with an implementation on a specific blockchain.

Proposed models for logistics process subsystems using IoT (RFID) are also initially proposed at a conceptual level [43–46], while in [47–52], the proposed models are tested on a specific blockchain but offer optimization of only one process. Models that cover several subsystems are proposed in [53–55], but they also offer logistics management within a specific business sector.

In [56–60], pilot applications using blockchains for various subsystems of the logistics process or businesses with a short life cycle are proposed. They are implemented with smart contracts on Ethereum and derivative blockchains. And in [61], a model is proposed but tested on a private blockchain, HyperLedger Fabric. The most implemented solutions in the field of logistics and supply chain are based on Ethereum, HyperLedger Fabric, and IOTA due to the specific role of the blockchain in the specific solution. The most common subsystems of the logistics process are related to inventory management [42,45,52,56,62,63], which are part of warehouse management as a whole [39–42,45,47,52,56,61–64].

Based on the analysis, Table 1 presents the most commonly used blockchain technologies applicable in the field of logistics. For greater security and privacy, private blockchains are preferred, while for payment-related applications requiring quick and easy approval, public blockchains with smart contracts are chosen. All blockchain technologies presented here achieve scalability but use different techniques to track goods and transactions.

Table 1. Blockchain Technologies Applicable in Logistics Processes.

Blockchain Name	**Ethereum**	**HyperLedger Fabric**	**Corda**	**Sweetbridge**	**IOTA**	**VeChainThor**
Access of peers on the Network	Public	Private	Private	-	Public	Public
Consensus mechanism	PoW/PoS	PBFT, Kafka, Raft	Optionally	Dual token model	DAG	PoA
Security	Ethash	SHA-256, P-256, RSA	SHA-256	SHA-256	Troika	SHA-256, ECDSA
Smart contracts	Yes	Yes	Yes	No	No	Yes
Cryptocurrency	Ether	No	No	Sweetcoin Bridgecoin	IOTA	VET
Scalability	Yes	Yes	Yes	Yes	Yes	Yes
Traceability	Yes	Yes	Yes	Yes	Yes	Yes
Existing solutions-test, pilot, implemented	Viant, Modum, Provenance	IBM FoodTrust, ChainTrack, PharmaChain	CordaTrack, AgriChain, LiquorLens	Sweetbridge	IoTrace, IoTangle Logistics, SmartChain Iota	VeChain

The choice of the blockchain platform for logistics processes and supply chains largely depends on the needs of the business: speed, privacy, programmability, or efficiency. There are other blockchain technologies suitable for various aspects of logistics processes, but they do not yet offer commercial or pilot solutions and are still at the lab prototype stage. The continuous development and improvement of blockchain technologies promise businesses increasingly flexible and adaptable solutions, addressing the shortcomings of traditional solutions without the application of blockchain technologies.

Table 2 presents automated solutions for logistics processes by different subsystems of the logistics process. The proposed blockchain-based models of the authors of this article are presented in a separate column. They also do not cover all logistics subsystems and focus on developing models for not particularly complex processes that allow tracking with IoT. It is noteworthy that in all the considered decisions, a clear hierarchy in decision-making in the overall logistics process and supply chains is not presented.

Table 2. Solutions for Logistic Management of Subsystems.

Logistic Subsystem	Examples Without Blockchain	Examples With Blockchain	Authors' Blockchain-Based Models
Production or specific process	[16]	[44]	[65–68]
Warehouse	[42,64]	[47,61]	[69]
Distribution	[50]	-	-
Inventory	[41,43,45,63]	[39,40,42,52,56,62,63]	[70,71]
Transport	[53,58]	[17,33,48]	[72]
Information and control	[43,45]	[49,59]	[70,71]
Reverse	[39,51]	[36,40]	-
Management	[43]	[41,46,59,61]	-

3. Proposed Hierarchical Logistic Management Model

In Table 3, logistics management is presented at four hierarchical levels in terms of decision-making and the type and volume of data processed. The first level (operational layer) refers to the physical work associated with the goods: warehousing, packaging, order processing, and inventory control. The largest volume of data is generated here, and IoT technologies can be used, such as QR tags and RFID. The second level (tactical layer) separates the activities related to the transport of the goods: planning the route, analyzing the transport costs, and optimizing the work process through cross-docking. The strategic level (strategic layer) is suitable for the integration of new technologies, risk management, and planning of the entire logistics network connected to third parties (insurers, distributors, suppliers, and customers). The highest level (integration and collaboration layer) is related to improving the overall process, making strategic decisions based on the results obtained from the analyzed information from the lower levels, implementing innovative technologies to improve logistics processes by forecasting deliveries, optimizing storage areas, inventory management, entering new markets, and so forth. The presented hierarchical scheme detects the gaps in the existing solutions and provides an opportunity for new fragmentation of processes and creation of new information flows along the management hierarchy, leading to reduction of duplication of processes, minimization of delays from incorrect planning, and clearer forecasting.

Existing solutions based on blockchains mainly solve problems at the bottom two levels of the model: operational and tactical. The most intuitive approach when switching to an automated management system is to take the layered approach. On the operational layer, where the material and financial flows occur and large volumes of data are generated, systems are applied to process these routine operations in order to minimize human errors, speed up material and financial flows, and ensure interaction between different departments and business partners.

The main purpose of these systems is to facilitate the control and management of day-to-day core logistics activities. The data generated at this level have large volumes and high levels of detail. They should be reworked into references and summarized when used by upper-level managers. At this level, management decisions can be made based on the analysis of employee productivity, useful working hours, volume of material flows, densification of storage areas, environmental control in warehouses, packaging, management of internal transport, and so forth. Thus, at the operational level, automated systems can be considered at two sublevels: the level of transactions (where data is collected) and the level of management of individual subsystems.

Table 3. Hierarchical Logistic Management.

Layer	Focus	Example
4. Integration and collaboration layer	Analytics and data-driven decision-making Integrating management systems Customer relationship management and service quality Innovation in logistics services	[57]
3. Strategic layer	Logistic network design Strategic partner and third-party logistics relationships Technology integration (IoT, RFID, QR) Risk management	[41,43,45,46,48,49,59,61]
2. Tactical layer	Route optimization Transportation cost analysis and freight auditing Cross-docking	[17,33,48,53,69]
1. Operational layer	Warehousing and storage Order fulfillment and distribution Packaging and handling Inventory control and management	[39,40,42,47,52,56,61,63,65, 68,70–72]

In the proposed hierarchical model, presented in Figure 1, these basic functions are at the lowest level, transaction processing system, and are reduced to delivery of materials, production, warehouse management, sales representative, and shipping. The chosen granularity is low, and each subsystem can be divided into stages and subsystems depending on the complexity of the specific business in which logistic management is applied.

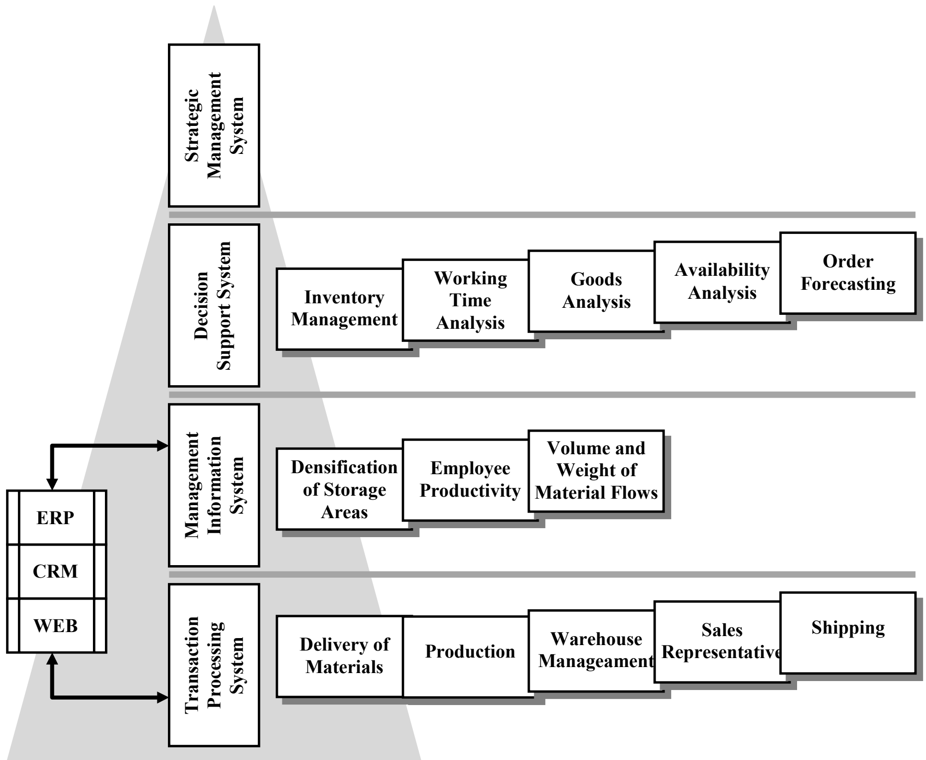

Figure 1. Proposed hierarchical logistic management model.

At the second level, management information system, tactical decisions are made for the company. They are based on the aggregated information from the lower level. They do not track all data in detail, but only certain indicators that guarantee stock security of sales, process continuity, inventory management, and delivery delays and are reduced to densification of storage areas, employee productivity, volume, and weight of material flows. Enterprise resource planning (ERP), customer relationship management (CRM), and website systems operate on these two levels.

At the third level, decision support system, there are systems that support decision-making by the top managers at a strategic level. In the proposed model, these systems are divided into subsystems such as inventory management, working time analysis, goods analysis, and order forecasting.

At the fourth level, strategic management system, no subsystems are presented because at this level, the systems are complex and work with different sources. These systems are related to optimization tasks, such as determining the type, number, and locations of distribution centers. Here, many tasks are relative to the details of the specific business and planning and forecasting strategic decisions, such as entering new markets with existing products or developing new products and so forth.

The proposed model outlines which data can be processed in real time, which can be stored as big data (e.g., Cloud-Edge solution) and which should be stored on the blockchain, depending on which level managers will use them and which subsystem they will be part of. Blockchain solutions are best suited for the bottom two levels, with separate links to third-level subsystems. Artificial intelligence systems are suitable for the upper two levels of the model, decision support system and strategic management system, while IoT technologies (QR tags, barcodes, and RFIDs) are only suitable for the lowest level, transaction processing system.

In our paper [70], we have analyzed existing abstract models (related works) and have proposed an abstract model for logistics based on blockchain and IoT. In the current paper, based on the idea from [70], we have mainly focused on the logistics management to propose a new abstract model. The model in [70] is oriented to the integration of two technologies (blockchain and IoT), and it is fine-grained layered, as it focuses on physical implementation, protocols, consensus mechanisms, and so forth. This makes it applicable in various industrial fields, not only in logistics. In [70], we have presented a use case of the logistics model based on blockchain and IoT, but in the context of tracking and proving events, not in the context of logistic processes management.

The current proposed layered model presents another cut of abstraction, which transforms the logistics process management through the prism of blockchain technology. It differs from the traditional model of management and control in logistics processes because it provides the opportunity for different levels of management to access through smart contracts only the data that is necessary to make a decision at the corresponding level. The proposed abstract model can be adapted to different specific domains. But for each of these areas, there may be different limitations of the model that can be subjectively interpreted as shortcomings.

Based on the proposed model, complex blockchain-based systems can be built, and following the model ensures that no business-essential processes will be omitted during the automation of management and there will be no duplicate, forged, or missing data.

4. Proposed Blockchain-Based Model of One Logistic Management Subsystem

To investigate the applicability of the proposed hierarchical model, the authors chose a linear supply chain process implemented with one subsystem, "Process for delivery of production to a distribution warehouse". This subsystem belongs to the first layer of the proposed hierarchical model, transaction processing system, delivery of production.

The process is linear (separate stages cannot be performed simultaneously) and is presented in Figure 2 with five subprocesses: packaging, labeling, production warehouse, shipping, and storage. The manufactured product is packaged, labeled with product information, and moved to the manufacturer's warehouse, where it awaits shipping to a distribution/sales site. This process is automated with smart contract management on a private blockchain, HyperLedger Fabric (HF), so all users of the recorded data in the blockchain (with the exception of the insurer) are internal to the company. This use case was experimentally implemented on a private blockchain, but because it is implemented on only one channel, the same model can be implemented on a public blockchain (e.g., the most popular, Ethereum) that works with smart contracts. The authors' choice of a private blockchain is dictated by the advantages of a private blockchain: it guarantees lower costs and shorter transaction validation times than a public blockchain. It is readable/writeable only by its owner, which reduces the risk of tampering with data, reduces the risk of attacks, and provides increased privacy (since read permissions can only be granted to selected nodes).

Figure 2. Process for delivery of production to a distribution warehouse.

HyperLedger Fabric supports several programming languages for creating smart contracts: Java, Typescript, and Go. The current implementation uses the Go language. It is an agent-based language where objects are viewed as self-operating modules that interact with each other to solve complex problems. Its interaction with the blockchain network built through HF is done through the Shim library, which is standard library for Go language, and provides an interface of classes and components for implementing smart contracts. Through it, transactions to the network and access to other smart contracts (called chain codes in the HF context) in the system are carried out.

Figure 3 shows the implementation of the presented model as an HF network. In the blockchain (Channel 1), information about the goods that are subject to forwarding and storage is recorded. Each good (object) is characterized by attributes:

- TypeOfGoods—the type of goods.
- ProductionDate—production date.
- ExpiryDate—expiration date.
- Weight—weight of the goods.
- Number—quantity of the goods.
- Temperature—storage temperature.
- Humidity—storage humidity.

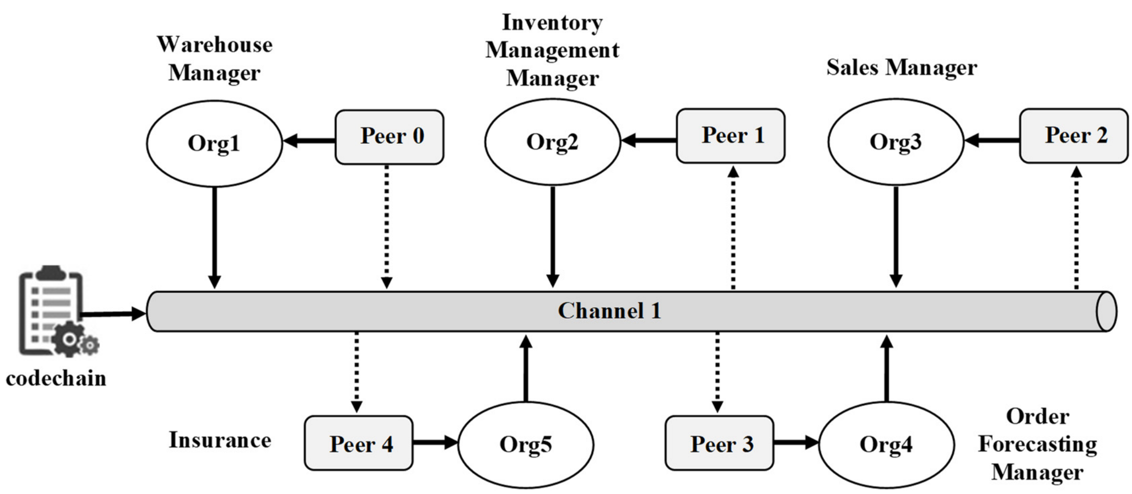

Figure 3. Blockchain-based solution of the proposed model for delivery of production.

The model contains several participants (organizations): Warehouse Manager (Org1), Inventory Management Manager (Org2), Sales Manager (Org3), Order Forecasting Manager (Org4), and Insurer (Org5). Warehouse Manager (Org1) has full control over the channel for writing and reading information. Only this peer can enter information into the blockchain. It is from the first level of the hierarchical logistic management model. Inventory Management Manager (Org2) is responsible for maintaining a sufficient amount of stock. It is from the third level of the hierarchical logistic management model. Sales Manager (Org3) is responsible for the sale of the product and maintaining relations with the sales representatives. It is from the first level of the hierarchical logistic management model. Order Forecasting Manager (Org4) analyzes consumer demand and predicts trends in product realization. It is from the third level of the hierarchical logistic management model. Insurer (Org5) will use the information stored in the blockchain in case of an insurance event. It is from the third level of the hierarchical logistic management model.

Solid lines represent organizations' access to the channel. Peers relevant to the organization implement read/write operations, and they are shown as dashed lines.

The business logic of the model is implemented by the smart contract (name in HF is "codechain"). It includes multiple objects and functions that provide the API to access the blockchain. Individual peers are implemented as Docker containers (Figure 4). This allows achieving the encapsulation of individual nodes within the execution runtime environment.

```
CONTAINER ID   IMAGE                                  COMMAND                   CREATED
  STATUS         PORTS                                                    NAMES
cd516e886332   hyperledger/fabric-tools:latest        "/bin/bash"               14 minutes ago
  Up 14 minutes                                                           cli
2014e2d57924   hyperledger/fabric-peer:latest         "peer node start"         14 minutes ago
  Up 14 minutes   0.0.0.0:7051->7051/tcp                                  peer0.org1.example.com
f6e27f4982e9   hyperledger/fabric-peer:latest         "peer node start"         14 minutes ago
  Up 14 minutes   0.0.0.0:11051->11051/tcp                                peer0.org3.example.com
139eace96fb3   hyperledger/fabric-peer:latest         "peer node start"         14 minutes ago
  Up 14 minutes   0.0.0.0:9051->9051/tcp                                  peer0.org2.example.com
00d50811a6be   hyperledger/fabric-orderer:latest      "orderer"                 14 minutes ago
  Up 14 minutes   0.0.0.0:8050->7050/tcp                                  orderer2.example.com
e22e62a83c33   hyperledger/fabric-orderer:latest      "orderer"                 14 minutes ago
  Up 14 minutes   0.0.0.0:11050->7050/tcp                                 orderer5.example.com
916c6659c0ea   hyperledger/fabric-couchdb             "tini -- /docker-ent…"    14 minutes ago
  Up 14 minutes   4369/tcp, 9100/tcp, 0.0.0.0:5984->5984/tcp              couchdb0
2ba5b53f4b15   hyperledger/fabric-orderer:latest      "orderer"                 14 minutes ago
  Up 14 minutes   0.0.0.0:9050->7050/tcp                                  orderer3.example.com
d89060f3ea45   hyperledger/fabric-couchdb             "tini -- /docker-ent…"    14 minutes ago
  Up 14 minutes   4369/tcp, 9100/tcp, 0.0.0.0:7984->5984/tcp              couchdb1
119b071f247e   hyperledger/fabric-orderer:latest      "orderer"                 14 minutes ago
  Up 14 minutes   0.0.0.0:7050->7050/tcp                                  orderer.example.com
e4677c441eaf   hyperledger/fabric-couchdb             "tini -- /docker-ent…"    14 minutes ago
  Up 14 minutes   4369/tcp, 9100/tcp, 0.0.0.0:9984->5984/tcp              couchdb2
4532aed0f225   hyperledger/fabric-orderer:latest      "orderer"                 14 minutes ago
  Up 14 minutes   0.0.0.0:10050->7050/tcp                                 orderer4.example.com
```

Figure 4. Implementation of the network with Docker containers.

Each Docker container runs as a stand-alone node. As seen in Figure 4, the communication between the nodes is based on the TCP/IP protocols. This enables a distributed implementation of the model.

Experimental tests of the functionality of the smart contract have been conducted. For this purpose, an administrative Docker node was created, which allows the execution of commands through which requests are sent to the smart contract. Requests perform certain functions of its API. Figure 5 shows the execution of a request to write in the blockchain information about a certain goods (Coffee) with corresponding values of its attributes.

Query executions are in DEBUG mode for detailed analysis. Successful completion is determined by the correct result code, 200.

All peers except Peer0 can only read data from the blockchain. Figure 6 shows the execution of a request to find a record(s) for corresponding goods. In this case, search is made by name (Coffee). Upon successful execution of the search query, the attributes of the found goods are displayed.

```
2024-07-12 10:15:06.873 UTC [chaincodeCmd] chaincodeInvokeOrQue
ry -> DEBU 04b ESCC invoke result: version: 1 response: <status
:200 > payload: {"TypeOfGoods":"Coffee","ProductionDate":"2024-
05-12","ExpireDate":"2025-05-12","Weight":"35","Number":"100","
Temperature":"22","Humidity":"3.4"} smartcontract endorsement:<
endorser:"Org1MSP">
2024-07-12 10:15:06.873 UTC [chaincodeCmd] chaincodeInvokeOrQue
ry -> INFO 04c chaincode invoke successful. result: status:200
```

Figure 5. Write a record into the channel.

```
2024-07-12 10:18:13.390 UTC [chaincodeCmd] chaincodeInvokeOrQue
ry -> DEBU 04b ESCC invoke result: version: 1 response: <status
:200 > payload: FOUND [ "Key":"Id-XV2Bzm", "Record": {"TypeOfGo
ods":"Coffee","ProductionDate":"2024-05-12","ExpireDate":"2025-
05-12","Weight":"35","Number":"100","Temperature":"22","Humidit
y":"3.4"} ] smartcontract endorsement:<endorser:"Org1MSP">
2024-07-12 10:18:13.390 UTC [chaincodeCmd] chaincodeInvokeOrQue
ry -> INFO 04c chaincode invoke successful. result: status:200
```

Figure 6. Search for object in the blockchain.

The tests proved the functionality of the proposed model.

5. Discussion

Automated process management with or without blockchain solutions is a complex and multifaceted process that cannot be formalized into a few universal solutions. The possibilities of combining blockchain technologies with other innovative technologies, such as artificial intelligence or the IoT, provide the potential to achieve greater efficiency and optimization of logistics processes. Currently, more than 30 global companies have fully functional products built on blockchain. For functions such as real-time data analysis and traceability, blockchain has a significant impact, especially when combined with big data analytics.

The existing solutions are based on best practices in the specific fields and are not focused on specific requirements of a specific business process. The participation of experts in the design of such complex systems with multiple subsystems managing interconnected information, financial, and material flows significantly increases the effectiveness of the included functionalities, as the focus of complex solutions does not shift only to a separate subsystem, for example, optimization of warehouse processes or optimization of financial flows serving financiers, accountants, and traders.

However, at the moment, business and pilot solutions based on blockchain are only in separate subsystems of logistics management. With regard to individual operations, priorities are determined, and during the organization process, the correct logical sequence of their implementation is observed, as well as optimization of the necessary resource. This minimizes downtime, which reduces overall processing time. It is in such subsystems that the blockchain application brings added value by minimizing operational costs and process execution time.

This article adds value by proposing a hierarchical-layered logistics management model, which provides insights into which subsystems the implementation of a blockchain solution will significantly improve the efficiency of the logistics process. In addition to this, it helps developers track which data will be used on which layers by which managers and for what purposes. The proposed layered model guides which data is suitable for processing with big data analysis and which for storage on blockchain and processing by smart contracts.

A use case implemented experimentally on HyperLedger Fabric is presented. It has been tested, and some of the results are presented. The results of the performed experiments show that the proposed solution is fully functional in terms of managing a logistics subsystem with a linear sequence of individual operations.

The proposed abstract layered model can be used to overcome gaps in existing logistics process management solutions. There are many solutions (not only blockchain-based) for transaction processing system-level management, but few solutions include multilevel management using the same data for the managed logistic process. Moreover, they do not include all subsystems proposed in the present abstract model. In this aspect, it is of community interest to study the applicability of blockchain technologies specifically for multi-aspect solutions covering more subsystems from all levels of the model.

The team's future work is aimed at creating and testing models related to personnel management in the context of logistics processes. The goal is to track workplace performance of workers, to reduce the risk during work with machines and in adverse environments, and to increase transparency of work processes using wearable devices and IoT. These models will refer to the decision support system layer and management information system of the proposed hierarchical logistic management model.

Author Contributions: Conceptualization, V.A. and H.V.; methodology, V.A.; software, H.V.; validation, A.H. and V.M.; investigation, V.A., H.V., A.H. and V.M.; data curation, V.A., H.V., A.H. and V.M.; writing—original draft preparation, V.A.; writing—review and editing, H.V., A.H. and V.M.; visualization, H.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. ERC-20: Token Standard. Available online: https://eips.ethereum.org/EIPS/eip-20 (accessed on 21 July 2024).
2. ERC-223: Token with Transaction Handling Model. Token with Transaction Handling Model Designed to Behave Identical to Native Currency (Ether). Available online: https://eips.ethereum.org/EIPS/eip-223 (accessed on 21 July 2024).
3. ERC-1820: Pseudo-Introspection Registry Contract. Available online: https://eips.ethereum.org/EIPS/eip-1820 (accessed on 21 July 2024).
4. ERC-777: Token Standard. Available online: https://eips.ethereum.org/EIPS/eip-777 (accessed on 21 July 2024).
5. ERC-721: Token Standard. Available online: https://eips.ethereum.org/EIPS/eip-721 (accessed on 21 July 2024).
6. Forecast. 81 of Top 100 Companies Use Blockchain Technology, Blockdata Research Shows. Available online: https://forkast.news/81-of-top-100-companies-use-blockchain-technology-blockdata/ (accessed on 16 October 2024).
7. Crustlab. Top 30 Blockchain Companies Shaping the Future of Technology. Available online: https://crustlab.com/blog/top-30-blockchain-companies-shaping-the-future-of-technology/ (accessed on 16 October 2024).
8. The Blockchain Infrastructure Suite for Web 3. Available online: https://cryptoapis.io (accessed on 21 July 2024).
9. European Parliament. News. Crypto-Assets: Green Light to New Rules for Tracing Transfers in the EU. 20 April 2023. Available online: https://www.europarl.europa.eu/news/en/press-room/20230414IPR80133/crypto-assets-green-light-to-new-rules-for-tracing-transfers-in-the-eu (accessed on 21 July 2024).
10. EC. Experience Cross-Border Services with EBSI. Available online: https://ec.europa.eu/digital-building-blocks/sites/display/EBSI/Home (accessed on 21 July 2024).
11. EC. Commission Launches European Regulatory Sandbox for Blockchain. Available online: https://digital-strategy.ec.europa.eu/en/news/commission-launches-european-regulatory-sandbox-blockchain (accessed on 21 July 2024).
12. CoinMarketCap. Top Logistics Tokens by Market Capitalization. Available online: https://coinmarketcap.com/view/logistics/ (accessed on 21 July 2024).
13. Cryptocurrency Prices. 14,899 Assets. Available online: https://www.blockchain.com/explorer/prices (accessed on 21 July 2024).
14. Hackius, N.; Petersen, M. Blockchain in logistics and supply chain: Trick or treat? In *Digitalization in Supply Chain Management and Logistics: Smart and Digital Solutions for an Industry 4.0 Environment, Proceedings of the Hamburg International Conference of Logistics (HICL), Berlin, Germany, 11–12 October 2017*; Epubli GmbH: Berlin, Germany, 2017.
15. Dobrovnik, M.; Herold, D.; Fürst, E.; Kummer, S. Blockchain for and in logistics: What to adopt and where to start. *Logistics* **2018**, *2*, 18. [CrossRef]
16. Kampf, R.; Hlatká, M.; Bartuška, L. Optimization of production logistics. *Adv. Sci. Technol. Res. J.* **2018**, *12*, 151–156. [CrossRef]
17. Pournader, M.; Shi, Y.; Seuring, S.; Koh, S.L. Blockchain applications in supply chains, transport and logistics: A systematic review of the literature. *Int. J. Prod. Res.* **2020**, *58*, 2063–2081. [CrossRef]

18. Moosavi, J.; Naeni, L.M.; Fathollahi-Fard, A.M.; Fiore, U. Blockchain in supply chain management: A review, bibliometric, and network analysis. *Environ. Sci. Pollut. Res.* **2021**, 1–15. [CrossRef]
19. Rejeb, A.; Rejeb, K.; Simske, S.; Treiblmaier, H. Blockchain technologies in logistics and supply chain management: A bibliometric review. *Logistics* **2021**, *5*, 72. [CrossRef]
20. Teoman, S. Achieving the customized "rights" of logistics by adopting novel technologies: A conceptual approach and literature review. *UTMS J. Econ.* **2020**, *11*, 231–242.
21. Müßigmann, B.; von der Gracht, H.; Hartmann, E. Blockchain technology in logistics and supply chain management—A bibliometric literature review from 2016 to January 2020. *IEEE Trans. Eng. Manag.* **2020**, *67*, 988–1007. [CrossRef]
22. Wijesekara, P.A.D.S.N.; Gunawardena, S. A Review of blockchain technology in knowledge-defined networking, its application, benefits, and challenges. *Network* **2023**, *3*, 343–421. [CrossRef]
23. Albshaier, L.; Almarri, S.; Hafizur Rahman, M. A review of blockchain's role in E-Commerce transactions: Open challenges, and future research directions. *Computers* **2024**, *13*, 27. [CrossRef]
24. Taherdoost, H.; Madanchian, M. Blockchain-based new business models: A systematic review. *Electronics* **2023**, *12*, 1479. [CrossRef]
25. George, W.; Al-Ansari, T. Review of blockchain applications in food supply chains. *Blockchains* **2023**, *1*, 34–57. [CrossRef]
26. Taherdoost, H. Smart contracts in blockchain technology: A critical review. *Information* **2023**, *14*, 117. [CrossRef]
27. Sharabati, A.-A.A.; Jreisat, E.R. Blockchain Technology Implementation in Supply Chain Management: A Literature Review. *Sustainability* **2024**, *16*, 2823. [CrossRef]
28. Li, X.; Jiao, H.; Cheng, L.; Yin, Y.; Li, H.; Mu, W.; Zhang, R. A Quantitative and Qualitative Review of Blockchain Research from 2015 to 2021. *Sustainability* **2023**, *15*, 5067. [CrossRef]
29. Guo, X.; Zhang, G.; Zhang, Y. A comprehensive review of blockchain technology-enabled smart manufacturing: A framework, challenges and future research directions. *Sensors* **2022**, *23*, 155. [CrossRef]
30. Tönnissen, S.; Teuteberg, F. Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies. *Int. J. Inf. Manag.* **2020**, *52*, 101953. [CrossRef]
31. Sever, Y.; Angin, P. Blockchain Integration into Supply Chain Operations: An Analysis with Case Studies. In *Industry Use Cases on Blockchain Technology Applications in IoT and the Financial Sector*; IGI Global: Hershey, PA, USA, 2021; pp. 329–350.
32. Acar, A.Z.; Clarke, O.E. Applicability of blockchain technology in the global logistics systems. *Eur. Proc. Soc. Behav. Sci.* **2021**, *121*, 236–246.
33. Wang, S.; Qu, X. Blockchain applications in shipping, transportation, logistics, and supply chain. In *Smart Transportation Systems 2019*; Springer: Singapore, 2019; pp. 225–231.
34. Saberi, S.; Kouhizadeh, M.; Sarkis, J.; Shen, L. Blockchain technology and its relationships to sustainable supply chain management. *Int. J. Prod. Res.* **2019**, *57*, 2117–2135. [CrossRef]
35. Tijan, E.; Aksentijević, S.; Ivanić, K.; Jardas, M. Blockchain technology implementation in logistics. *Sustainability* **2019**, *11*, 1185. [CrossRef]
36. Shih, D.-H.; Huang, F.-C.; Chieh, C.-Y.; Shih, M.-H.; Wu, T.-W. Preventing return fraud in reverse logistics—A case study of ESPRES solution by Ethereum. *J. Theor. Appl. Electron. Commer. Res.* **2021**, *16*, 2170–2191. [CrossRef]
37. Singh, H.; Dehraj, P. A Study on Importance of Blockchain Technology in Logistics Supply Chain Management. In Proceedings of the 6th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 29–31 March 2022.
38. Grace, A.L.; Thenmozhi, M. Optimizing Logistics with Regularization Techniques: A Comparative Study. In Proceedings of the IEEE World Conference on Applied Intelligence and Computing (AIC), Sonbhadra, India, 29–30 July 2023.
39. Liao, T.-Y. Reverse logistics network design for product recovery and remanufacturing. *Appl. Math. Model.* **2018**, *60*, 145–163. [CrossRef]
40. Wu, J. Sustainable development of green reverse logistics based on blockchain. *Energy Rep.* **2022**, *8*, 11547–11553. [CrossRef]
41. Gao, Z.; Xu, L.; Chen, L.; Zhao, X.; Lu, Y.; Shi, W. CoC: A unified distributed ledger based supply chain management system. *J. Comput. Sci. Technol.* **2018**, *33*, 237–248. [CrossRef]
42. Tejesh, B.S.S.; Neeraja, S. Warehouse inventory management system using IoT and open source framework. *Alex. Eng. J.* **2018**, *57*, 3817–3823. [CrossRef]
43. Laxmi, A.R.; Mishra, A. RFID based logistic management system using internet of things (IoT). In Proceedings of the Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, 29–31 March 2018.
44. Hou, L.; Sun, J. A security architecture for garment production based on blockchain technology and traditional RFID. In Proceedings of the 2nd International Conference on Computing and Data Science, Stanford, CA, USA, 28–29 January 2021.
45. Mishra, A.; Mohapatro, M. Real-time RFID-based item tracking using IoT & efficient inventory management using Machine Learning. In Proceedings of the 4th Conference on Information & Communication Technology (CICT), Chennai, India, 3–5 December 2020.
46. Ugochukwu, N.A.; Goyal, S.; Arumugam, S. Blockchain-Based IoT-Enabled System for Secure and Efficient Logistics Management in the Era of IR 4.0. *J. Nanomater.* **2022**, *2022*, 7295395. [CrossRef]
47. Liu, S.; Roy, D.; Hennequin, S. Blockchains and internet of things for the pooling of warehouse resources. *South Asian J. Soc. Stud. Econ.* **2019**, *15*, 1–16. [CrossRef]

48. Humayun, M.; Jhanjhi, N.; Hamid, B.; Ahmed, G. Emerging smart logistics and transportation using IoT and blockchain. *IEEE Internet Things Mag.* **2020**, *3*, 58–62. [CrossRef]
49. Augusto, L.; Costa, R.; Ferreira, J.; Jardim-Gonçalves, R. An application of Ethereum smart contracts and IoT to logistics. In Proceedings of the 2019 International Young Engineers Forum (YEF-ECE), Costa da Caparica, Portugal, 10 May 2019.
50. Mutanov, G.; Ziyadin, S.; Serikbekuly, A. Application of system- dynamic modeling to improve distribution logistics processes in the supply chain. *Komunikácie* **2020**, *22*, 29–39. [CrossRef]
51. Yalabik, B.; Petruzzi, N.C.; Chhajed, D. An integrated product returns model with logistics and marketing coordination. *Eur. J. Oper. Res.* **2005**, *161*, 162–182. [CrossRef]
52. Lakshmi, G.V.; Gogulamudi, S.; Nagaeswari, B.; Reehana, S. BlockChain based inventory management by QR code using open CV. In Proceedings of the International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 27–29 January 2021.
53. Kashansky, V.; Agha Hossein Kashani, S.; Zhuge, H.; Garcia-Blas, J.; Marozzo, F. Intelligent and sustainable transportation through multi-objective model for the logistic route-order dispatching system. In Proceedings of the 2023 ACM Conference on Information Technology for Social Good, Lisbon, Portugal, 6–8 September 2023.
54. Dolgui, A.; Ivanov, D.; Potryasaev, S.; Sokolov, B.; Ivanova, M.; Werner, F. Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain. *Int. J. Prod. Res.* **2020**, *58*, 2184–2199. [CrossRef]
55. Helo, P.; Hao, Y. Blockchains in operations and supply chains: A model and reference implementation. *Comput. Ind. Eng.* **2019**, *136*, 242–251. [CrossRef]
56. Ho, G.T.; Tang, Y.M.; Tsang, K.Y.; Tang, V.; Chau, K.Y. A blockchain-based system to enhance aircraft parts traceability and trackability for inventory management. *Expert Syst. Appl.* **2021**, *179*, 115101. [CrossRef]
57. Ar, I.M.; Erol, I.; Peker, I.; Ozdemir, A.I.; Medeni, T.D.; Medeni, I.T. Evaluating the feasibility of blockchain in logistics operations: A decision framework. *Expert Syst. Appl.* **2020**, *158*, 113543. [CrossRef]
58. Cordeau, J.-F.; Klibi, W.; Nickel, S. Logistics network design. *Netw. Des. Appl. Transp. Logist.* **2021**, 599–625. [CrossRef]
59. Tan, R.; Li, Y.; Zhang, J.; Si, W. Application of blockchain technology to the credit management of supply chain. In Proceedings of the Frontiers in Cyber Security: Third International Conference, FCS 2020, Tianjin, China, 15–17 November 2020.
60. Tan, R.; Zhai, H. Application Research of Blockchain Technology in Logistics Supply Chain. In Proceedings of the Sixth International Conference on Information Management and Technology, Jakarta, Indonesia, 19–20 August 2021.
61. Shaffan, N.H.; Astha Ekadiyanto, F.; Putri Ratna, A. Blockchain Based Warehouse Supply Chain Management using HyperLedger Fabric and HyperLedger Composer. *IJITEE Int. J. Innov. Technol. Explor. Eng.* **2020**, *2278*, 3075.
62. Li, X. Inventory management and information sharing based on blockchain technology. *Comput. Ind. Eng.* **2023**, *179*, 109196. [CrossRef]
63. Chen, M.C.; Cheng, Y.T.; Siang, C.Y. Development of Inventory Management System Based on Radio Frequency Identification Technology. *Sens. Mater.* **2022**, *34*, 1163–1177. [CrossRef]
64. Voronova, O. Improvement of warehouse logistics based on the introduction of lean manufacturing principles. *Trans-Portation Res. Procedia* **2022**, *63*, 919–928. [CrossRef]
65. Aleksieva, V.; Valchanov, H.; Huliyan, A. Application of Smart Contracts based on Ethereum Blockchain for the Purpose of Insurance Services. In Proceedings of the International Conference on Biomedical Innovations and Applications (BIA'19), Varna, Bulgaria, 8–9 November 2019.
66. Aleksieva, V.; Valchanov, H.; Huliyan, A. Implementation of Smart Contracts based on HyperLedger Fabric Blockchain for the Purpose of Insurance Services. In Proceedings of the International Conference on Biomedical Innovations and Applications (BIA'20), Varna, Bulgaria, 24–27 September 2020.
67. Aleksieva, V.; Valchanov, H. Smart Contracts based on HyperLedger Fabric Blockchain for the Purpose of Health and Life Insurance Services. In Proceedings of the Conference on Communications, Information, Electronic and Energy Systems (CIEES'21), Rouse, Bulgaria, 25–27 November 2021.
68. Valchanov, H.; Aleksieva, V. Novel Blockchain—Based Models for Healthcare and Life Science Solution. In Proceedings of the Conference on Communications, Information, Electronic and Energy Systems (CIEES'22), Veliko Tarnovo, Bulgaria, 20–22 November 2022.
69. Maleshkov, V.; Valchanov, H.; Aleksieva, V. Blockchain-Based Model for Warehouse Management Systems for Artworks and Collectibles. *Eng. Proc.* **2024**, *70*, 39. [CrossRef]
70. Aleksieva, V.; Valchanov, H.; Haka, A.; Dinev, D. Logistics Model Based on Smart Contracts on Blockchain and IoT. *Eng. Proc.* **2023**, *41*, 2–10. [CrossRef]
71. Aleksieva, V.; Valchanov, H.; Haka, A.; Dinev, D. Model of Controlled Environment based on Blockchain and IoT. In Proceedings of the Conference on Communications, Information, Electronic and Energy Systems (CIEES'23), Plovdiv, Bulgaria, 23–25 November 2023.
72. Valchanov, H.; Aleksieva, A. Blockchain and IoT integration for smart transportation. *J. Phys.* **2022**, *2339*, 012012. [CrossRef]