Blockchain as Middleware+

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Abstract. In supporting decision making of manufacturing companies, the added value of cross-domain data exchange for aggregating information is well established in enterprise organization research and is represented, for example, in the reference model "Internet of Production" (IoP). Currently, there is little research regarding the role of Blockchain technology in such a reference model and how specifically the IoP needs to be expanded to address cross-company data exchange. This paper presents a proposal for such an extension to outline the use of Blockchain technology and to elaborate the open research demands for implementation. In particular, desk research and the development of concrete use cases for cross-company data exchange between business application systems were carried out. The results are, on the one hand, extending the IoP by a third dimension, which corresponds to the supply chain, and, on the other hand clarification of the role Blockchain technology can take in this context.

Keywords: Blockchain, Supply-Chain-Management, Middleware+, Internet of Production, Supply-Chain-Data-Management.

1 Introduction

1.1 Challenges in Supply Chain Management

The decline in value added per individual company observed in recent decades will continue over the next few years [1]. This is facilitated by increasingly complex products, which in turn means that more and more different suppliers have to be integrated into the value chain for the production of a product [2]. There is a need to cooperate with more and more value creation partners. At the same time, ever-shorter product life cycles and the associated ever more frequent changes to products mean that value-adding partners have to be changed more and more quickly.

Increasing competitive pressure and the shift from the seller to the buyer's market are forcing companies to exploit the potential for optimization through digital data exchange, previously considered to be too costly or insufficiently productive [3]. For example, the use of data from the supplier can prevent a company from having to recollect data itself, which often avoids inaccuracies and duplication of effort. Collaboration concepts such as just-in-sequence, in which the supplier delivers the parts according to the sequence at the car manufacturer, should reduce inventory and handling

costs. The prerequisite is that the car manufacturer transmits the sequence to the supplier - digitally to keep the administrative costs reasonably low.
Ultimately, therefore, there is the need for quickly established digital networking with many value-added partners. The concept of the organization of the data exchange along a value chain should be called Supply-Chain-Data-Management in the further.

1.2 Digital connection / Industry 4.0

"Industry 4.0" has established as term for the mass connection of information and communication technologies [4]. It refers to the real-time capable, intelligent, horizontal and vertical networking of people, machines, objects and information and communication technology in order to be able to manage complex systems [5]. For implementation in production, Klocke et al. define the reference architecture "Internet of Production" (see chapter 2) and present some use cases of such connection.
As part of **change requests** in production, technical changes in the form of state changes of actually released products are necessary [6, 7]. Due to the increasing dynamisation of the industrial environment, technical change management has become increasingly important [6, 8]. Due to the many negative effects of such requests (budget overruns, time delays), companies usually try to avoid them if possible. Cost drivers in change management are in particular cross-departmental coordination efforts and media discontinuities in the participating operational application systems. A significant improvement of the change request process could therefore be achieved, among other things, through meaningful linking of CAQ, PLM, CAD, FEM, and ERP systems: The introduction of the change request without this link often leads to large expenses in the manual transfer of data between the systems mentioned and ultimately to inconsistent data and ultimately to high error and failure costs. [9]
The **design of additional systems for technical process stabilization** in order to retrofit them to a machine is necessary, for example, if the machine has critical structural vibrations during operation. These vibrations could be alleviated with the help of individually designed multi-mass dampers. Such additional systems are usually easier to implement than structural adjustments. The design of such systems requires the availability of data such as the frequency and waveform as well as the equivalent oscillating mass of the machine structure. Therefore at least data from the CAD and the FEM system are necessary. [9]
The use cases presented impressively show the added value of connecting various business application systems, but remain at the corporate level. Even in those use cases in which customers are involved, not their systems but self-used systems with customer data are used. In the following chapter, the Internet of Production is introduced, presenting a framework that is able to address the digital connection between business application systems used in the presented use cases.

1.3 Internet of Production

Fig. 1 shows the reference architecture of the Internet of Production, which was presented at the Aachen Machine Tool Colloquium in 2017 and culminated in 2018 in the eponymous Aachen Cluster of Excellence sponsored by the DFG. Seen from left to right, it includes the three phases "Development Cycle", "Production Cycle" and the "User Cycle". At the lowest level, the raw data usually generated in the respective phases and (graphically above) the application software in which this data is managed are displayed. At the highest level, the vision of decision support Smart Expert systems is presented, which support the employees in the respective phases. They feed on the layer of so-called "smart data", ie data which has already been pre-refined by analytical methods. Input for these data analyzes comes from the already mentioned application software systems. The access to the proprietary operational application systems therefore is allowed by a Middleware+, which, however, has not been further specified in its design. [9]

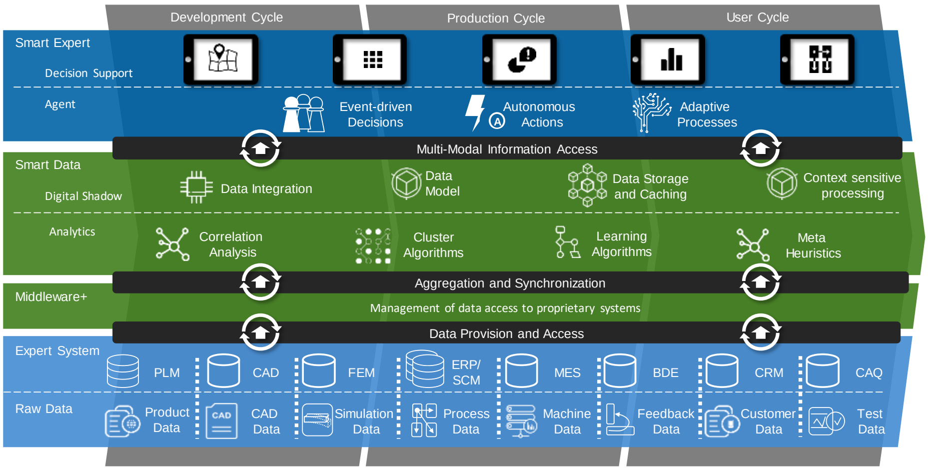

Fig. 1. Internet of Production [9]

2 Cross-company Internet of Production (Three-dimensional)

The attempt to expand the IoP with regard to cross-company data connection is carried out per level below.

The lowest level of **raw data and application software systems** remains company-specific. The attempt to create data through the use of common systems across companies would fail due to the aspiration to quickly achieve connection with new partners. Any change of value-added partners would be associated with the introduction of new business application systems - at least if it can be assumed that systems that are not globally consistent will be used. With the example of ERP systems it becomes clear: More than 2000 different systems are currently offered on the market [10]. Correspondingly, a cross-company representation of the IoP would have to show a separate raw data and application software layer.

The **Smart Expert** view, including the apps shown there, contains expert systems that specifically provide those users with information that is relevant to them. However, the information to be extracted from each company's data may differ significantly from company to company. For example, it may be helpful for the customer of an aluminum parts supplier to see how well their supplier has met the prescribed component tolerances. The employees of the aluminum supplier, on the other hand, are more likely to receive orders from the customer in the Smart Expert System. In many cases, there is a high overlap of the contents of the Smart Expert systems along the supply chain - once developed apps can be used in several companies. However, standardization of the level must be avoided.

This results in a direct conclusion for the **Smart Data** layer. Features such as data integration or the data model, as well as the data analysis method to use, are highly dependent on what results are displayed on the Smart Expert level. Consequently, the same applies here as for the Smart Expert level: there is certainly a high degree of reusability of the functions used. However, standardization does not make sense.

The situation is different at the level of **Middleware+**: especially in this area, a breakthrough in the form of cross-company connection is indicated and would enable many use cases along the supply chain. A Middleware+, which would ensure overall management of data access to proprietary systems and data there, would enable organizations to efficiently use data from their value-added partners. A connection via a shared Middleware+ would also reduce the connection costs of new partners, since the number of interfaces is considerably reduced - the rapid change of the value-added partners and the connection of many partners for the realization of Supply-Chain-Data-Management are therefore possible.

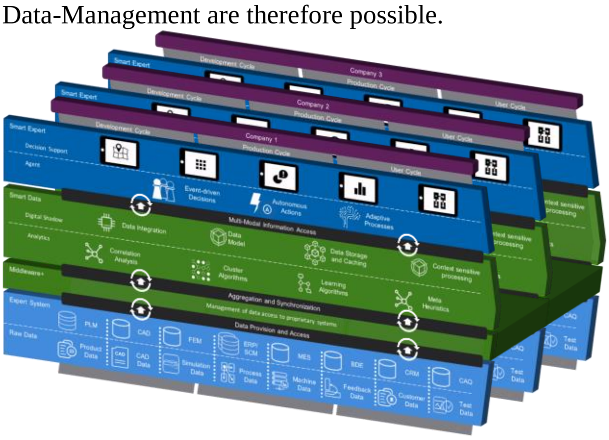

Fig. 2. Cross-company Internet of Production

The selected form of representation extends the IoP by one dimension: the different value creation stages. Two problems of this form of representation should be briefly addressed. On the one hand, this representation could give the impression that expressly only classical value chains with a defined sequence are displayed instead of value networks. In fact, the order of the companies here is not decisive, a connection between company 1 and company 3 is possible. On the other hand, in the industrial supplier-customer relationship, the "user cycle" of one company is often the "production cycle" of the follow-up company. This is not explicitly made clear in the presentation, but also irrelevant for multilateral networking. The fact that test data in the CAQ could come from the customer's BDE is already taken into account by the fact that the Middleware+ is consistent across all cycles.

For the concrete design of such a cross-company Middleware+ is to be noted that there is a conflict of trust between the companies. Even with in-house connection, it has become apparent that the specific technical design of a Middleware+ is not trivial. In the case of a cross-company perspective, it is to be expected that this arrangement will be much more difficult. While there is an escalation level in the organization of a corresponding implementation project with a higher hierarchical level, which can simply make a decision in the event of disagreements between the stakeholders, such an escalation level is missing in the cross-company case. Furthermore, simple authentication methods for in-house connection can prevent data from being illegally manipulated - this is not the case with cross-company connection. Centralized approaches (platforms) have so far hardly established themselves for such sensitive business areas. Blockchain technology was introduced in 2008 as a technology which, without a trusting intermediary, should make data forgery-proof and highly available; even with this technology, the industrial use is already much discussed, but hardly brought into the real application [11]. The mentioned Blockchain technology will be further considered in more detail for fit as Middleware+ in cross-company IoP.

3 Blockchain as Middleware+

3.1 Blockchain technology

A scientifically recognized, uniform definition of the term "Blockchain" does not currently exist [12]. There is general agreement, however, about some properties of the Blockchain technology, which will be explained below. A Blockchain is a decentralized database (often called "distributed database"). The included data is usually not available at a central or a small number of distributed locations to which authorized participants can access (see Clouds on central servers or on distributed server networks), but completely for each participant in a network of distributed, decentralized units. The data is stored in the form of transactions in blocks of data arranged chronologically. [12, 13]

This decentralized structure prevents a loss of one or more network nodes from permanently losing the stored data - as long as at least one network node remains intact [12]. With a sufficient number of participants, the loss-security of the data is sufficiently high. The involved network nodes continuously synchronize their data status, new information is sent to all nodes in the network [14].

A block consists of a block header and its associated transactions. The transactions are combined via a hash tree to a root, which is part of the block header. In addition to the "hash value of the predecessor block" explained below, a timestamp is usually stored in the block header which indicates the date of origin of the block. Depending on the Blockchain also the storage of further data is provided. [13]

A key feature in the data structure of Blockchain technology is that the individual data blocks are linked using hash functions. For the subsequent blocks, these are linked in chronological order by means of pointers. The replacement of the simple reference with a cryptographic hash function yields an authenticated data structure which, with sufficient probability, ensures that the previous data is not compromised. This anti-counterfeiting security benefits those elements that are included in the calculation of the linking hash value. In the case of a Blockchain, a cryptographic hash function is usually used for linking the blocks, for which the preceding block header is used as data input. Since the block header contains the root of the hash tree of the associated transactions, the security against forgery thus extends to the entire previous block and ultimately to the entire data structure. [13, 15]

Consciously, a more detailed description of the Blockchain technology and specific sub-technologies (hash functions, consensus algorithms, cryptography, etc.) should be omitted here - the reader should refer to the relevant specialist literature.

3.2 Blockchain in the Internet of Production

It becomes clear that the Blockchain technology is transaction-based. As a redundant database, it can provide data forgery-proof and high availability of Data. As part of the reference architecture of the IoP, the Blockchain could therefore serve as Middleware+. This application would solve the problem that in use cases of cross-company data usage, a comprehensive data storage or accessibility solution can not be easily installed. Which of the two mentioned would be the Blockchain, incidentally, would depend on the configuration. It would be possible to use the Blockchain for storing access authorizations to proprietary systems as well as the use for storing the data itself, which would then be redundant with storage in the company's own databases. Since the first case has been little explored so far it will be assumed from the second in the following.

In order to clarify the mode of operation, a few potential use cases are briefly outlined, in which the Blockchain technology is used as Middleware+ in the cross-company Internet of Production.

In the BDE system of an aluminum supplier, the **process parameters from the production** process are stored unambiguously per component. These process parameters have a significant influence on the material properties and thus on the machine parameters to be set during further processing. The process parameters can be written from the supplier's BDE to a Blockchain, with the summary of the process parameters corresponding to part of a transaction. During further processing of the parts, the parameters can be retrieved by the appropriate operational application systems. It would be conceivable in addition to the transmission of the process parameters and the transmission of desired-dimension deviations that are then used in further processing - eg. in the assembly robot offset these deviations. As a result, the processing company could allow higher deviations, which in turn would save costs.

In the ERP / ME-System, especially for convergent and divergent material flows, the **relationships between the predecessor and successor** parts are maintained and relevant data is copied to a Blockchain. The transactions in the Blockchain contain the information about which components were merged. Through the documentation along the entire value chain, it is thus possible to ensure the traceability of a product or all of its components across the entire value chain. If several faulty products are identified, it can be determined by a simple analysis, where similarities lie - for example, in the fact that with all faulty products a component was manufactured on the same day. Thus, callbacks can be carried out in a particularly targeted manner.

The BDE of a company documents how many **working hours** a particular machine has been used. The distributor of the machine offers additional industrial services, such as maintenance contracts or subscription models. The BDE transfers the data necessary for the implementation and / or billing of the specific services into a Blockchain. Thus, for example, a maintenance contract, which provides for maintenance after a certain period of use, or a pay-per-use billing can be created.

4 Summary, outlook and research needs

In this paper, it was presented which current developments force companies to operate Supply-Chain-Data-Management, ie to share data along the value chain. One of the challenges of this cross-company data management is the technical feasibility. It was also shown that the reference architecture of the Internet of Production is suitable for enabling use cases of cross-domain networking - however, cross-company networking could not yet be represented in the IoP. Consequently, the architecture has been extended to a cross-company Internet of Production.

Furthermore, it was explained how the Blockchain technology - which is often described as an enabler for cross-company data exchange - can be classified in the cross-company IoP: it assumes the role of Middleware+. Also how these solutions addressed the problems that are to be expected in the Supply-Chain-Data-Management was executed.

It becomes clear that the described use cases of cross-company data exchange can be implemented with a Blockchain as Middleware+, but the demands on this Blockchain are clearly different per use case. These claims and the use-case-specific design of the respective Blockchain are not trivial. In the beginning it was already stated that the technology is not described in a uniform way. There is a lack of a comprehensive description of the technology and its various features and feature types to explain how to design the specific Blockchain, depending on the use case. The description of features such as the type of data to be stored, the information release, etc. could provide a remedy.

Also it remains an open technical problem that data in Blockchains are indeed stored counterfeit-proof, but this does not guarantee that they were correct when they were created. The consensus algorithm is expressly only to ensure the immutability of the data and not to verify their accuracy.

A non-technical problem, which is best described under the name “Supply-Chain-Project-Management”, also weighs heavily: Even if it is technically possible to execute the mentioned use cases, this does not mean that they can be implemented. The lack of a superior authority, the necessary economic advantage per company and the lack of initiative by an involved company can mean that digital connection across corporate boundaries is never implemented. This is similar to a problem of component design: There are components that can be drawn and in this form perform certain functions very well - but can not be produced after all because, for example, screw points would not be reached.

References

1. Schmieder, M., von Regius, B., Leyendecker, B.: Qualitätsmanagement im Einkauf. Vermeidung von Produktfehlern in der Lieferkette. Springer (2018)
2. Schuh, G., Gartzen, T., Basse, F., Schrey, E.: Enabling Radical Innovation through Highly Iterative Product Expedition in Ramp up and Demonstration Factories. Procedia CIRP **41**, 620–625 (2016)
3. Cooper, R.G.: What's Next?: After Stage-Gate. Research-Technology Management (2014). doi: 10.5437/08956308X5606963
4. Schuh, G., Anderl, R., Gausemeier, J., Hompel, M. ten, Wahlster, W.: Industrie 4.0 Maturity Index. Die digitale Transformation von Unternehmen gestalten. acatech – Deutsche Akademie der Technikwissenschaften, München (2017)
5. Bauer, W., Schlund, S., Marrenbach, D., Ganschar, O.: Industrie 4.0 - Volkswirtschaftliches Potenzial für Deutschland. BITKOM, Berlin, Stuttgart (2014)
6. Jarratt, T.A.W., Eckert, C.M., Caldwell, N.H.M., Clarkson, P.J.: Engineering change: an overview and perspective on the literature. Res Eng Design **22**(2), 103–124 (2011)
7. Langer, S.: Änderungsmanagement. In: Lindemann, U. (ed.) Handbuch Produktentwicklung. Hanser, München (2016)
8. Storbjerg, S.H., Sommer, A.F., Bruno, T.D., Thyssen, J.: Development of an engineering change management capability framework for enterprise transformation. In: Lindemann, U. (ed.) Design for harmonies. ICED 13, vol. 75, pp. 161–170. Design Society (2013)
9. Brecher, C., Klocke, F., Schmitt, R., Schuh, G. (eds.): Internet of Production für agile Unternehmen. AWK Aachener Werkzeugmaschinen-Kolloquium 2017, 18. bis 19. Mai, 1st edn. Apprimus Verlag, Aachen (2017)
10. Bach, T., Frey, D., Krebs, U., Reschke, J., Schiemann, D., Sontow, K., Treutlein, P., Wetzchewald, P., Schröer, T.: Marktspiegel Business Software ERP/PPS 2017/2018. Anbieter - Systeme - Projekte, 9th edn. Trovarit, Aachen (2017)
11. Nakamoto, S.: Bitcoin: A Peer-to-Peer Electronic Cash System (2008)
12. Schlatt, V., Schweizer, A., Urbach, N., Fridgen, G.: Blockchain: Grundlagen, Anwendungen und Potenziale, Bayreuth (2016)
13. Tschorsch, F., Scheuermann, B.: Bitcoin and Beyond: A Technical Survey on Decentralized Digital Currencies. https://eprint.iacr.org/2015/464.pdf (2016). Accessed 21 July 2017
14. Badev, A., Chen, M.: Bitcoin. Technical Background and Data Analysis. FEDS (2014). doi: 10.17016/feds.2014.104
15. Böhme, R., Pesch, P.: Technische Grundlagen und datenschutzrechtliche Fragen der Blockchain-Technologie. DuD-Datenschutz und Datensicherheit **41**(8), 473–481 (2017)