Blockchain for forming technology – tamper-proof exchange of production data

P Frey[1], M Lechner[1]*, T Bauer[1,2], T Shubina[1], A Yassin[1], S Wituschek[1], M Virkus[1], M Merklein[1]

[1]Institute of Manufacturing Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg, Egerlandstr. 13, 91058 Erlangen, Germany
[2]Fraunhofer Institute for Process Engineering and Packaging IVV, Giggenhauser Strasse 35, 85354 Freising, Germany

*michael.lechner@fau.de

Abstract. An increasingly connected production in the sense of Industry 4.0 allows completely new possibilities in regard to improved and more efficient production and higher product quality. But a key factor to Industry 4.0 is a consistent data flow along the production chain. However, the exchange of data, especially between companies, still is a major obstacle to overcome in order to achieve the aforementioned advantages. Currently, there are increasing efforts to record and analyse data. But there is a lack of a holistic system to handle data, therefore commonly company databases or other inefficient methods are used. These solutions are limited with regard to data exchange since the ownership of data cannot be proven, production data has no unforgeable timestamp, which in turn hinders the generation of complete production history from the final product (e.g., car door) back to the semi-finished product (e.g., steel sheet). As a result, there is insufficient to no data exchange along the production chain. In order to solve these problems blockchain is a promising approach. At the Institute of Manufacturing Technology, an operational blockchain system was developed and implemented using standard production machines. With the combination of a quarto rolling mill and a 400t - press, representing the sheet metal supplier and a forming company, respectively, the typical process chain of sheet metal processing is represented, which allows the detailed investigation of the established blockchain in this field of application. Within this contribution, the conceptual approach of a blockchain system for forming technology will be presented. The nature and the classification of occurring data throughout the production chain will be addressed.

1. Introduction

The current trend towards digitalization in production is tightly linked to the vision of great chances regarding higher efficiency, individualisation, more transparency and thus the potential of improved quality [1]. The underlying concept is obtaining data and interconnecting information along the production chain in order to create holistic insights which can be used to react to interdependencies of the different process steps and improve production processes accordingly. Especially in forming technology there are strong dependencies between the different production steps since not only the geometry of the product shaped but also its properties are significantly changed in the course of thermo-mechanical processing. Therefore, the sheet as semi-finished product is considerably affecting the forming process and the final product properties. Given the fact that variation in composition and solidification is subject to stochastic variation, processing of material has to deal with deviation [2]. In order to deal with deviation, existing attempts of a closed loop control in forming are reviewed in [2]. The idea is measuring actual product properties rather than the state of the equipment and using this information to adjust the forming process. The approach focuses mainly on the forming process as a control loop. One given example is the spring back control of a V-bending process. In the simplest setup, there is only the punch as a single actuator which defines the resulting bending angle due to its stroke. However, other forming operations, e.g. deep drawing, have to deal with more restrictions. Due to the use of rigid tools, the resulting geometry cannot be easily altered by the punch stroke during the process, thus limiting the possibilities of intervention during the process. Other data-driven approaches for that reason use a feedforward control system, which combines data obtained previously to the forming process and process models to adjust the process settings [3]. Since material properties, as well as sheet thickness, vary along one coil [4], although within the specification, the acquisition of data is typically located inline before processing. Examples for implemented systems in production lines are presented in [4] for deep drawing kitchen sinks and in [5] for car manufacturing. However, the implementation cost of inline measuring is high and the options of influencing the forming process in order to avoid scrap can be limited. Especially critical forming processes close to the forming limit can react sensitively to varying conditions which might not be compensated by standard measures like adjusting the binder force or the drawing speed. For high volume press lines, the economic decision can be to produce several scrap parts in the course of manufacturing since the cost of scrap will not justify the cost of a changeover of a coil. If the information of the material properties were provided at an earlier stage before the coil is set-up, it would be possible to direct coils with higher variation to press lines with more robust forming processes. Therefore, the incorporation of information along the complete production chain would be of interest to avoid scrap and improve product quality.

The rolling mills of sheet metal suppliers are typically equipped with a continuous measurement of certain material properties, e.g. thickness, flatness, roughness etc., for quality assurance. Thus, the data obtained at the press line is already measured once at the supplier. However, at the moment there is no exchange of this data, although the data is highly valuable and available in advance of processing. Reasons for the missing exchange are manifold. From the view of the sheet metal supplier, there are uncertainties regarding the usage of the data by the client and the fear of uncontrolled access to the data, possibly by competitors. Even if the data is provided by the supplier as a service, there is the challenge of ensuring the ownership of the data as well as the data integrity.

The blockchain technology offers the potential to overcome these obstacles regarding the data exchange between companies and eventually supports a consistent data flow along the production chain. In this work considerations and the adaption of the blockchain for the utilization in forming technology is presented.

2. Basics of blockchain technology

The blockchain technology has its roots in the development of the concept of hash trees by Ralph Merkle in 1979 [6]. The idea is that a mathematical one-way function is used, which is easy to compute but difficult to invert, in order to create a digital signature of data [7]. As shown in figure 1, the hash function accepts inputs of different type and size but always produces a small fixed output, the so-called hash [8]. The most used hash function for blockchain is the Secure Hash Algorithm 256 (SHA-256) [9]. The computed hash is 256 bit long, therefore having $2^{256} = 1.15 \times 10^{77}$ possible combinations. This is close to the number of atoms in the observable universe (10^{78} to 10^{82}) and qualifies as secure at the time of writing.

Linking these hashes leads to a chain of hashes, which allows for efficient verification of big data structures [6]. Since even slightly altered data leads to a different result of the hash function the comparison of the calculated hash with the linked hashes can identify tampered data. This method ensures the security of the blockchain.

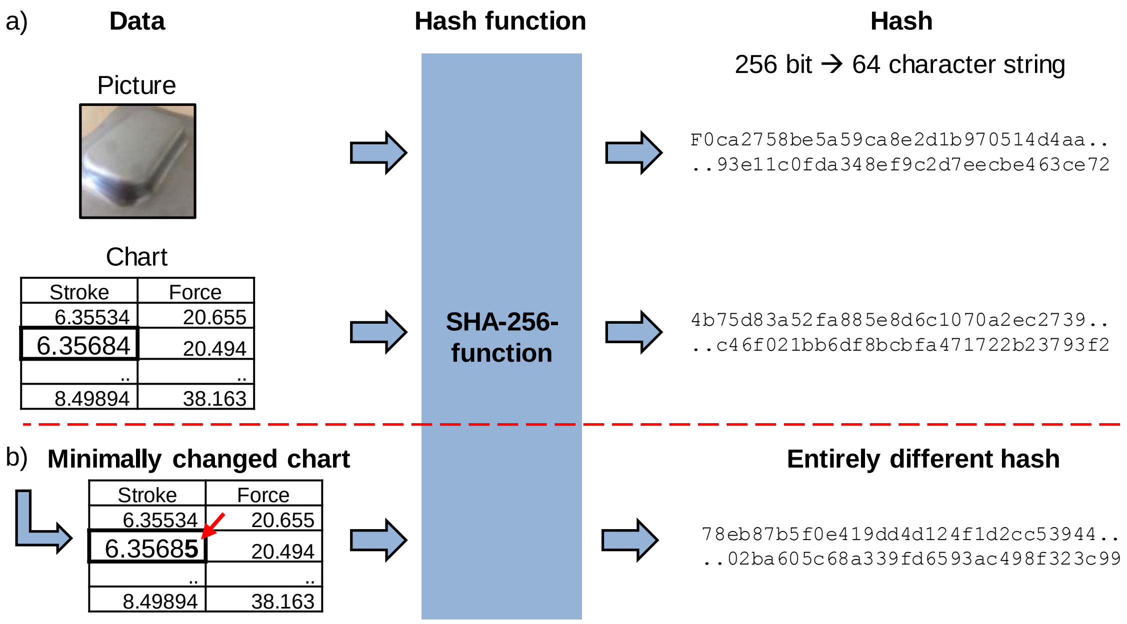

Figure 1: a) Hashes (SHA-256) of different input, b) the effect of changes on the hash value

The second main aspect of blockchain technology is the concept of a definite timeline [10]. The idea is to link the timestamps of digital documents or data in order to create a chain of linked timestamps, thus ensuring the existence and the definite sequence of appearance. This evidence of existence is an essential requirement to prove ownership of data which is crucial for the exchange or trade of data. As a brief conclusion, the aspect of the hashes as a fingerprint of the data blocks and the definite order of linked timestamps add up to the blockchain technology. As shown in figure 2, new data is added by creating a new block, which is linked to the previous block by including the previous hash, the so-called prehash, in the calculation of the new hash.

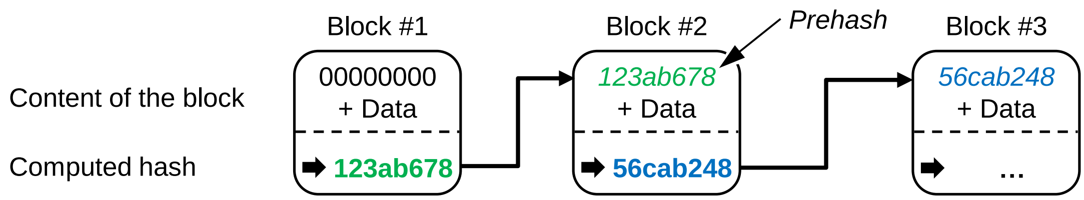

Figure 2: Linking of blocks using hashes. Adapted from [11]

Blockchain as a technical concept could be compared to a digital ledger, which allows companies or individuals to share information or data and control the exchange. In contrast to banks where only one centralized bank-owned ledger exists, blockchain is based on distributed-ledgers of which a copy is held by every participant party of the blockchain network, so-called nodes. Since the network has the capability to verify data by itself, there is no need for a centralized trustworthy authority, which manages transactions. The resulting properties of these aspects are:

- Proof of data ownership
- Definite timestamp
- Tamper-proof data exchange
- No need for centralized authority

3. Conceptional considerations for a blockchain system in forming technology

The decomposition of actual physical systems in defined parts and classes is an essential part in order to implement a blockchain system. Thus, this work focuses on necessary considerations and requirements for a successful realization of a blockchain system for forming technology. The multitude of data and information throughout the production lead to a quickly increasing complexity of the occurring data. This poses a challenge in defining a blockchain system for production. Thus, an appropriate division of data is necessary for its efficient handling. The following classification shall build the foundation for the technical implementation, which is also transferable to other industrial use cases.

3.1. Data of the production chain in forming technology

Along the process chain of forming products, there are several processing steps, like rolling of the sheet, heat treatments, coating, blanking and forming. All these steps together define the properties of the final product.

3.1.1. Data structure

At each stage, a lot of different data is obtained, which differ regarding their data structure. The data can be distinguished by their:

- value, whether it is a single value or a continuous measurement
- data type, e.g. text file or picture
- size

The alloy composition can be viewed as a single value for each batch, whereas the sheet thickness is measured continuously along one coil. Also, the stroke-force-curve would be continuous data from which single values, e.g. the maximum force, can be derived. Depending on these properties different measures have to be taken regarding the handling of the data.

3.1.2. Semantic classification of production data

In contrast to the data structure, there is also a semantic perspective in the context of production. Obtained data could be classified into three main categories:

1. Process data
   It includes data obtained when the condition of the material is changed regarding shape or properties. The data is mostly recorded by the process equipment, e.g. forces or temperature. But also input values, which allow the tracking of change to settings, are associated with process data. In addition, the time and the date of the processing are classified as process data.
2. Material / Product data
   This kind of data is associated with the semi-finished or the final part and its properties. This involves for example sheet thickness, strength, measured geometry and the quality status.
3. Organizational data
   This includes data originating without altering the physical condition of the product or material. Thus, it can be information regarding legal aspects, e.g. ownership, and in the context of logistics, e.g. location, shipping date or definite identification number of a coil or a part.

3.2. Accessibility and controlled data access

The accessibility and the management of data access are major points of discussion from an industrial point of view. The fear of uncontrolled access to data is a major obstacle regarding the implementation of connected production systems or the exchange of data. In this chapter, a typical process chain in forming is introduced as use case to clarify the matter.

3.2.1. *Classification of accessibility of production data*

The presented use case starts with the rolling process. Consequently, the coil is the first object being created. In figure 3 the material flow in the horizontal direction is within one entity, whereas the vertical direction indicates material flow across entities. Within each entity, there can be several peers who can be compared to departments or persons. For example, the rolling mill and shipping could be separated peers of the supplier. In this example, the three entities (supplier, logistics and car manufacturer) are assumed to be different companies, although they could as well be e.g. different divisions within one company.

Beginning with the rolling process, the creation of the coil, the associated process data of the rolling mill and the product data build the first block of the chain. To simplify the example the pass reduction is assumed as process data and the sheet thickness is used as product data. With every production step or handling of the coil, like transfer to shipping, additional data is generated and reflected in the blockchain. In this case, the term "reflected" is used instead of saving or storing on the blockchain, since the type of data varies vastly especially in size, which in turn makes it impractical to store everything on the blockchain.

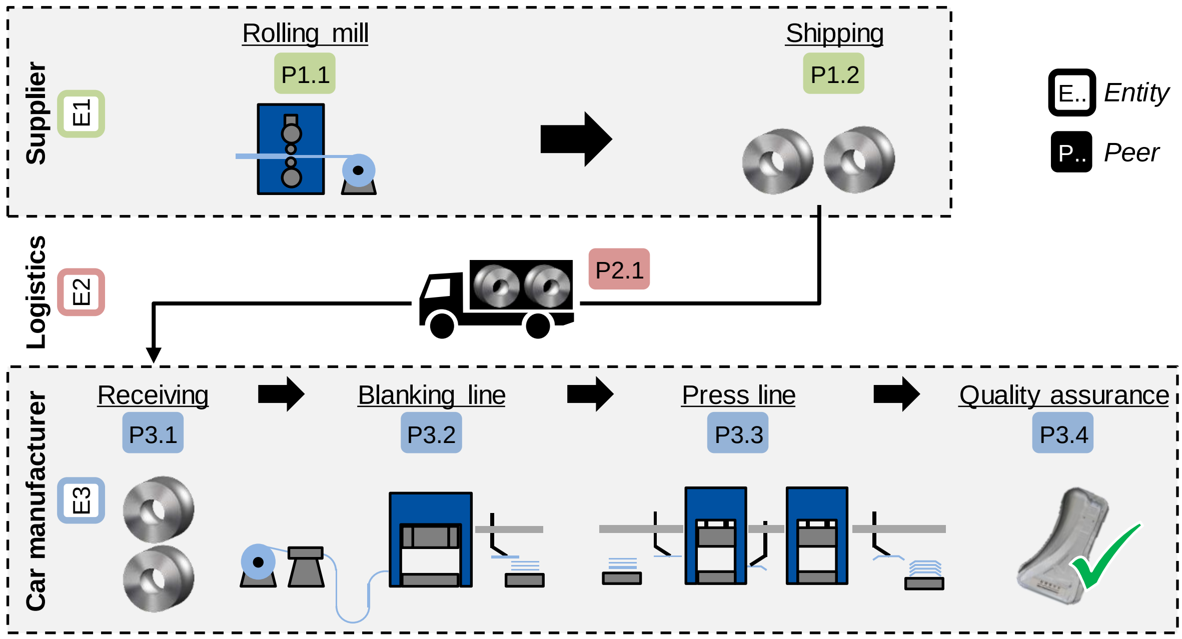

Figure 3: Material flow from the supplier of sheet metal to the finished part

For big data packages it is reasonable to store the data at a different location, e.g. locally at the supplier, but creating a hash, a definite fingerprint of the data, and only saving this hash on the blockchain. As a result, the existence of the data is acknowledged and can be verified anytime with the blockchain. This procedure is favourable for data, which is primarily used for tracing the processing history and is not intended to be used by other downstream processes. Data can be classified according to their accessibility for the different entities in the following categories:

1. Closed accessibility
   During the production process, there is a lot of process data recorded. This data can contain fundamental process knowledge, e.g. special parameter settings, which is why it should be treated as a company secret. This kind of data should not be exchanged with other entities and belongs to the first category "closed accessibility". This data represents a log of the production history and should only be used or exposed under special circumstance, e.g. in the case of settling a liability claim.

2. Conditional accessibility
   This category contains data which is valuable but not necessary for subsequent processes. This data, for example, can be made available as an offered service (data as a service). Within the presented process chain, the continuous measurement of the sheet thickness could be provided to the car manufacturer by the supplier.
3. Required accessibility
   This category includes data which needs to be accessible by other entities to perform their operations. This kind of data may be shared rather openly if it contains no classified information, e.g. weight of the coil shared among supplier, logistics and car manufacturer.

However, the rating of the secrecy status of the information can change depending on the involved entities. The information of the coil weight and the number of transferred coils could be a measure for production performance, thus becoming data which should not be shared.

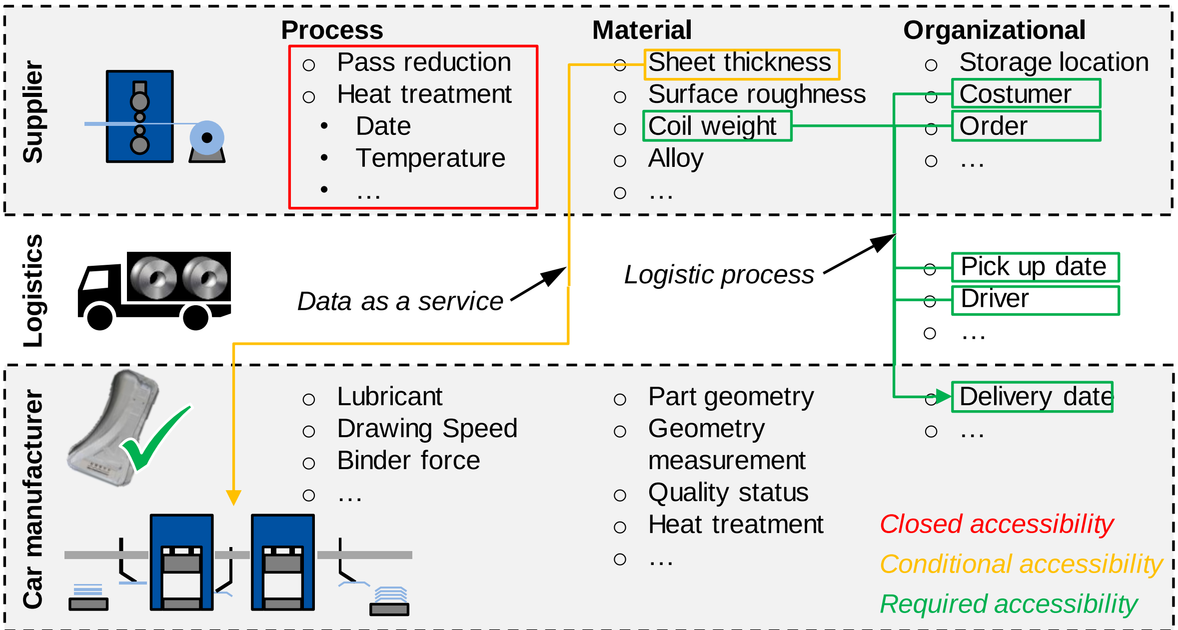

Figure 4: Exemplary accessibility of data

3.2.2. Means of controlled data access and exchange via channels

As mentioned before, the properties of the blockchain are the identification of data ownership, the creation of a definite timeline, thus an explicit order of events, and certainty of data integrity by storing definite fingerprints (hashes) of data. These aspects and the fact that every participant of the blockchain has a copy of the ledger are crucial for establishing mutual trust and build the foundation of an enhanced data exchange. At the same time in the context of production not all the data and information which is reflected in the blockchain should be openly accessible or visible by every participant of the blockchain. In addition, if data is provided as a service, an access management system is necessary. These challenges can be overcome by using so-called channels, which are part of some of the available blockchain frameworks, e.g. Hyperledger.

A channel is a kind of a subnet that offers the possibility to share data with critical security clearance between two or more specific blockchain participants (entities) [12]. The channel and thus the participants of the channel have their own assigned ledger. Other participants without this ledger are excluded from the channel, therefore, have no access to the data.

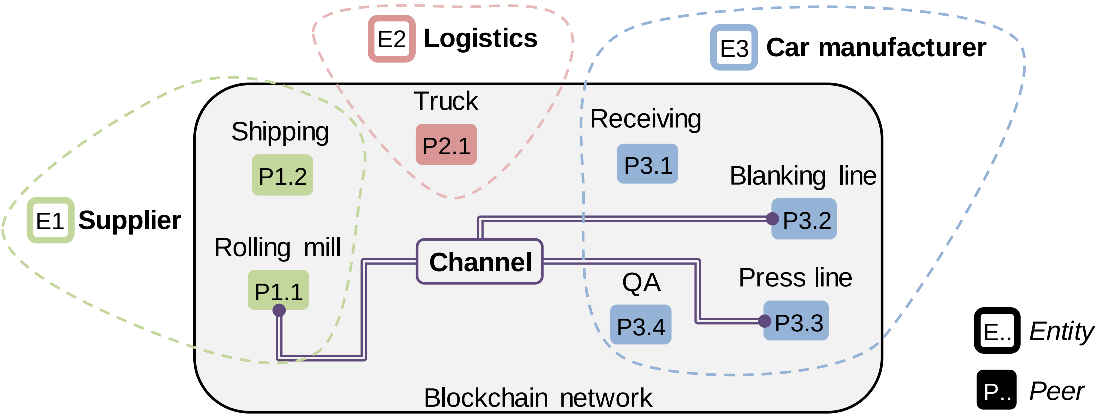

Figure 5: Channel within a blockchain network

For the use case in the manufacturing technology, this means that a confidential data stream can arise between the supplier and the car manufacturer, in which for example the continuous measurement of the sheet thickness of one coil can be transmitted. Logistics is not part of the channel in figure 5 because it is not involved in the manufacturing process, therefore, has no use for the sheet thickness data. Different access rights can also be granted within one entity, because the supplier and the automobile manufacturer may have different peers, e.g. departments. For example, process data is only relevant for the shop floor, thus the peer "receiving" is excluded from the channel. The contents of the channel remain hidden for outsiders. Using channel technology secure data transmission within the blockchain network is guaranteed.

4. Blockchain demo factory

In order to gain knowledge of the implementation of blockchain in forming technology as well as further development of specific properties for the production environment, a blockchain demo factory was established at the Institue of Manufacturing Technology. The production chain from the manufacturing of the sheet to the finally formed part is established on industrial scale equipment. A quarto rolling mill represents the sheet metal supplier whereas the CO_2 - laser cell and 400t - press represent the production steps of blanking and forming at a car manufacturer, figure 6.

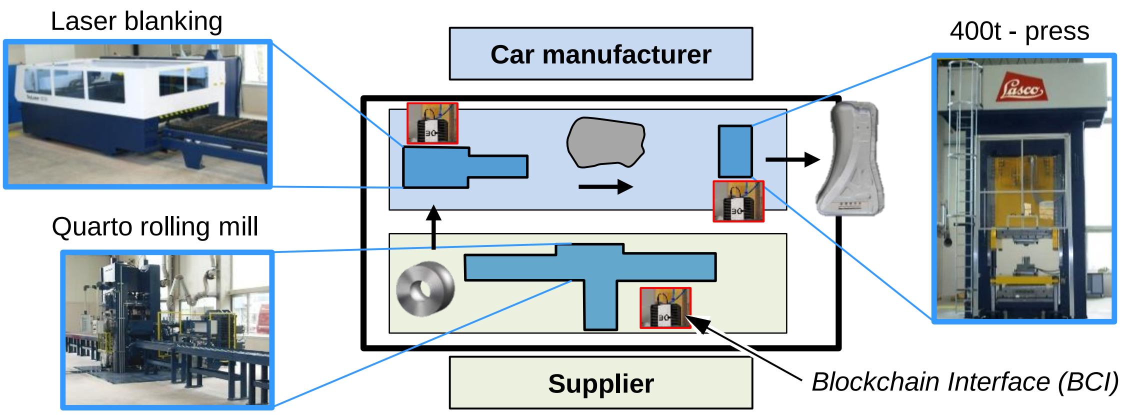

Figure 6: Blockchain demo factory at the Institute of Manufacturing Technology (LFT)

As shown in Figure 6, each machine is equipped with a blockchain interface (BCI). The BCIs are connected to the control units of the machines and additional measuring equipment and collect data which is transferred to the blockchain. Each BCI acts as a node for the blockchain network holding a copy of the ledger. This setup allows the testing and validation of the blockchain network for forming.

5. Conclusion

In forming technology there are various approaches for data-driven systems for the adaption of processes in order to cope with varying material properties and avoid scrap. This requires a sufficient amount of data for the systems to work. At the moment a lot of data is recorded along the production chain. Segments of the recorded data could be of high value for other processes but often there is no exchange of data, especially between different organizations. This leads to redundant measurements of the same parameter at different times and locations instead of exchanging the data. As a consequence, high costs are generated for measuring equipment. And still, if data, e.g. sheet thickness, is obtained right at the press line, the possibilities of intervention, e.g. changeover of a coil, are limited due to economic reasons. In contrast, a different assignment of the coil in advance would have been feasible. But this would require information on the sheet thickness beforehand. This information could be provided by the supplier of the sheet metal ahead of the forming process and could be considered in production planning. However, the lack of trustworthy solutions for communication prevents the necessary data exchange. In this work, the concept of blockchain as an instrument for the tamper-proof exchange of production data is presented as an answer to the mentioned challenges. The classification and semantic description of different types of data are introduced as well as a method to handle selective data access using channel technology. These considerations are the basis for the implementation of a fully operational blockchain system at the Institute of Manufacturing Technology comprising of a rolling mill, a CO_2 – laser cell and a 400t – press.

Next steps will be the specification and implementation of smart contracts, which is a program code on the blockchain that allows the automatization of conditional logic decisions. For example, a downstream process could automatically reject further processing if certain properties are not within the specifications. This propels the ideas of intelligent production and industry 4.0.

6. References

[1] Bauernhansl T, Krüger J, Reinhart G and Schuh G 2016 *WGP-Standpunkt Industrie 4.0*

[2] Allwood J M, Duncan S R, Cao J, Groche P, Hirt G, Kinsey B, Kuboki T, Liewald M, Sterzing A and Tekkaya A E 2016 Closed-loop control of product properties in metal forming *CIRP Annals - Manufacturing Technology* **2** 573–96

[3] Heingärtner J, Fischer P, Harsch D, Renkci Y and Hora P 2017 Q-Guard – an intelligent process control system *J. Phys.: Conf. Ser.* 12032

[4] Heingärtner J, Renkci Y and Hora P 2013 Application of non-destructive testing to control material properties of stainless steel in kitchen sink production *IDDRG 2013* ed P. Hora 75–80

[5] Purr S, Meinhardt J, Lipp A, Werner A, Ostermair M and Glück B 2015 Stamping Plant 4.0 – Basics for the Application of Data Mining Methods in Manufacturing Car Body Parts *KEY ENG MATER* 21–30

[6] Schiller K. 2018 *Merkle Tree – Eine Basis der Blockchain,* Information on: https://blockchainwelt.de/merkle-tree-basis-von-blockchain-und-hash-trees/ [11.02.2019]

[7] Merkle R C 1988 A Digital Signature Based on a Conventional Encryption Function *Advances in Cryptology — CRYPTO '87* ed G. Goos, et al.(Berlin, Heidelberg: Springer) pp 369–378

[8] T. Kanade, et al. (Eds.) *Selected Areas in Cryptography*: Springer 2004

[9] Norm FIPS PUB 180-4 2015 *Secure Hash Standard* National Institute of Standards and Technology

[10] Haber S; Stornetta WS 1991 How to time-stamp a digital document *J. Cryptology* **2** 99–111

[11] Gupta M 2018 *Blockchain for dummies* (Hoboken, NJ: John Wiley & Sons, Inc)

[12] Hyperledger *Channels,* Information on: https://hyperledger-fabric.readthedocs.io/en/release-1.4/channels.html [13.02.2019]