Blockchain Design for Digital Supply Chain Integration

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Abstract. The supply-chain process involves multiple actors and intermediary companies that need to coordinate but often lack interoperability and do not fully trust each other. Supply-chain digitalization, including the use of cloud services and domain-specific standards, enables significant improvements in efficiency throughout the entire process. We conduct a case study by collecting and analyzing data from a large business consortium represented by experts in the fields of industry, logistics, banking, and information and communications technology (ICT). Based on the case study's outcomes, we propose the architecture of a blockchain-based system for use in a practical intermodal logistics project and discuss future research directions regarding it.

Keywords: Digitalization, Supply Chains, Blockchain, Integration

1 Introduction

Supply-chain process involves multiple actors and intermediary companies that need to sequentially interact with each other. With the objective of maximizing customer value and providing a profit for each supply chain member, stakeholders form heterogeneous network, interconnected with financial, information, and product/service flows [1]. Heterogeneity of the supply network incurs the following challenges that have been extensively discussed from different perspectives in literature [2]. Digitalization aims at addressing the technical challenges to make an and-to-end supply-chain process efficient, fast, and compliant. The business processes and data models are thus company specific and not interoperable with the systems in the other companies. While it is possible to deploy intra-organizational system integrations through ERP systems, e.g., by SAP and Oracle [3], it is extremely challenging to achieve end-to-end information integration through supply networks and the complex interrelationships among multiple organizations.

Emerging blockchain technology has the potential to drastically change the environment in which inter-organizational processes operate by offering a way to execute processes in a trustworthy manner even in a network without any mutual trust between nodes [4]. To date, several research studies have already indicated that blockchain technology can enable secure decentralized transactions between the actors in the supply network [5, 6, 7. This paper adopts qualitative research to investigate applicability of blockchain technology in heterogeneous supply networks.

2 Blockchain Technology and its Application to Supply Chain Processes

Blockchains are a type of distributed ledger technology (DLT). Blockchain platforms such as Bitcoin [8], Ethereum [9], Hyperledger [10], [11], and others enable secure, decentralized transactions between various parties without the involvement of intermediaries or third parties. Blockchains integrate several methods of trusted and reliable record-keeping, such as timestamping of transactions, smart contracts, and the storage of transactions in an immutable distributed ledger. A blockchain network [5] consists of a set of independent peers (e.g., software agents), which together form the blockchain network. The peer architecture provides a high degree of resiliency, allowing the blockchain network to operate even if some of the peers become unavailable or corrupted (for example from malicious attacks or faults). Each blockchain peer maintains a copy of an immutable ledger. The ledger consists of a series of ordered and timestamped transactions organized into cryptographically connected blocks. This cryptographic connection allows for verification that the ledger was not tampered with and that none of the transactions were modified since being recorded.

The transactions are generated by a smart contract, which is a business-logic component (such as a software code) that is agreed upon by the participants of the blockchain network. An identical copy of the smart contract is hosted by each peer of the blockchain network. When a client submits a request for a transaction into the network, the peers invoke the smart contract and calculate the transaction. Smart contracting code is software written in a programming language. The code acts as a software agent, or as the delegate of the party that employed it, with the intention of fulfilling certain obligations or exercising certain rights. The code may take control of assets within a distributed ledger in an automated way. Thus, the code takes on tasks and responsibilities in the distributed ledger realm by executing code that models or emulates the contract logic of the real world, although the legal justification for this may be unclear [12]. Permissioned blockchains, such as Hyperledger Fabric or Corda, are in contrast, designed as closed-access networks of distributed peers. In such blockchains, identities of the users and the rights to participate in the consensus (right to write to the ledger and/or validate the transactions) are controlled by a membership service. Figure 1 shows general architecture of permissioned blockchain technology with an example of Hyperledger Fabric.

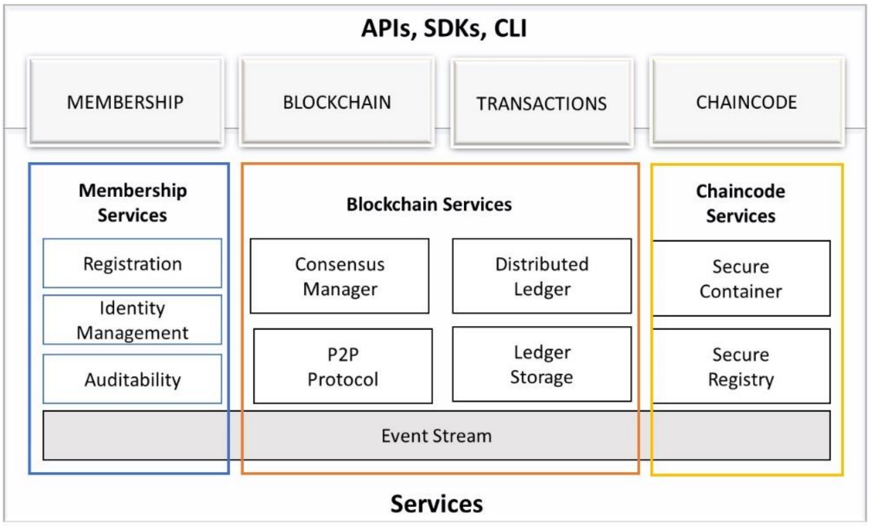

Fig. 1. General architecture of permissioned blockchain, Hyperledger Fabric example.

Similarly to permissionless blockchains, trust and immutability are established by combining a smart contract with a configurable consensus protocol, as well as by the redundancy of the network nodes the stakeholders operate. Unlike in permissionless blockchains, the consensus protocol is custom defined, reflecting the needs of the specific types of transactions involved and of the network itself. From an operational point of view, one important advantage of permissioned blockchains is the high performance available from the optimized software and hardware used for such blockchains [13], which provide several-magnitude faster processing of transactions than is possible with permissionless blockchains.

The use of blockchains in the DSC in most cases requires private blockchain technologies, since one requirement is that the identity of the transacting parties must be known. The transactions recorded into the ledger contain the identities of those who have submitted the transactions into the ledger as well as those who have validated and endorsed those transactions. This type of information serves as a retrospective audit trail and allows further development of various analytical and operational solutions—such as "know your customer" (KYC) and anti-money laundering (AML) processes for financial transactions—as well as various types of audit and compliance solutions [14]. To conduct DSC transaction and document exchange using blockchains, parties must first agree on how this will be done, which is where smart contracts enter the picture [15]. Smart contracts are extremely flexible and can be used to automate DSC transactions at a very detailed level.

Abeyratne and Monfared [16] note several key technological advantages of Blockchain relevant to the supply-chain processes, such as durability, transparency, immutability and process integrity. There exist also several conceptual designs aiming to address the question "Whether blockchains have a disruptive effect on supply chains".

These works are based on case-studies conducted either in the specific domain: such as a manufacturing supply chain for cardboard boxes [16], alimentary supply-chain [17], or in supply-chain in general [18, 19], and attempt to draw a map of further research. An empirical investigation of the main drivers of Blockchain adoption and related challenges were recently conducted [19]. The authors claim that despite some existing findings and the potential of digitalization and use of blockchain technology to promote changes in all types of supply chains in terms of new operation models, the literature about blockchain technology in the SCM field is in its infancy. Sternberg and Baruffaldi [18] also report the lack of successful supply chain implementations can pave the way for doubt about the disruptive role of this technology in supply chains. Therefore, research questions related to the applicability of the blockchain technology remain open and of a high interested to the research community.

3 Blockchain-based Architecture for an Intermodal Logistics Project

In this section, based on the results of the case study and the summary of the related works (cf. Section 3), we present an architecture of a blockchain-based framework for an intermodal logistics project. Prior to this, we first describe the use-case scenario and provide detailed description of Hyperledger Fabric – the blockchain technology implementation – that will be employed in the architecture presented. Our goal is to conduct a proof of concept (POC) evaluation of the usefulness of blockchain in the framework of the specific practical example of the two railway transportation corridors that link Scandinavian exporters to their Central and Southern European customers via the Baltic republics. We aim to develop an open-source solution to be offered to all stakeholders to investigate user experiences and benefits. More specifically, we will investigate how the improved visibility of supply chain information, enabled by blockchain technology, influences each stakeholder company and how the blockchain technology as a whole impact the logistics operations in these two railway transportation corridors. The ultimate objective is to reduce cargo end-to-end transit times.

3.1 Use Case Scenario

In cross-border logistics, the main problems are currently the large proportion of manual work necessary to execute business transactions as well as the lack of communication and information sharing between logistics companies, especially in upstream supply chains. The cornerstones of the logistics industry are transferring cargo units between locations and knowing where each cargo unit is at any given time during transportation. Cargo units can only be transferred as efficiently as the underlying infrastructure allows. Information about logistics transactions is now delivered mostly manually, which makes logistics operations expensive, time consuming, and error-prone. To study a possibility to implement permissioned blockchain technology in logistics business operations, we have chosen as a use case scenario of the intermodal logistics with the following stakeholders: supplier companies that export their products, transportation companies, customers, and value-adding service providers. Figure 2 illustrates the concept of blockchain integration of the intermodal logistics project, which aims to solve these problems.

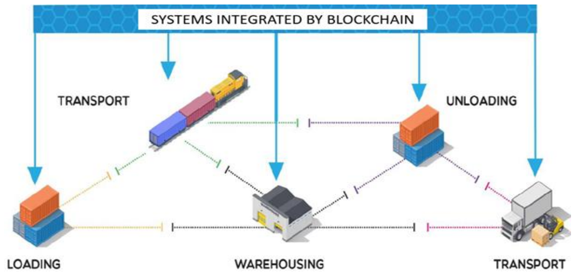

Fig. 2. Multi-modal logistic operations.

Logistics operations use several communication channels and technologies, such as phone calls, text messages, structured and unstructured emails, fax messages, and diverse information systems (IS). Electronic Data Interchange (EDI) messaging is still popular, although company-specific implementations lead to significant integration costs and slowness. Each company purchases and installs its own IS for use in logistics operations. This creates data interoperability challenges with regard to cross-organizational data transfer. In sum, all the necessary logistics information is stored in company-specific ISs, but the lack of data interoperability prevents automated data transfers and integration between companies. We apply blockchain technology for DSC integrations in the environment of multiple stakeholders and various ISs of the logistics companies. In the next section, we present the detailed description of the Hyperledger Fabric - open-source blockchain implementation.

3.2 Hyperledger Fabric Description

Architecture. Within Fabric, nodes are differentiated depending on whether they are clients, peers, or orderers. A client acts on behalf of an end-user and creates transactions, which is also called invoking. Clients communicate with both peers and orderers. Peers maintain the ledger and receive ordered update messages from customers to commit new transactions to the ledger. Endorsers are a special type of peer. Their task is to endorse a transaction by checking whether the transaction fulfills the necessary and sufficient conditions, that is, the five provisions required by the signatures. Ordering service provides a communication channel to clients and peers over which messages containing transactions can be broadcast. During consensus creation in particular, the channels ensures that all connected peers deliver exactly the same messages in exactly the same logical order [10]. Figure 3 shows the communication between the components of Hyperledger Fabric.

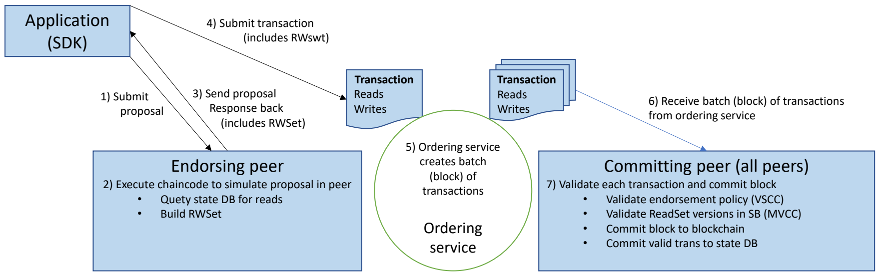

Fig. 3. Hyperledger Fabric communication diagram.

Consensus mechanism. Fabric's understanding of consensus is broad and encompasses the entire transaction flow, that is, from proposing a transaction to the network to adding a new transaction block to the ledger. Different nodes assume different roles and tasks in the process of reaching consensus. It is generally known that faults may occur in the delivery of messages when many mutually untrusted orderers are employed. This necessitates the use of a consensus algorithm to reach consensus despite potential faults, such as the inconsistency of message order. This solution makes the replication of the distributed ledger fault tolerant. Fabric employs a "pluggable" algorithm. This means that various algorithms can be used depending on the application-specific requirements. For example, Byzantine fault-tolerant (BFT) algorithms could be used to deal with random or malicious replication faults. In Fabric, it is an orderer, (which can be implemented as a node, or a cluster of nodes) that participates in the consensus and runs the communication service that implements a delivery guarantee, such as atomic or total order broadcast. This is done by verification and ordering of the transactions. During the verification phase, digital signature of the issuer of the transaction is verified, as well as so-called endorsement policy. Endorsement policy is defined for a chaincode and is used to instruct a peer on how to decide whether a transaction is valid. An example of such a policy can be defined as a requirement that all the peers in the network have to validate (and therefore sign) the transaction. Then the orderer, during the verification, must ensure that the transaction is indeed signed by all the peers, and that the signatures are valid [21].

3.3 SmartLog - Proposed Blockchain-Based Platform For DSC Integration

In this project, we have adopted the latest available (at the moment of the project start) version of Hyperledger Fabric, 1.0, that contains all the necessary components to establish the blockchain environment in the framework of our use case. We used the open-source UBL 2.1 standard to design logistics business processes and business transaction integrations. The aim was to establish full visibility of logistics transactions for all stakeholders in the supply chain. By doing so, we also developed a platform for future Internet of Things (IoT) integrations, with the aim of increasing the data content of logistics data delivered between stakeholders.

The participating companies wanted to obtain real-time information on container locations and automate the business transactions between intra- and inter-organizational ISs. The most important functionality of the blockchain environment is providing an open distributed ledger, which efficiently records transactions between parties in a verifiable and permanent way. Smart contracting components are made up of programmed business rules that automatically trigger transactions.

Verification of the actual movements along the railway corridors is provided via a simple device (a sensor) attached to containers. Access to such real-time sensor data serves several purposes: participating companies are able to analyze and develop their operations and resource management and optimize their route planning. Blockchain technology offers significantly improved visibility and potential for process automation in the investigated case context. The solution presented here is under constant testing and evaluation. The developed solution is highly scalable. When transaction volumes start to grow (exponentially), the processing load can be allocated among the stakeholders so that allocated resources correspond with added value. The creation of a blockchain environment with a large number of participating companies encourages follow-up projects.

The deployment of these technologies makes it possible to deliver the SmartLog platform to practically any infrastructure; it also allows codebases to be maintained with significantly more efficiency than in environment-specific infrastructure compilation and conversion models. Implementation of the blockchain in the logistics context can be beneficial for all the supply chain stakeholders, including suppliers, logistic operators, end customers, and IT service providers.

For the suppliers (manufacturers and exporting companies) the expected benefits are the following:

- Increased information visibility of the supply chain, beginning from the factory gate.
- Increased information visibility of the supply chain enables precise control over manufacturing processes and timely invoicing (accuracy).
- Enhanced off-site inventory management and control.
- The expected benefits for the transportation companies and other logistics operators:
- Both direct and indirect business value is created.
- Full visibility of upstream supply chain operations enables planning and execution of just-in-time logistics instead of tying resources to non-productive events and capacity.
- Automation of manual data entry and decision-making processes, resulting in cost savings.

The expected benefits for the end customers, buyers:

- Improved inventory control creates business value.
- In retail, increased efficiency and accuracy of annual planning.
- In production, increased efficiency and accuracy of production management and process planning.

The expected benefits for the IT service providers:

- Enhanced business opportunities resulting from the ability to aggregate information flows and to perform and offer predictive analytics
- All stakeholders have the potential to automate data-dependent processes, thus achieving cost savings.

4 Conclusions and discussion

Digital supply chains (DSCs) involve the integration of business processes and data regarding products, services, finance, and information flows. The development of intra-organizational system integration is often conducted in global development environments, such as business ecosystems, and digital platforms are used to accelerate development and systems interoperability.

Although several advocates of blockchain technology have emphasized its capability to preclude the use of trusted third-party intermediaries, such avoidance may not be necessary in the digital supply chain integration scenario. By using a business-process model integrated in a smart contract [16], the seller and buyer can mandate a trusted intermediary to "supervise" the execution and flow of transactions, similar to how financial services currently operate. As part of their smart contract and secure transactions, the parties may even agree that a trusted third party will receive one or more security keys necessary to perform its role. In general, blockchains have enabled secure decentralized transactions between parties without the involvement of non–value-adding intermediaries or third parties.

Permissioned blockchain technology (such as Hyperledger Fabric) is developing rapidly and offers automated data exchange within DSCs as a new integration platform. The design of the blockchain system that this project proposes to use for DSC integration promises an integration platform that is cost-effective and flexible. In addition, new services, such as trade finance, can be established based on these trusted transactions.

The business managers participating in this project generated plenty of ideas for integration supported by blockchain technology. They viewed the permissioned blockchain ledger, smart contracting, and consensus elements as the most valuable pieces of functionality. However, transactions need to be standardized. Combining a permissioned blockchain with standardized transactions has the potential to disrupt ecosystem integration and the security of end-to-end interoperability. Public and private cloud integration combined with blockchain integration yield a cost-effective many-to-many integration model.

As pointed out, the literature about blockchain technology in the supply chain management (SCM) field is in its infancy [13]. We advanced it by designing proof of concept (POC) for a blockchain-based platform for DCS integration and by analyzing the potential benefits of such a system for all supply-chain stakeholders, including suppliers, logistics operators, end customers, and IT service providers. Because there are few examples of successful blockchain implementations, the presented SmartLog platform case study adds knowledge to the literature about the potential of this technology to disrupt supply chains. Future research could evaluate cloud applications that can accelerate and simplify DSC integration and examine the advantages and disadvantages for supply chains of various blockchain designs.

References

1. Abeyratne, S.A., Monfared, R.P.: Blockchain ready manufacturing supply chain using distributed ledger. International Journal of Research in Engineering and Technology 5(9), 0-10 (2016).
2. Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Muralidharan, S.: Hyperledger fabric: a distributed operating system for permissioned blockchains. In: Proceedings of the Thirteenth EuroSys Conference, ACM, Porto Portugal (2018).
3. Brown, R.G.: Introducing r3 corda: A distributed ledger for financial services. R3, (2016).
4. Buterin, V.: A next-generation smart contract and decentralized application platform. White paper, (2014).
5. Di Ciccio, C., Cecconi, A., Mendling, J., Felix, D., Haas, D., Lilek, D., Riel, F., Rumpl, A., Uhlig, P.: Blockchain-based traceability of inter-organisational business processes. In: proceedings of International Symposium on Business Modeling and Software Design, pp. 56-68. BMSD, Vienna Austria (2018).
6. Francisco, K., Swanson, D.: The supply chain has no clothes: Technology adoption of blockchain for supply chain transparency. Logistics, 2(1), 2 (2018).
7. Gaur, N., Desrosiers, L., Ramakrishna, V., Novotny, P., Baset, S., O'Dowd, A.: Hands-on blockchain with hyperledger: Building Decentralized applications with hyperledger fabric and composer. Packt Publishing (2018).
8. Hyperledger.: Hyperledger Fabric, https://www.hyperledger.org/projects/fabric last accessed 2021/04/10.
9. Mendling, J., Weber, I., Aalst, W.V.D., Brocke, J.V., Cabanillas, C., Daniel, F., Debois, S., Ciccio, C.D., Dumas, M., Dustdar, S., Gal, A.: Blockchains for business process management-challenges and opportunities. ACM Transactions on Management Information Systems (TMIS) 9(1), 4 (2018).
10. Nakamoto, S.: Bitcoin: A peer-to-peer electronic cash system. Decentralized Business Review, 21260 (2008).
11. Queiroz, M.M., Telles, R., Bonilla, S.H.: Blockchain and supply chain management integration: a systematic review of the literature. Supply Chain Management: An International Journal. (2019).
12. Queiroz, M.M., Wamba, S.F.: Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. International Journal of Information Management 46, 70-82 (2019).
13. Sternberg, H., Baruffaldi, G.: Chains in chains–logic and challenges of blockchains in supply chains. In: Proceedings of the 51st Annual Hawaii International Conference on System Sciences, pp. 3936-3943). Hawaii (2018).
14. Swanson, T.: Consensus-as-a-service: a brief report on the emergence of permissioned, distributed ledger systems. Report (2015).
15. Tapscott, D., Tapscott, A.: Blockchain revolution: How the technology behind bitcoin is changing money, business, and the world. Penguin, (2016).
16. Xu, X., Pautasso, C., Zhu, L., Gramoli, V., Ponomarev, A., Tran, A. B., Chen, S.: The Blockchain as a Software Connector. In: Proceedings of the 13th Working IEEE/IFIP Conference on Software Architecture (WICSA). Venice Italy (2016).