

Differentiating Blockchain Technology to optimize the Processes Quality in Industry 4.0

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Abstract—The complexity of supply chains increase, especially due to the geographical spread of supplier and customer networks. In the connected and automated supply chains of the industry 4.0, even more nodes are incorporated in supply chains. This paper discusses the possible improvement of process quality in the industry 4.0 through the different blockchain and distributed ledger technologies. We derived hypotheses from a literature review and asked German blockchain experts from the industry to validate and discuss the hypotheses. We find that the different blockchain technologies and consensus algorithms have different strength with regard to quality improvement. One central finding is that IOTA, developed especially for the IoT and deemed the 'next evolutionary step' is scalable and hence may increase the process efficiency, but at the same time is more vulnerable than other blockchain implementations, which again may reduce the overall process quality.

Index Terms—blockchain, industry 4.0, industrial IoT, process quality

I. INTRODUCTION

In the beginning of 2017, the majority of the decision makers in the German mittelstand voiced that the term blockchain has no meaning to them (64%), or they heard the term, but have not yet looked into the topic (19%) [1]¹. Then, during 2017, the crypto currency Bitcoin surged by a factor of 15 [2] and blockchain, the technology behind Bitcoin, attracted remarkable public attention.

Beyond enabling a crypto currency, the blockchain technology is interesting for applications in the so-called German 'Industry 4.0' (also referred to as 'industrial internet' [3]). The blockchain technology combines known methods as distributed networks, cryptography and consent building in such a way that it can establish trust between otherwise unrelated parties, reliably store transactions [4] and increase the security of connected systems against intruders [5]. Introducing a blockchain based technology, for example into the supply chain management of companies to optimize

¹Online study carried out for the Association of Internet economy with 266 decision makers from top- and middle management of the German mittelstand between 25.01.2017 and 04.02.2017.

processes quality, is one obvious area of future application [6].

However, there are various generations and methods that have developed and are linked to the term blockchain. These may have a different impact on the improvement of process quality in industry 4.0. Hence the question arises, which of the current blockchain methods is the most beneficial in order to increase the process quality in industry 4.0?

II. BACKGROUND

The fundamental of the blockchain technology is the distributed ledger technology [7]. It comprises of a distributed computer network and the data base itself is organized in a decentralized peer-to-peer network, as suggested first by [8]. With the use of digital signatures, cryptography and different organizational forms, the blockchain technology can control and verify access privileges and user identities. In addition, the real time and the irreversible transactions are a key element of the technology [7]. The original bitcoin blockchain utilized the proof-of-work consensus (PoW) algorithm.

The PoW algorithm searches for a value that fulfills certain mathematical requirements. The mathematical verification is fast and easily executed by a single calculation, but fulfilling the requirements to solve the mathematical puzzle is an increasingly hard problem, the more blocks exist [8]. The PoW consensus algorithm thus has been criticized, as it has a small throughput, requires a waiting time before confirmation of the transaction and still leaves a statistical possibility that the transaction can be reversed [9]. Further, a study estimates that mining the virtual currency Bitcoin alone will consume at least 2.55 GWh (Ireland for comparison consumes 3.1 GW) and potentially 7.67 GW (Austria consumes 8.2 GW) [10].

An example of the so called blockchain generation II is the Ethereum blockchain [11]. Its Ethereum Virtual Machine enables the crypto currency the conduction of the source code from smart contracts. A smart contract is a script which has the ability to steer digital contents. Smart contracts can be described as decentralized apps which can accomplish

an automated value exchange when receiving a certain input signal [12]. The ability to process an operation in an automated and decentralized way, is a key factor for the technology of the future [13] and a powerful driver for new business models in the IoT [14]. As a further improvement to the blockchain generation I, a fork of Ethereum plans to replace the originally utilized PoW consensus algorithm by a proof-of-stake (PoS). The update, which is considered a hybrid between PoW and PoS, has already been published in May 2018 on Github.

The basic idea of the PoS and the probability of generating a block depends on the value of a participant in the network. PoS requires a much lower electricity consumption than PoW. Criticism on the PoS consensus suggest, that due to the low costs of working in several chains, block generators may vote for several forks; that the algorithm prefers users that have bound a larger stake and thus is not truly decentralized.

IOTA, a new crypto currency designed for the Internet-of-Things (IoT), describes its implementation as "*the next evolutionary step*" [15]. The author claims that IOTA addresses issues of the earlier generations such as transaction fees or a discrimination of participants [15]. Thus, IOTA and other crypto currencies are sometimes addressed as generation III - despite fundamental differences between the technologies. The distributed ledger of IOTA is not grouped in blocks and sequenced in chains. It's technology can be rather described as a stream of transactions which are linked - 'tangled' - to each other. Therefore every user has to assume computational tasks. A computational task consists of the verification of two previous transactions. The structure of IOTA and the underlying tangle principle may enable a high scalability and a zero-fee-transaction which might pose an asset for the industry 4.0.

The industry 4.0 initiative was launched by the German government in 2011 as part of a high-tech strategy. The goal is to promote the vision of a connected industry [16]. The industry 4.0 combines of interconnected machines and manufacturing equipment with IT-Systems to allow a redesign and improvement of production and sales processes [17]. A prominent example for potential benefits of the blockchain technology in the industry 4.0 is the digital supply chain [6], [18].

The complexity of supply chains increase through regulatory and compliance requirements, geographically spread suppliers and customer networks, outsourcing, risk and security considerations and through increasing speed of change in supplier networks and customer expectations [19]. The blockchain technology can potentially address issues of already automated supply-chain processes, which are missing interfaces and inadequate master data quality that prevent a fast data provision within the supply chain [20]. The blockchain technology is considered to be immutable,

meaning that it can reliably store transactions [4] and it can increase the security of connected systems against intruders [5].

This paper discusses the possible improvement of process quality through blockchain technology. Two quality features are the effectiveness and efficiency. Effectiveness is influenced by quality of results, customer satisfaction, employee satisfaction and business value. The efficiency is determined by the productivity (which is the output quantity divided by input quantity) and the reuse or the recycling in the processes [21].

In summary, the currently available digital supply chains are but one example that offer room for process improvement in the industry 4.0. The blockchain technology is often named as a remedy to optimize processes quality within industry 4.0. In order to answer the question which current blockchain method is the most beneficial in order to increase the process quality in industry 4.0, we will explore in this paper the following investigative questions:

- What are the benefits and drawbacks of the different blockchain generations with regard to process quality in the German industry 4.0?
- Which of the current blockchain technologies best addresses the named drawbacks?

III. METHODS

In order to answer the questions we first carried out a literature review to collect strengths, weaknesses, opportunities and threats named for any blockchain technology with regard to process quality improvement in industry 4.0. Then we derived hypotheses and asked experts from the industry to validate and discuss the hypotheses. The research focus was Germany, hence experts working in Germany and available German literature were taken into account.

A. Literature review and SWOT analysis

We search the literature with a pairwise AND combination of the following keywords: 'Blockchain', 'Industrie 4.0', 'Digitalisierung', 'Qualität', 'Kosten', 'Zeit', 'Disruption', 'Integration' in the data base of SpringerLink. The data base was chosen due to availability. The period under consideration was from January 2017 to June 2018, in order to limit the research on latest available information. The search yielded 130 sources, of which 26 sources were deemed relevant after reading title and abstract. We then performed a SWOT analysis based on the identified manuscripts. The SWOT analysis is a strategic analysis of the own activities towards the competition [22]. It is often used economy, but also is discussed as a methodology in scientific research [23]. We use the SWOT analysis to provide a detailed examination of the blockchain technology with regard to its strengths, weaknesses, opportunities and threats.

B. Hypotheses from SWOT analysis

We base on the SWOT analysis to derive hypotheses. The hypotheses combine strengths, weaknesses, opportunities and threats into five key questions regarding the efficiency of different aspects of the blockchain technologies industry 4.0 processes.

C. Validation of hypotheses with experts

We validate the hypotheses qualitatively with experts from the industry. The goal is to approve, decline or enhance the hypotheses in the light of recent professional knowledge from industry. We chose semi-structured interviews, to be able to control the dialog, while leaving room for gaining exploratory information [24]. We systematically contacted five experts from the industry after their presentations on Blockchain at the Hanover Industry 4.0 fair. Three of the experts agreed to an interview and two of them (anonymized as I1 and I2 in this paper) had time to carry out the telephone interviews in mid 2018. To address concerns about quality, quantity and time-frame in semi-structured interviews, we further validated and triangulated the results, with a third similar semi-structured telephone interview with a researcher, an expert in the field of blockchain, operations management and industry 4.0.

IV. RESULTS

A. SWOT analysis

Table I summarizes results from the SWOT analysis.

B. Hypotheses

The SWOT analysis suggests that many of the identified publications utilize ‘blockchain’ as an umbrella term and one-dimensional issue, without differentiating between different technologies. We follow the wording without further differentiation and derive the following five hypotheses with regard to the process optimization potential in industry 4.0:

- 1) On reasons for process optimization potential:
The design of the any Blockchain generation, it’s network architecture and underlying consensus mechanism allow the processes within industry 4.0 to be more efficient by enabling saving potential; ensuring tamper resistance and providing transparency.
- 2) On blockchain as a global an cross-company architecture:
Through the global disposition of the blockchain, corporate boundaries become more transparent and make global trading processes more efficient.
- 3) On increasing efficiency by smart contracts:
Transactions are executed through the blockchain in an automated way (smart contracts) and in real time, which can increase the efficiency of the supply chain.
- 4) On the scalability potential of zero-fee transactions:
Zero-fee-transactions and high scalability, such as f.e. IOTA, have a future in the industry, and may help to improve process quality.

TABLE I
RESULTS OF THE SWOT ANALYSIS

Strengths
The design and network architecture leads to the fact that central entities can be bypassed [25]
Through the design costs can be saved and transactions authenticity and immutability can be ensured through one cornerstone of the blockchain technology - the consensus mechanism [26]
The consensus mechanism can contribute to security against manipulation and provides transparency [13]
Transactions can be transferred in real time which can revolutionize trade processes [13]
Through smart contracts processes can be automatized. Consequently an increasing liquidity, transparency and trust can be provided within the supply chain [13]
The blockchain is globally available [7]
Weaknesses
A small data throughput in comparison to a common central solution provider like Visa which provides 24 000 transactions per second causes a low scalability and therefore the blockchain technology is perhaps not ready for public use cases. [27] Solving cryptographic puzzles in the Bitcoin blockchain consumes enormous amounts of power [28].
Opportunities
The possibility exists, to shape the stream of commercial documents within the supply chain in a more efficient way [29]
A higher scalability and zero-fee-transactions can be created through the omission of the mining process – IOTA and the tangle principle are providing these characteristics [15]
New markets can be accessed through low costs, accessibility, acquisition and data integrity. As well to smaller suppliers the opportunity is offered to compete with bigger suppliers [30]
There is also the chance to secure data and process integrity for companies through blockchain technology [30].
Threats
If quantum computers are commercialized, the current cryptographic encryption is vulnerable and a new blockchain protocol required [31].

- 5) On the weakness of high power consumption
The high power consumption makes the blockchain technology uninteresting for the industry.

C. Validation of the hypotheses

Hypothesis 1: On reasons for process optimization potential

I1 cannot confirm the hypothesis. For the miners it is irrelevant whether right or wrong values are being processed. The consensus mechanism ensures tamper-proof processing of the values, yet I1 sees the biggest challenge that hackers mess with the data in the transmission of the data from the sensor to the blockchain.

I2 is also of the opinion that an implementation of the blockchain cannot provide 100 percent certainty. However, according to him, the consensus mechanism complicates internal and external manipulations to a maximum. Tamper-evident security can be ensured by a solid IT security concept with a solid data protection rating and a hardened IT infrastructure.

As an alternative to the PoW algorithm in the industrial context, I2 envisions a proof of authority consensus

mechanism governed by a consortium with a distributed consensus. I1 reflects on the implementation of a kind of professional consensus mechanism that is able to compare input values.

The PoW consensus mechanism is not ideal for the industry, according to I1, but according to I2, there is the possibility to build private Bitcoin Protocol stacks so that transactions can be validated faster.

Hypothesis 2: On blockchain as a global an cross-company architecture

According to I1, blockchain technology can increase the efficiency of processes when they reach beyond company boundaries. He names as a typical application the global commerce, when multiple parties engage in business with each other and trust between the parties does not exist. In addition, I1 says that by creating regulations through the blockchain, trust in global trade can be created. I1 states that due to the global availability of the blockchain, it can be assumed that a certain network size has to be achieved in order to ensure a stable system. If a certain network size is achieved, a stable system and link between different process participants is proven.

Hypothesis 3: On increasing efficiency by smart contracts

The company of I1 not only uses smart contracts to perform services, but also to provide continuous quality assurance. Here, the smart contract assumes the role of an automated rule, whereby quality assurance can be generated at low cost. I2 finds that smart contracts are a useful application if the right use case is given. This is i.e. the case when many connections or many automatic mechanisms in a process initialize an event. In this case the implementation of smart contracts increases the efficiency. On the contrary, if a user only transfers one datum per week, but requires this datum to be highly available and very secure, I2 suggests that even the public bitcoin blockchain could handle this transaction, here the PoW-method offers the safest application because it is the least predictable method.

Implementing blockchain in the field of logistics is a relevant topic to I2. Logistics reach beyond company boundaries and involve different companies or parties who benefit from an interaction via a common database. Automatically initiating events through smart contracts may optimize existing processes and the goods can ultimately be charged with value.

I1 cannot imagine that blockchain technology can be integrated in traditional industrial operations where a car is assembled on an assembly line. But if processes do not have data systems or are written on paper, the blockchain technology provides a way for immediate access (in real time) to data in a blockchain database. As a result, transparency and efficiency can increase.

I2 has the same opinion as I1. To increase the efficiency of production operations, topics such as factory automation

or production processes are interesting. However, I2 also assumes that blockchain technology does not necessarily have a role in making machines work more efficiently in production.

Hypothesis 4: On the scalability potential of zero-fee transactions:

I1 stresses that IOTA is not based on the blockchain technology, but pursues the principle of Tangle. IOTA or the Tangle principle is not able to provide a complete proof of manipulation and a major weakness is the use of a central server, which means that "hacker attacks" are possible. I1 does not believe that zero-free-transactions will permeated, since at the end of the day, a system must earn money. In addition, I1 claims that IOTA is a foundation and has so far collected money and therefore is unable to offer zero-free-transactions over a longer period of time. The tangle principle does not make sense in the industry, but addresses issues that the blockchain technology currently cannot solve. A problem of the blockchain technology is the large amount of data that participants have to hold in a blockchain. I1 believes, however, that IOTA and the underlying tangle are a good approach in the area of embedded devices.

I2, claims that a private or consortium Ethereum blockchain may provide the same zero-fee-transactions as the "Blockchain 3.0" approach. In an organization form of a consortium not all transactions must run over the Ethereum blockchain, but transactions can also run off-chain. This allows transactions to be handled free of charge. Zero-free-transactions only provide use cases in the field of public blockchains. A blockchain in industry 4.0 should therefore be set up in a private operating environment in order to be able to adapt the blockchain to the specific use case as much as possible. I2 agrees with I1 that IOTA still has to prove that they can do what they promise. However, I2 announces that a combination of the two technologies (blockchain and tangle) can be introduced to the market for eliminating the inefficiencies of both technologies.

Hypothesis 5: On the weakness of high power consumption:

I1 sees the cause rather in the chosen consensus mechanism. The PoW consensus mechanism provides massive stability and invulnerability, but has the disadvantage of consuming big amount of resources. He believes transactions could be handled even without high power consumption if the Bitcoin community agreed on a new consensus mechanism. However, it is unclear how the whole thing will develop when f.e. the Bitcoin community agrees on a PoS consensus mechanism as miners are rewarded by generating bitcoins.

V. DISCUSSION

This study finds that none of the current blockchain implementations is a panacea to improve the quality of processes in the Industry and IoT for each and every situation. In some cases, if not yet implemented, any digitization of processes may already leverage substantial

savings, independent from the implementation of a blockchain.

Apart from these cases, our research confirms the common suggestion in the literature that any blockchain technology may in general improve the process quality in the industry 4.0 (i.e. by [6] and [18]). This is specifically true for processes that need to overcome cross-company boundaries and when where disparate parties do not trust each other. Due to the established regulations within the blockchain, a traceable and transparent transfer of digital values is possible. Since transactions can be processed in real time and the decentralized approach allows intermediaries to be bypassed, an increase in efficiency within the supply chain can be achieved.

The blockchain generation I uses the PoW consensus method. It offers process quality improvements especially due to the immutability of data in its distributed ledger network. However, the generation I has various drawbacks: It offers only rudimentary smart-contracts. In the context of industry 4.0, a blockchain protocol that enables smart contracts (generation II) is not only useful for adding transparency, automated financial transactions and facilitating sharing of services and property, as [14] suggests. Our research indicated that smart contracts additionally can provide continuous quality assurance, where the smart contract assumes the role of an automated rule and hence improve the efficiency of processes.

Another drawback of the blockchain generation I are transaction costs. In the industry 4.0, potentially many small transactions are required, where the transaction costs may exceed the actual cost for the service. This is addressed by the crypto currency IOTA, which is designed for the IoT [15], [32]. Our research suggests that the technology as it is, might probably prevail, since at the end of the day, the system itself generates costs and hence must work profitably. An interesting suggestion during our study that requires further research was to combine the two technologies (blockchain and tangle) to eliminate the inefficiencies of both technologies.

With regard to the consensus mechanism, the PoW algorithm might not be the most efficient choice for industry applications. For the industry 4.0 the proof of authority should be considered as suitable consensus mechanism for a consortium blockchain, but the reduced security must be considered. Another recently suggested solution is the proof of authentication consensus mechanism. This mechanism removes the reverse hash function from PoW to lightweight the process and ensures an energy efficient distributed secure communication and computing in the IoT [33].

VI. CONCLUSIONS

We set out to answer the question which of the current blockchain concept is the most beneficial in order to increase the process quality in industry 4.0. Our research suggests

that as soon as cross-company processes are involved, any blockchain technology may improve the efficiency of by improving the data immutability, especially generation I with PoW. Further efficiency improvements may be gained by implementing automated smart contracts of generation II. We find somewhat surprisingly, that the crypto currency IOTA, which was especially designed for the IoT and sees itself as the next evolutionary step from blockchain, is not necessarily the best solution in any case, with regards to process quality improvements. IOTA addresses some issues of earlier blockchain generations, such as keeping a large amount of data and still ensuring high scalability. However, IOTA is using a central server which is vulnerable to attacks. Thus, we found that recommendations on which technology to implement are case-specific, depending on whether data immutability, flexibility or scalability are of higher importance.

This study contributes to the body of knowledge by collecting evidence and comparing and discussing the strength and drawbacks of different blockchain generations for industry 4.0. with regard to the quality improvement of processes. Many studies exist that discuss a technical aspects of the blockchain technology or research the benefits of blockchain in IoT. Thereof, some studies do address the impact of the blockchain technology on quality improvement. However, to the best of our knowledge a comparison of the different technologies and methods with regard to quality improvement in industry 4.0 was missing.

As in implication for practitioners, our research suggests in order to improve the efficiency of in-company production processes, factory automation is a more relevant topic than implementing a blockchain.

This study is limited, since the SWOT analysis has been carried out mainly based on the SpringerLink database, thus might not be complete. As a result, some of the derived hypotheses were not specific enough. This became obvious during the validation with the experts, who significantly discussed and amended the hypotheses. Our study yields two interesting suggestions for further research. Firstly, how can the technologies, blockchain and tangle, be combined to eliminate the discussed inefficiencies of both technologies? Secondly, while the blockchain generations provide security to store data, they cannot ensure that the data from the sensor reach the ledger a tamper-free way. An overall IT security concept is needed, to make existing processes in the industry more efficient.

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