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Review and analysis of blockchain projects in supply chain management

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Abstract

Supply chains have become increasingly complex, making it difficult to ensure transparency throughout the whole supply chain. In this context, first approaches came up, adopting the immutable, decentralised, and secure characteristics of the blockchain technology to increase the transparency, security, authenticity, and auditability of assets in supply chains. This paper investigates recent publications combining the blockchain technology and supply chain management and classifies them regarding the complexity to be mapped on the blockchain. As a result, the increase of supply chain transparency is identified as the main objective of recent blockchain projects in supply chain management. Thereby, most of the recent publications deal with simple supply chains and products. The few approaches dealing with complex parts only map sub-areas of supply chains. Currently no example exists which has the aim of increasing the transparency of complex manufacturing supply chains, and which enables the mapping of complex assembly processes, an efficient auditability of all assets, and an implementation of dynamic adjustments.

Keywords: Blockchain; Supply Chain Management; Transparency; Complex Supply Chains; Systematic Review

1. Introduction

Companies have to deal with the growing interests of customers, governments, and non-governmental organizations in having a greater transparency of brands, manufacturers, and producers throughout the supply chain

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[1, 2]. As a result, social and environmental sustainability issues have become increasingly important for manufacturers in order to maintain the flawless reputation of their brand [3]. In addition to the risk of being unintentionally involved in social and environmental sustainability issues, a lack of supply chain transparency also increases the probability of counterfeit components being introduced into a supply chain. For example, the counterfeiting of electronic parts causes potential risks including safety and loss of profits to companies, as well as maligning the reputation of manufacturers and distributors [4–6]. According to Machado et. al. [7], control and trust in the supply chain are mandatory initial aspects when integrating buyers and suppliers in order to avoid harmful practices. However, achieving full transparency and detecting counterfeit components is extremely complex and can be a costly undertaking [4, 7, 8]. Chen et. al. [2] suggested that the development of a strictly monitored public database to exchange information about suppliers' identities and compliance records could eventually solve the transparency and sustainability problems of globalised supply chains. To overcome these transparency challenges in supply chains, recent research and industrial projects investigate the utilisation of the blockchain technology in this particular field [9–12].

The blockchain technology can be defined as a technology to process and verify data transactions based on a distributed peer-to-peer network. It uses cryptographic procedures, consensus algorithms, and back-linked blocks to make transactions practically unchangeable [13]. The technology was introduced for the first time by the pseudonym Satoshi Nakamoto in 2008, who published the famous Bitcoin white paper and thus introduced the blockchain technology with the aim of changing the traditional financial sector and making trusted third parties superfluous [14]. In 2013, Vitalik Buterin published the Ethereum white paper and therefore extended the idea behind Bitcoin. Compared to Bitcoin, the Ethereum protocol moves far beyond using the blockchain technology just as a currency. Ethereum is a blockchain with an embedded fully fledged Turing-complete programming language [15]. Turing-completeness describes a mathematical concept and is a measure of the computability of a programming language. A Turing-complete language design includes complex constructs such as loops and conditions, which enable the creation of general purpose programs [16]. Thus, Buterin [15] coined the term *smart contract* with blockchain-based decentralized applications.

Decentralized applications form the basis for blockchain-based use cases outside the financial sector. In this context, first approaches came up, adopting the immutable, decentralised, and secure characteristics of the blockchain technology to increase the transparency, security, authenticity, and auditability of assets in supply chains [9, 17]. However, blockchain in supply chain, blockchain in logistics and transportation, and smart contracts are currently at their peak of inflated expectations, leading to the assumption that supply chains of any complexity can be mapped on the blockchain [18].

This paper investigates recent publications combining the blockchain technology and supply chain management and classifies them regarding the complexity to be mapped on the blockchain. The aim is to capture the current scientific state of the art and to identify present research gaps. First, a complete overview of relevant publications is created. Subsequently the publications that deal with complex parts are classified and analyzed in detail with regards to the investigated complexity.

2. Methodology

The literature review approach conducted in this paper is semi-systematic review. It seeks to map theoretical approaches or themes as well as identifying knowledge gaps within the literature [19]. It includes a systematic selection of sources allowing an evaluation according to defined criteria. In this context, these also involve an explicit description of what types of sources are to be included to limit selection bias on the part of the reviewer [20]. The literature databases IEEE Explore, Springer Publishing, Scopus, China Academic Journals, and the libraries of Stellenbosch University and Reutlingen University were searched using the following keywords: Supply chain management, blockchain technology, and smart contracts. Subsequently, only publications from 2018 onwards were taken into account and examined in more detail. Since the aim of this paper is to investigate the current supply chain/product complexity to be mapped on the blockchain, the publications are classified by project, maturity, industry, project aim, product state, and product structure.

3. Analysis of blockchain projects in supply chain management

This section first explains the terminology used to classify the literature found. Then a general overview is shown, which represents a classification of all sources examined. Table 1 lists and defines the relevant terminology.

Table 1. Classification regarding the investigated complexity

Term	Description
Visibility	"The extent to which actors *within* [emphasis added] a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit" [21].
Transparency	Supply chain transparency, by way of comparison, extends the aspect of supply chain visibility to the disclosure of all information to *all* stakeholders, including the customers [22]. According to Khan and Yu [23] transparency includes even the ability for customers to gain access to information without actively participating in the supply chain system landscape or architecture.
Automation	In this context the term describes the automation of supply chain processes
Disintermediation	In this context, disintermediation describes the elimination of individual stages in the value chain.
Assembling	Describes the mapping of parts with the ability to change their modular compositions throughout the supply chain
Transformation	Refers to events that can affect and change raw materials, intermediate components or final products without changing their modular composition. (e.g. processing steps or temperature treatments)
Final Product	Products that do not experience any changes in their modular composition or transformation processes.
Single parts	A categorization for parts that do not change their modular composition but can experience transformation events.
Complex parts	A categorization for parts that can experience changes in their modular composition.

Table 2 shows the enlistments of all publications. In total 43 publications meet the quality criteria of having elaborate concepts or an advanced project maturity and could be classified according to the criteria described in Table 1.

Table 2. Classification regarding the investigated complexity

Count	Year	Project maturity	Industry/Field	Project Aim	Product state	Product structure	Source
1	2019	Pilot	Automotive	Visibility,Automation	Assembling	Complex parts	[24]
2	2018	Experiment	Production	Automation	Transformation	Single parts	[25]
3	2018	Experiment	Food	Transparancy	Assembling	Complex parts	[26]
4	2018	Experiment	E-commerce	Transparancy	Final product	Single parts	[27]
5	2019	Experiment	Healthcare	Transparancy	Final product	Single parts	[28]
6	2019	Experiment	Food	Transparancy ,	Transformation	Single parts	[29]
7	2019	Concept	Food	Transparancy,Disintermediation	Final product	Single parts	[30]
8	2020	Experiment	Food	Transparancy	Transformation	Single parts	[31]
9	2019	Experiment	Food	Transparancy	Transformation	Single parts	[32]
10	2017	Pilot	Healthcare	Visibilty,Automation	Final product	Single parts	[33]
11	2018	Industrialization	Food	Transparancy	Transformation	Single parts	[34]
12	2019	Industrialization	Transport	Visibility,Disintermediation	Final product	Single parts	[35]
13	2019	Pilot	Food	Transparancy	Final product	Single parts	[36]
14	2019	Experiment	Automotive	Transparancy	Assembling	Complex parts	[37]
15	2019	Experiment	Automotive	Transparancy	Assembling	Complex parts	[38]
16	2019	Pilot	Food	Transparancy	Final product	Single parts	[39]

17	2019	Experiment	E-commerce	Visibility,Automation	Final product	Single parts	[40]
18	2017	Experiment	Retail	Transparancy	Final product	Single parts	[41]
19	2019	Experiment	Transport	Transparency,Automation	Final product	Single parts	[42]
20	2019	Experiment	Healthcare	Transparancy,Automation	Final product	Single parts	[43]
21	2019	Experiment	Food	Transparancy,Automation	Final product	Single parts	[44]
22	2019	Experiment	E-commerce	Transparancy	Final product	Single parts	[45]
23	2019	Experiment	Production	Transparancy	Assembling	Complex parts	[46]
24	2018	Pilot	Food	Transparancy	Transformation	Single parts	[47]
25	2019	Concept	E-commerce	Visibilty,Automation	Final product	Single parts	[48]
26	2020	Experiment	Food	Transparancy	Transformation	Single parts	[49]
27	2020	Experiment	Healthcare	Transparancy	Final product	Single parts	[50]
28	2018	Concept	Production	Visibility,Automation	Transformation	Single parts	[51]
29	2019	Pilot	Food	Transparancy	Final product	Single parts	[52]
30	2019	Experiment	Production	Transparancy	Assembling	Complex parts	[53]
31	2019	Experiment	Food	Automation	Final product	Single parts	[54]
32	2018	Experiment	Food	Transparancy,Automation	Transformation	Single parts	[55]
33	2018	Concept	Food	Transparancy	Transformation	Single parts	[56]
34	2020	Experiment	Food	Transparancy	Transformation	Single parts	[57]
35	2019	Concept	Food	Transparancy,Disintermediation	Transformation	Single parts	[58]
36	2019	Experiment	Food	Transparancy,Disintermediation	Final product	Single parts	[59]
37	2020	Experiment	Healthcare	Visibility	Transformation	Single parts	[60]
38	2019	Experiment	Food	Transparancy,Automation	Final product	Single parts	[61]
39	2019	Experiment	Food	Transparancy	Assembling	Complex parts	[62]
40	2019	Experiment	Food	Transparancy	Final product	Single parts	[63]
41	2018	Experiment	E-commerce	Transparancy,Automation	Final product	Single parts	[64]
42	2019	Experiment	Food	Visibility,Disintermediation	Final product	Single parts	[65]
43	2019	Experiment	Production	Transparancy	Transformation	Single parts	[66]

As Table 3 shows, blockchain projects in the area of food supply chains are the most represented industry. Followed by production, healthcare, and E-commerce.

Regarding the project aim shown in Table 4, the increase of supply chain transparency is with 33 publications by far the most reasonable aim for the adoption of blockchain technology in supply chain management. With 13 entries, automation is the second most common project aim. In total 8 projects aim to increase supply chain visibility and 5 projects aim to achieve disintermediation.

As Table 5 indicates, most of the publications are dealing with the mapping of final products. At least 14 publications include the mapping of transformation events. Only 7 out of 43 publications describe advanced architectures or frameworks meeting the criteria of mapping complex parts. In the following sections, publications dealing with the mapping of complex parts are analyzed and classified in detail.

Table 3. Overview industry

Industry/Field	Total
Food	22
Automotive/Production	8
Healthcare	5
E-commerce	5
Transport	2
Retail	1

Table 4. Overview project aim

Project aim	Total
Transparency	33
Automation	13
Visibility	8
Disintermediation	5

Table 5. Overview part complexity

Product state	Product structure	Total
Final product	Single parts	22
Transformation		14
Assembling	Complex parts	7

3.1. Classification regarding the investigated complexity

A holistic mapping of manufacturing supply chains must contain the mapping of raw materials, intermediate components, final products, and transformation events. In this context, intermediate components refer to components that can be clearly identified and that can be assembled into a final product at a later stage. An exploration of the literature results a classification regarding the investigated mapping complexity shown in Table 6.

Table 6. Classification regarding the investigated complexity

Source	Project maturity	Industry	Investigated mapping complexity				Methodology
			Raw material	Intermediate component	Final product	Transformation events	
[24]	Pilot	Automotive		X	X	X	Architecture
[37]	Experiment	Automotive		X	X	X	Architecture
[26]	Experiment	Food	X		X	X	Framework
[38]	Experiment	Automotive		X	X	X	Architecture
[53]	Concept	Production		X	X	X	Architecture
[62]	Experiment	Food	X		X	X	Architecture
[46]	Experiment	Production	X	X	X		Architecture

As Table 6 illustrates, no existing approach enables the mapping of a holistic manufacturing supply chain.

3.2. Analysis of blockchain mapping approaches

As Table 6 indicates, current approaches have problems with the mapping of the transition from raw materials to intermediate components. In the listed food supply chain approaches, this transition can be skipped, as in these approaches the final products are mixed directly from different raw materials. Therefore, these approaches can also be seen as a solution for raw material 'blending' problems. However, these cannot be transferred to manufacturing supply chains in which intermediate components are essential elements. Raw materials differ most from the other components in their properties. This is mainly because they can be strongly subdivided into smaller units. This places considerable technical demands on a holistic architecture because the mapping of raw materials requires both subdivision and traceability of the respective units. Thereby, the tracking and mapping of raw materials such as cobalt even represents an essential driver for many blockchain projects in manufacturing supply chains [67]. The approach by Westerkamp et. al. [46] represents the only approach allowing the embedment of raw materials into the architecture. However, this leads to considerable shortcomings when applying it to complex manufacturing supply chains.

The architecture proposed by Westerkamp et. al. [46] solves the problem of mapping complex manufacturing processes by deploying smart contracts representing assets or batches. However, these smart contracts are *not* logically coupled. The coupling only takes place at program code level and is expressed in the form of ‘token recipes’. This ensures that the assembly of tokens takes place under legitimate conditions. Even though this approach solves the assembling problem, it creates a new problem when tracking these tokens. Since each token is managed by different smart contracts which are not logically coupled, it requires great effort to link information between the tokens after they have been merged [68]. In addition, this logical decoupling causes considerable administrative problems with increasing supply chain complexity. A change in one of the smart contracts inevitably leads to the deployment of a new smart contract. As a result, all subsequent token contracts must be redeployed include this changed smart contract in their token recipes. As a result, a change at the very beginning of a supply chain (e.g. in the raw material) affects the *entire* token structure that follows. Such structure makes it difficult to maintain the smart contract construct, especially in the case of dynamic changes in the composition of products or the structure of the supply chain. These changes would result in massive adaptations of each smart contract. This results in a current conflict between enabling the mapping of assembling processes, an efficient auditability of assets, and an implementation of dynamic adjustments in one holistic solution.

4. Conclusion

The blockchain technology is used in supply chain management of various industries. Thereby, the main objective of recent blockchain projects is to increase the supply chain transparency. The simpler requirements in terms of product complexity, for example in food supply chains, can already be completely mapped on the blockchain. Food supply chains take a major part of supply chain related blockchain projects. In supply chains dealing with complex parts no solution exists which has the aim of increasing the transparency and which enables the mapping of assembly processes, an efficient auditability of all assets, and an implementation of dynamic adjustments. Raw materials, intermediate components, final products, and transformation events all have very different properties and still inevitably interact or merge with each other at a certain point in complex manufacturing supply chains. None of the analyzed scientific publications deals with an approach covering complex supply chains from raw materials to final products with transformation events included.

Obviously, the holistic mapping of such supply chains for complex products represents a particular challenge for blockchain technology. The proposed solution by Westerkamp et. al. [46] has considerable shortcomings when tracking complex parts and administrating supply chains. A holistic smart contract-based architecture could represent an important milestone in making the characteristics of the blockchain technology accessible to complex manufacturing networks. Nevertheless, other aspects, such as the scalability of the blockchain technology, may also limit blockchain applications in complex manufacturing networks. These aspects are not considered in this paper and must be further investigated. Currently, further research is being conducted by the authors in order to develop a holistic smart contract-based architecture.

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