Development of a Blockchain Technology based Supply Chain Traceability Concept in R for the Automotive Industry

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Abstract. This thesis develops a concept to improve the reliability of the current traceability system of the automotive industry in R with blockchain technology. The traceabillity concept records the information of every link in the supply chain and integrates all information using blockchain technology. This concept provides an easy to use user interface based on the Shiny library.

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig und eigenhändig sowie ohne unerlaubte fremde Hilfe und ausschließlich unter Verwendung der aufgeführten Quellen und Hilfsmittel angefertigt habe.

Berlin, 11.02.2020

Assignment

The supply chain of an automotive company involves multiple parties. From design and marketing to selling and maintenance of vehicles. For an effective coordination with many suppliers and logistics parties, a manufacturer has to ensure timely delivery and in the end a product satisfying all requirements.
Currently, most information is managed by a centralized ledger which lacks transparency between different parties within the supply chain. Therefore, information are not or just slowly transfered between different suppliers. This creates multiple issues for the main manufacturer. For example, the backtracking of a spare part to its manufacturer location takes weeks. (Hackett, 2017: [21])
Within this thesis we will be using an existing traceability system based on simulated data for an automotive manufacturer as well as an already existing blockchain code in R. Using these, we will compare the traditional centralized ledger with a blockchain technology based concept to analyze the primary challenges transparency, traceability, and trust which are leading to large warranty costs in the context of the automotive industry.

Zusammenfassung

Die derzeitige Automobilindustrie wird von vielen unterschiedlichen Lieferanten beliefert. Ein gutes Supply-Chain-Managementsystem kann viele Vorteile bringen, sowohl für ökologische und soziale Belange als auch Kosten- und Wettbewerbsvorteile.
Viele diverse Aspekte verhindern in Unternehmen ein Supply-Chain-Managementsystem einzuführen. Gründe dafür sind beispielsweise fehlende Ressourcen, fehlendes Know-how und der große organisatorische Aufwand.
Ein fehlendes Supply-Chain-Management kann jedoch zu großen finanziellen Belastungen führen. Denn derzeit existiert kaum ein Datenfluss zwischen verschiedenen Fabriken. Liefert ein Produzent fehlerhafte Teile an einen anderen Produzenten, so können hierbei viele unnötige Kosten durch das Suchen der Fehlerquelle der fehlerhaften Bauteile entstehen.
Um ein transparentes, kostengünstiges Supply-Chain-Managementsystem für die Automobilindustrie zu testen, wird in dieser wissenschaftlichen Arbeit mit Hilfe von Open Source Software und einem existierenden Traceability System ein Konzept entwickelt. Hierbei soll eine auf Blockchain Technologie basierende Lieferkette eine Verbesserung der Leistungsfähigkeit der einzelnen Unternehmen und der Lieferkette als Ganzes bringen und somit anfallende Rückrufkosten zu senken.

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Abbreviations

DPM Direct Part Marking

ID Identification Number

OEM Original Equipment Manufacturer

PoET Proof of Elapsed Time

PoS Proof of Stake

PoW Proof of Work

SQL Structured Query Language

QR code Quick Response code

1 Introduction

Traceability, is according to the International Organization for Standardization (ISO) 9000 “the ability to trace the history, application, use and location of an item or its characteristics through recorded identification data”(ISO: [26]), becomes more and more important. In supply chains it is a regulatory as well as an ethical and environmental issue. It has huge impact not only on locating food contamination or avoiding illegal logging, it also enables companies to do recalls and therefore to strengthen customer relations. Since most products are not traceable for customers all information about their ingredients, origin and brokers stay hidden. In order to produce more sustainable products and make their information more transparent to customers, researchers have developed the idea of using blockchain technology for this purpose.(Casado-Varaa/Prietoa/De la Prietaa, 2018: [43]) Blockchain technology stores data in chronological order, almost impossible to manipulate. With this technology, everyone involved would have full access to the product’s information of its entire lifespan, which creates a unique level of credibility and contributes to a more sustainable and transparent industry.

1.1 Motivation

Our world becomes more and more digitalized. From farming to ordering to self-driving. Knowledge about products and their parts is more important than ever. Unfortunately, verifying this information is not easy. Especially tracking information backwards about a specific product. *"Tracking a package of sliced mangoes purchased from a Walmart store took an internal team six days, 18 hours and 26 minutes to complete."*(Hackett, 2017: [21])

In this case, Mangoes do not seem important enough to enhance this tracking time. However, what about tracking a part that is ensuring human safety?

Due to a low number of recalls in the past the need of improving traceability systems was not given. Now-a-days we are experiencing a huge need of improvement. A big issue about our current system is the lack of transparency.

For example, part manufacturers usually have limited knowledge where their parts will be shipped from and where they get integrated into some other device.(Holmström/Främling/Ala-Risku, 2010: [29]) This is important for every vendor since they are liable for the safety and reliability of their products. If one does trigger a recall this vendor can be made accountable. Reasons for this lack of trust between multiple vendors are not only caused by fear of competition but also due to lack of technology.

There are *"many fragmented players, different technologies, lots of choices, and no single standard."* (Bateman, 2015: [9]) Companies have issues to evaluate the mix of solutions available, and are deterred by the lack of a clear Return on Investment. Many tools, like databases, are already in place in some phases of the supply chain.(Bateman, 2015: [9]) However, often the information are not transferred between different actors. Therefore, data management is only possible on a fragment of data and cannot show a view on the entire supply chain. Hence, there is enough data but no standard between systems. This lack of standardization makes it difficult to manage the flood of available data. Innovative solutions are being developed (Mao/Wang/Hao, 2018: [15]), but companies often struggle to justify investments in the technology.(Bateman, 2015: [9])

The cost of acquiring existing software and additional hardware is mostly extremely high, but also highly needed for scanning and logging, in and outgoing products. Accessible Internet is highly recommended and most importantly training staff and qualified employees are non-avoidable costs.

Studies have shown that many small to medium enterprises have issues in their efforts toward traceability. (Uchida/Matsuno/Ito, p. 9, 2009: [50]) One of the reasons is that a license can easily cost a couple thousand dollars. In order to resolve the cost related issue, this thesis uses R and SQLite, open source languages which are free of charge.

Literature shows that this new method of using open source blockchain technology (Uchida/Matsuno/Ito, 2009: [50]) within a supply chain is capable of solving a few issues, like traceability and transparency (Jeppsson/Olsson, 2018: [30]). Transparency is the visibility or accessibility of information for all participants.(Merriam-Webster: [37]) Multiple pilots for different industries have been constructed using blockchain based supply chains. (Jansson/Petersen, 2017: [18]), (Thrill, 2018: [47]), (ByteAlly Software, 2019: [46]) For instance pilots for the agriculture industry (Casado-Varaa/Prietoa/De la Prietaa, 2018: [43]), raw materials (Wadhwaa/Liena, p.7 , 2013: [42]) as well as a food traceability system (Mao/Wang/Hao, 2018: [15]) using blockchain and Ethereum (Lin/Shih/Liu, 2017: [27]), (Finan, 2018: [17]) have been build and analyzed. Nevertheless, inherent technical limitations of blockchains within a traceability supply chain (Jansson/Petersen, 2017: [18]) have been spotted. It is also known that there are some trade-offs between different waist reuse blockchain and there is no fully compatible configuration for the industry yet. (Lönnfält/Sandqvist, p. 3, 2018: [25])

To enhance the tracking speed of malfunctioning products this thesis is looking into the advantages of blockchain technology using an existing traceability system.

"Blockchain technology could cut down the time to trace the same sliced mangoes to just two seconds." (Hackett, 2017: [21]) Additionally, tracking the required data with blockchain technology might reduce useless recalls of perfectly functioning products and even spot malfunctioning parts before the actual fault occurs. (Clauson/Breeden/Davidson 2018: [33])

1.2 Blockchain based Traceability Concept

Blockchain is a chain consisting of many blocks. Those blocks are depending on another, thus tampering is impossible. In order to get a new "block" accepted by the peer-to-peer network, a hard but feasible cryptographic challenge has to be computed. If this is done correctly and the majority of network partitions accept this new block, it will be referenced by the next block and thereby be again verified as valid. Conflicts between parties and malicious actors can easily be spotted and resolved. No organization has more responsibilities than others. No specific party is in control. Each enterprise from small to large is treated equally and is able to track all their products forward as well as backwards. The concept developed within this thesis will propose a possible solution for the lack of standardization. Blockchain technology will be the fundamental structure underneath an easy to use data analysis dashboard.
Just like in Bitcoin (Nakamoto, 2008: [40]), this concept can in principle create transparency between all parties. All information can in principle be distributed by a peer-to-peer system and be constantly supervised by multiple parties. The blockchain will be the central information storage redundantly distributed within the network. This ensures a high availability of the storage network. Based on this concept the five primary challenges: visibility, risk, cost containment, customer demands, and globalization will be analyzed.

The first chapter is an introduction into the state of art of first traceability followed by blockchain technology. Afterwards follows an overview of how blockchain can be used within the supply chain sector. Followed up with the blockchain based traceability concept and its user manual.

2 State of the Art Technologies

2.1 Traceability Systems

Traceability is the capability to trace something. (Keyence corporation: [4]) It is also interpreted as the documentation of a product's location or entire history. Hence, the documentation is tracking each and every step, from raw materials to the end product, its consumption and also its disposal. Due to mass production, there is a huge demand for improving product quality and consumers safety. In order to specify which product lacks compliance to quality standards a traceability system is needed. In order to track the products movements each product will be assigned an identification number.

Traceability can be divided into two categories as seen in figure 1.

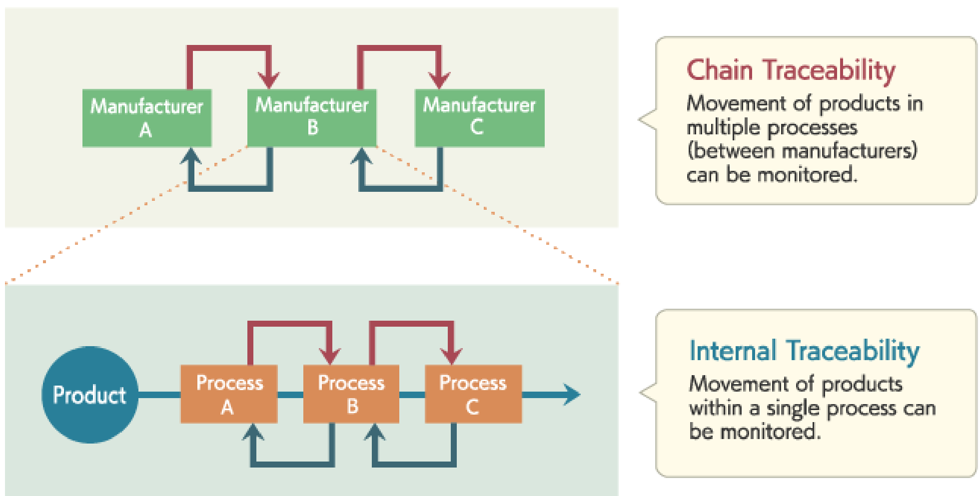


Fig. 1: Internal and Chain Traceability

Source: Technological Innovations and Development of a Traceability System (Keyence corporation: [4])

Internal Traceability Internal Traceability records are all moments of products within a single or a limited process of a supply chain, for instance within one manufacturer. For example, an automotive seat plant produces car seats with leather seat covers which are imported from a leather manufacturer.

Internal traceability considers importing materials from one or multiple manufacturers, collecting, documenting and managing all information regarding those imports as well as what is going to happen within the own facilities.

Chain Traceability Chain Traceability records all moments of products within multiple processes and between multiple manufacturers. It displays each and every single step of creating a product. Starting from raw material: location, manufacturer, date, time and even more information will be stored in connection to the specific product, for each supply chain manufacturer. This enables manufacturers to trace back where products came from if an issue occurs. Also it is possible to track forward and take a look at where the manufacturers products were delivered to.

2.1.1 Tracing Products

Tracing forward Tracking where the manufactured product goes next by following its planned time line is important. For example, if a safety critical issue occurs, identifying all faulty products and where they were shipped to can save a lot of money during a recall. The faster faulty products can be tracked, the more limited the scope of a recall becomes, as fewer downstream systems need to be recalled. This can lead to great savings for the initial manufacturer liable for the faulty parts and might prevent their bankruptcy.

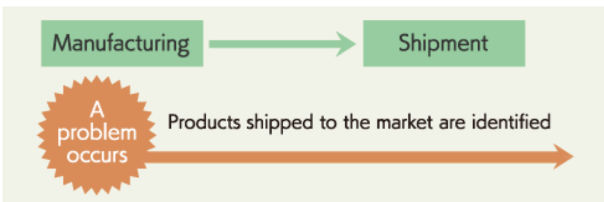


Fig. 2: Tracking forwards

Source: Technological Innovations and Development of a Traceability System (Keyence corporation: [4])

Tracing backwards Tracking backwards within the manufacturing time line discloses all involved manufacturers and their production steps. For example, if an issue occurs with shipped products looking back in those records can accelerate the investigation. Quick actions can be taken to ensure higher product quality.

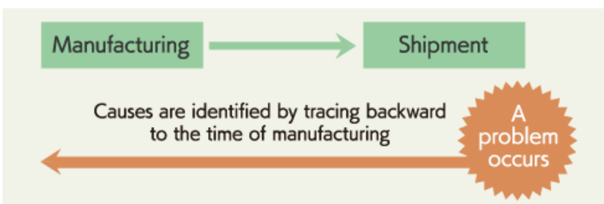


Fig. 3: Tracking backwards

Source: Technological Innovations and Development of a Traceability System (Keyence corporation: [4])

Current Technological Innovations for Part Identification In order to track the entire history of a product, each and every part has to be identified, for example by a serial number. This number will be recorded within each step of the manufacturing process and deposited as one part of the entire product. Monitoring the process of manufacturing single parts helps manufacturers to control the entire process and prevent errors. It ensures costumer satisfaction and guarantees higher quality within the end product. In a case of a non-compliance the serial number gives access to the history of its production chain and provides the opportunity to solve the issue efficiently. In order to provide an identification for each part it is necessary to come to an agreement within a supply chain, to determine what type of serial number or identifier each manufacturer uses.

Labels There are many different type of authentication for parts. Identification symbols like characters and 2D codes are commonly used to record delivery status, production plans, achievement rates, inventory quantities and a lot of other information.

Bar-codes and 2D Quick Response codes Printed bar-codes are already used for decades. Due to the limited amount of individual bar-codes and the limited amount of information that can be stored in one code, different kinds of code were invented. 2D codes can store more information in a limited space than a bar-code. Thus 2D Quick Response codes have been used for part and product management which includes traceability. Those can achieve reliable individual management by compressing all information within its limited space and creating a higher density. The QR code was originally invented in 1994 by Modex exhibitor Denso ADC to enhance tracking of discrete components in automotive manufacturing facilities and supply chains. Now, the codes are being used as a marketing and advertising tool, warehousing, retail and more. (Keyence corporation: [4])

Disadvantages of Bar-codes and 2D Quick Response codes Producing individual labels for each product is expensive. Once produced and fixed on the product, this label has a short lifetime. Paper labels for instance are destroyable with as little as rain. The easy procedure to glue a label on the product has therefore also disadvantages. The glue used is usually not waterproof. Even with more advanced glue labels cannot stand harsh environments. Hence, labels are likely to fall off at a certain time. Another issue is tampering of labels. Paper labels can be replaced without traces of its procedure. Tampering is also a concern regarding the information on the label itself. A slight alteration can lead to a completely different product label while scanning it. Those arguments are a huge vulnerability for a supply chain, since reliable, trustworthy traceability is therefore not possible. An alternative is direct part marking.

Fig. 4: Bar- and QR-Code

Source: Technological Innovations and Development of a Traceability System (Keyence corporation: [4])

Direct Part Marking Direct Part Marking (DPM) are lot serial numbers and 2D codes printed right on the product. They have greatly contributed to the advancement of traceability systems. For example detecting and sorting out fake chips has been solved by direct part marking. Since all necessary information to make such a decision is right on the product, countermeasures can be quickly arranged. Direct part marking also sustains hard environments and is usable for many materials.

Pin Stamping or Dot Pen Marking Those methods use a carbine pin to engrave a continuous deformation within the material. The engraved text can withstand harshest manufacturing conditions. However the process of engraving the material is relatively slow, requires a lot of maintenance and cannot engrave bar-codes and is not applicable on all machines.

Laser Marking Laser marking uses light to etch permanent text or symbols onto the material. It is heat resistant and has minimal maintenance work. The laser technology provides constant and high quality. Bar-codes are possible with its high contrasts. (Keyence corporation: [4])

Fig. 5: Laser, Pin stamping and dot peen marking

Source: Technological Innovations and Development of a Traceability System (Keyence corporation: [4])

2.1.2 Traceability in Supply Chains of Different Industries In order to provide a constant quality to consumers, manufacturers throughout different industries are developing solutions fitting their needs. These supply chains have standards and agreements from the part identification all the way to the transportation requirements.

Food Industry For the demand of safety and health, consumers have the rights to know where the food came from, when the food was being delivered, who should take the responsibility once problems occurred. (Lin/Shih/Liu, 2017: [27])

"We have the right to know what we're eating." This is the catchphrase for TE-FOOD the world's largest and most successful food traceability solution. In utilizing the blockchain, they propose that a distributed ledger based system would vastly improve scalability and value to their offchain product. Offchain is a method for scaling blockchains, it moves computation and data off-the-chain, without compromising the properties introduced and benefits gained by using blockchains in the first place (Eberhardt, Tai, 2017: [28]). Their farm-to-table system is live and fully operational. The Vietnam/Hungary based company started in 2016 and serves 6000+ business customers, handles 400,000 transactions per day and reaches over 30 million people."(Thrill, 2018: [47])

Within the food industry the exact tracking of fresh products during its supply chain is already established. Key reasons for the rush of this regulation is the health of consumers. The World Health Organization (WHO) estimates that 420,000 people die annually from food contamination, which affects one in 10 people worldwide. Children under age five are at the highest risk with 125,000 children dying every year from food-borne illness. (World Health Organisation, 2015, [6]) Therefore issues of contamination require an immediate recall of all contaminated products. In order to comply with those safety standards, methods like RFID tags and bar-codes were introduced. The precise date, time and location of possible contaminated products are now traceable in a short amount of time.

TE-FOOD commitment is to improve food safety, stave off corruption, and support fair trade while building trust between food supply chain companies, consumers and authorities. Approximately 2/3 of all food fraud comes from these unregulated countries. (Thrill, 2018: [47]) With increasing awareness among the world population, there is a demand for product history, insight and transparency.

Trade Control and Expert System The implementation of a traceability system for food and feed operators is required by European Union's General Food Law, which was passed in 2002. Previous systems like the ANIMO and SHIFT were too inefficient to prevent outbreaks like the swine fever at the end of the 1990s as well as the foot-and-mouth disease during 2001. In April 2004, the EU introduced its Trade Control and Expert System, or TRACES. TRACES is web-based veterinarian certification tool. It uses a central database to track all imports and exports of all animal products within as well as across EU borders. TRACES is able to track an animal throughout its entire lifespan, monitoring animal diseases and combating fraud while speeding up the administrative procedures. It protects consumers and facilitates trading. Even though other countries are using some version of TRACES themselves, the EU one is the only supranational network with 80 countries and 30000 users. (European Commission: [12])

Pharmaceutical Industry Risk and complexity is in comparison to other fields especially high in the health sector. Each issue is most likely going to affect patients health directly. Additionally to supply chain issues the infiltration of counterfeit, sub standards and fake drugs are a huge issue. Counterfeit drugs are drugs that do not contain the active ingredients they are supposed to and consequently can harm patients. Tracking and identifying those is nearly in possible enabling bad actors to avoid immediate legal consequences. (Clauson/Breeden/Davidson, 2018: [33])

"The World Health Organization (WHO) estimates this illegal market at $75 billion per year but estimates range up to $200 billion. The pharmaceutical supply chain and health-care system are particularly susceptible to disruption in countries like Vietnam, where the vast majority (i.e., 90%) of drug expenditures are contingent upon imported sources." (Clauson/Breeden/Davidson, 2018: [33])

The supply chain in the pharmaceutical industry is complex, with drugs changing ownership from manufacturers to distributors, re-packagers, and wholesalers before reaching the customer. There is little to no visibility for manufacturers throughout the supply chain to track authenticity. Consequences include the counterfeit drug problem and inefficient processes for conducting recalls and returns processing. These inefficiencies result in financial losses, physical harm and loss of trust with consumers.

Automotive Industry The Automotive industry is a complex ecosystem with multiple parties involved in the design, production, distribution, marketing, selling, finance and servicing of vehicles. Logistics and transportation companies have to ensure timely delivery and sufficient inventory. For example, within a supply chain a manufacturer must coordinate effectively with multiple tiered suppliers. An average car is build out of 30.000 parts manufactured all over the world. Often several different planning departments are involved in planing and constructing a single part. Guaranteeing the correct functionality and fulfilling all requirements are very important for safety. Therefore, each part has to be tested with a range of tests in all sorts of environments. When some parts do pass those test but will later turn out to be malfunctioning a recall of those products will be triggered. Unfortunately, tracking those parts can take some time. In order to limit possible accidents, usually a huge range of cars will be recalled. This procedure cost a lot and usually the producer of the malfunctioning product will be made responsible. This scenario can easily ruin not only small but also medium size enterprises. (Chakravarty, 2017: [11])

"The supply chain management software market grew by 12.5% to $14 billion in 2018."(Swinehart/Abbabatulla, 2019: [22]). "Driving much of that growth are companies that need better internal and external visibility, as well as those that need to upgrade or replace aging systems in order to gain new functionality. The [...] top five market leaders have dominated the list since at least 2012, with SAP, Oracle, JDA, Manhattan Associates and Epicor leading the pack."(McCrea, 2016: [36]) Since the last 10 years not a lot has changed in regard to visibility.

A blockchain based system could enable transparency and therefore reduce the recall costs. Backtracking and locating specific cars would be faster and therefore enable more precise, and thus cheaper, recalls.

2.2 Blockchain Technology

"Current business ledgers in use now-a-days are inefficient, costly, non-transparent, and subject to fraud and misuse. These problems caused from reliance on centralized, trust-based, third-party systems, such as financial institutions, clearinghouses, and other intermediaries of existing institutions. "

(Lin/Shih/Liu, 2017: [27]) Within a traditional network each party has to keep their own ledger with duplication of the data. This usually results in disputes and bigger settlement times to agree on a certain state. Data of a distributed ledgers however are not stored on central servers. Instead their are distributed into different nodes and stored within the network itself.

2.2.1 What is Blockchain Technology?

A blockchain is basically a way to store data. It is called a Distributed Ledger. This blockchain is literally a chain or a sequential list of blocks of data. A blockchain starts with the first block, it is usually called the genesis block. After this, a block contains a number of items, depending on its implementation:

- Block header:
  - block number
  - previous block header's hash
  - timestamp
  - block size
  - hash which represents the block's data
- Block Data:
  - A number of transaction
  - depending on the implimentation other data

Due to the hash of the previous block tampering, in terms of appending a wrong block, is infeasible.

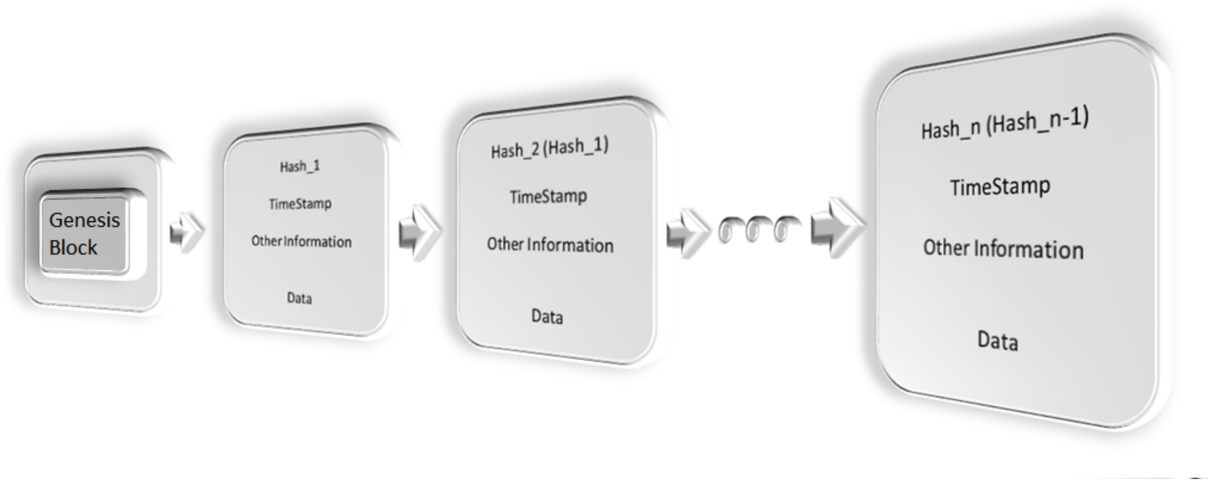


Fig. 6: Chain of Blocks

Source: own image

Hash-functions H(x) An important component of blockchain technology are cryptographic hash functions. Hashing turns data into a relatively unique output of digits. The input can be of any size, the output will be of the same amount of digits each time. This transformation is infeasible to reverse, i.e., given a hash h it is infeasible to find input data that generates h (National Institute of Standards and Technology, 2002: [41]). *"It allows individuals to independently take input data, hash that data, and derive the same result – proving that there was no change in the data. Even the smallest change to the input (e.g., changing a single bit) will result in a completely different output digest."* (Yaga/Mell/Scarfone, 2018: [16]) This can be seen in the provided table 1.

Input Text	SHA-256 Output
1	`0x6b86b273ff34fce19d6b804eff5a3f5747ada4eaa22f1d49c01e52ddb7875b4b`
Hello, World!	`0xdffd6021bb2bd5b0af676290809ec3a53191dd81c7f70a4b28688a362182986f`

Table 1: Comparison of hashes with different input values

Source: Blockchain Technology Overview (Yaga/Mell/Robym/Scarfone, 2018: [16])

For those properties cryptographic hash functions have the following security requirements:

- Pre-Image Resistant: given y, it is infeasible to find an input x with $H(x) = y$
- Second-Image Resistant: given fixed input x, it is infeasable to find a different input x' such that $H(x) = H(x')$
- Collision Resistant: it should be infeasible to find any inputs x_1, x_2 so that $H(x_1) = H(x_2)$

One of the most popular cryptographic hash functions is the Secure Hash Algorithm (SHA) with an output size of 256 bits (SHA-256). Many computers support this algorithm in hardware, making it fast to compute.

These hashes are very important for blockchain technology. For example they are used for the following:

- creating unique identifyers
- securing data within a block
- securing the block header

Decentralization Once a block is appended to the blockchain, modifying or removing a block is infeasible. Since this chain is not on a single server instead distributed within a peer-to-peer network a majority always decides on the correctness of every block. This makes it infeasible for a single node, also called miner, or a group of miners to control the underlying infrastructure. Every miner has the same amount of responsibility and they all have to adhere to the same protocols. A not trivial agreement within a short amount of time between all or at least a majority of parties is not easy.

Consensus Algorithms In order to achieve a consensus within a network all participants have to agree to the same state of data. Consensus leads to all nodes sharing the exact same data. Therefore a consensus algorithm

- ensures data throughout the ledger is the same for all nodes,
- prevents malicious actors from manipulating the data.

Different blockchain implementations have different consensus algorithms.

Bitcoin, which was developed by Satoshi Nakamoto and started the blockchain hype, uses Proof of Work as the consensus algorithm. (Nakamoto, 2008: [40])

Proof of Work – PoW Proof of Work is the most famous consensus algorithm. In order to append a new block onto the blockchain a miner must solve a challenging but still feasible cryptographic puzzle. The process is also known as 'mining'. The miner that solves the puzzle first gets to append the new block. As reward he will receive a payoff from the system itself as well as a reward from every node that included a transaction within the miners block. As described in the 2016 Kudelski Security report, "Proof-of-work (PoW) is the outcome of a successful mining process and, although the proof is hard to create, [it] is easy to verify"(Aumasson/Jovanovic, 2016: [32]). For better understanding, here is an example by Ofir Beigel: "(...) guessing a combination to a lock is a proof to a challenge. It is very hard to produce this since you will need to guess many different combinations; but once produced, it is easy to validate. Just enter the combination and see if the lock opens" (Beigel, 2018: [10]).

PoW is criticized for its "labor for nothing" approach. It requires a huge amount of energy due to the given computational algorithm. The most famous use case for Proof of Work (PoW) is bitcoin.

Proof of Stake – PoS Proof of Stake (PoS) is a generalization of Proof of Work (PoW). Here the nodes, network participants, are called "validators" and they are no longer mining in order to append a block to the blockchain. In Proof of Stake (PoS), validators vote on the authentic transactions based on their stake, an amount of coins that they deposit into an account, which is frozen for a certain period of time. Malicious behaving participants lose their deposit. (Gui/Hortaçsu/Tundón, 2018: [20]) Therefore there is no longer a selection process based on the computation power of participants. Even weak nodes are able to validate. Proof of Stake (PoS) is therefore not as wasteful with its resources as Proof of Work (PoW).

There are many other consensus algorithms focusing on different and possibly fairer strategies, like Byzantine Fault Tolerance and variants. (Baliga, 2017: [8])

Permissioned vs. Permissionless blockchain networks can be categorized based on their permission model. This model determines who is authorized to publish new blocks. If every node can, it is a permissionless blockchain model. In contrast, in a permissioned model only a select group can publish nodes. Those are mainly constructed for a group of organizations and individuals. (Yaga/Mell/Scarfone, 2018: [16]) If the model is not mentioned, it is usually a permissioned blockchain model.

Permissioned blockchain networks are only accepting operations triggered by an authority. Therefore a restricted read and issue transaction access is a possible feature. Permissioned blockchain networks are therefore particular useful to organizations that need to more tightly control and protect their blockchain. For example a use case would be organizations with multiple not all trustworthy partners. They can invite business partners to interact with the blockchain but they can also limit rights. Hence this network does not only provide trust but also transparency and insights into the action of organizations. Permissioned blockchain networks can be implemented using both open source or closed source software. *"Consensus models in permissioned blockchain networks are then usually faster and less computationally expensive. However, if a single entity controls who can publish blocks, the users of the blockchain will need to have trust in that entity."* (Yaga/Mell/Scarfone, 2018: [16])

Permissionless blockchain networks are decentralized ledger platforms open to anyone publishing blocks, without needing permission from any authority. Permissionless blockchain platforms are often open source software. Any blockchain network user within a permissionless blockchain network can read and write onto the Blockchain. This can cause many security issues. Permissionless blockchain networks therefore use a consensus algorithm that builds a bridge between the digital and physical world. For example Proof of Work (PoW) requires users to use their resources to be allowed to participate. This prevents malicious users from easily joining the system due to the high costs.

Forks Every technology has to be maintained. So does Blockchain technology as well. There are two different ways to update. Basically the chain itself will be separated. This separation onto the new rules is called a fork. (Casado-Varaa/Prietoa/De la Prietaa, 2018: [43]), (Aumasson/Jovanovic, 2016: [32]) There are two ways to fork a Blockchain:

Softfork A soft fork is a update on the rules about how nodes will find a consensus. A softfork does not require all nodes to adapt to the new rules, only a majority. If only a part of nodes will update the new rules will not be accepted and therefore they will be discarded. Once the new rule is updated by the majority the nodes with the old rules will agree on both old and new rules. However, the majority who has adapted the new rules will only accept nodes with the new rules. Hence, after a while, the new rules will be distributed throughout the system until every node is updated. A possible example of a soft fork would be if a blockchain decided to reduce the size of blocks. Updated nodes would change to the new block size and continue to transact as normal.

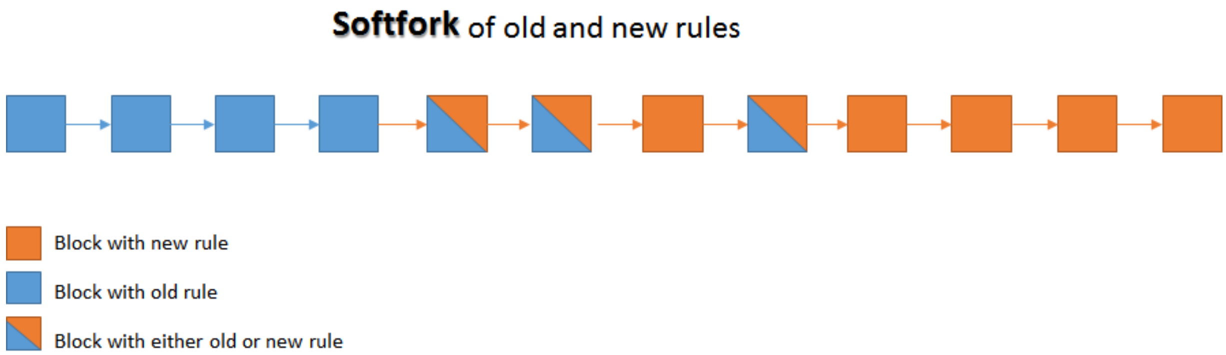


Fig. 7: Softfork within a Blockchain

Source: own image

Hardfork With a hard fork, every node has to accept the new rules in order to participate in the network. Therefore once updated there is no way to go back. Non-updated nodes cannot append transactions on the updated blockchain because the network is programmed to reject any block that does not follow their version of the specifications. Hence, this results in a fork, where two different versions of this blockchain exist. Users can no longer interact across versions. These hardforks are mostly triggered in order to update some algorithm or fix security issues. Sometimes, however, software errors produce unintentional hard forks. The most famous hardfork is from the Ethereum chain. It contains a so called smart contract (see 2.2.1) called the Decentralized Autonomous Organization. This smart contract contained a flaw which enabled an attacker to extracted $50 million of Ether, the cyptocurrency of Etherium. A hardfork resolved this issue. After a hardfork the the cryptrocurrencies of both forks will be independent on each other. Eventually the old fork will die due to lack of activity.

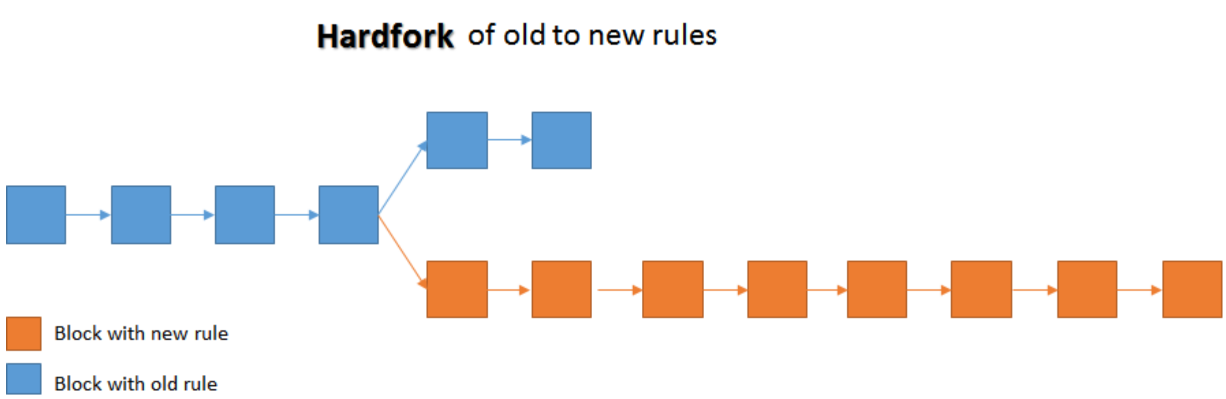


Fig. 8: Hardfork within a Blockchain

Source: own image

Smart Contracts Smart Contracts helped blockchain technology to its breakthrough. 1994 Nick Szabo defined them as *"a computerized transaction protocol that executes the terms of a contract. The general objectives of smart contract design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries."* (Yaga/Mell/Scarfone, 2018: [16]) A smart contract are functions and states in form of code. It is deployed with signed transactions on the blockchain network. Every node within the network executes this smart contract and has to come up with the same result. This will be stored on the blockchain. For example, a smart contract could perform calculations, store information, expose properties to reflect a publicly exposed state and automatically send funds to other accounts. Since this code is stored on the blockchain it is also tamper evident and tamper resistant. Thus, smart contracts are like a trusted third party. A smart contract can represent a multi-party transaction for a business process. This sort of a trusted third party is completely transparent to all parties. It is also faster in completing transactions. Hence, better business decisions can be made due to the provided insights.

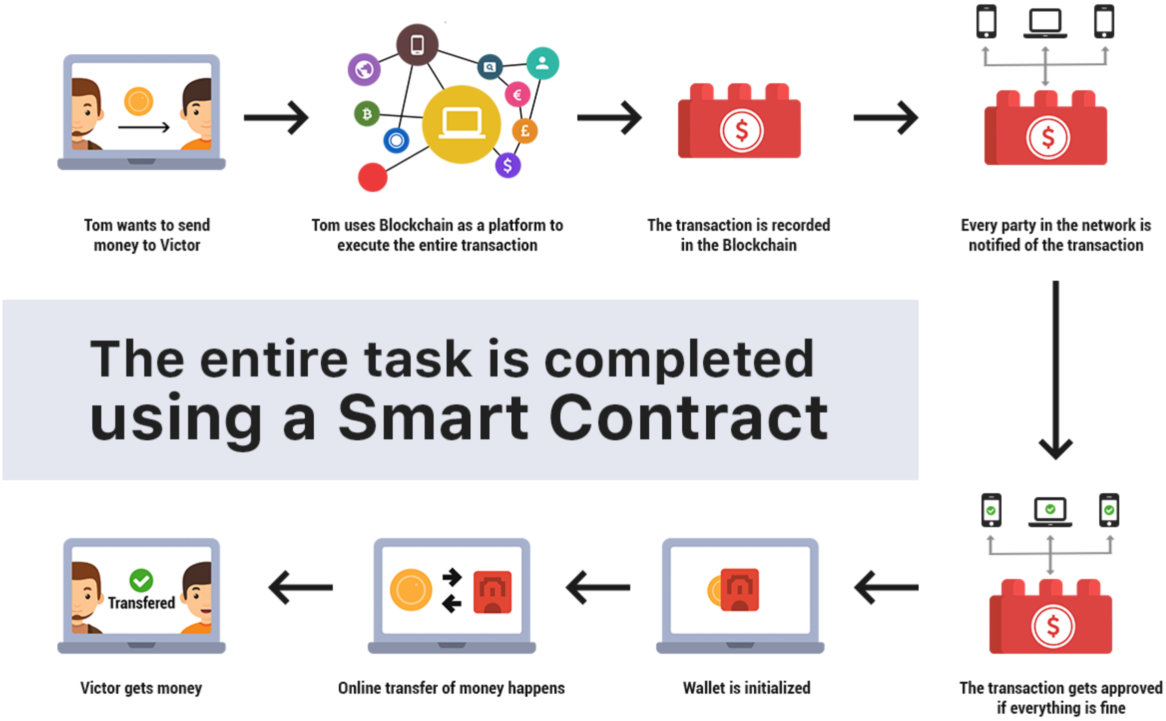


Fig. 9: Example of an transaction via a smart contract

Source: Smart Contracts 101 (Challen, 2017: [7])

Blockchains Limitations and Misconceptions Due to Bitcoin's hype, blockchain technology is overused in many areas. Some companies do hackathons mainly to find a possible project to incooperate blockchain technology within their business. Many projects are based on blockchain technology even though a central ledger would be more appropiate. This technology carries many misconceptions about its advantages. This section considers highlights and limitations of blockchain technology.

Blockchain Identities vs. Real-world Identities Blockchain technology often incorporates a public key infrastructure, but this is not equal to real-world identities. This is because there is no one-to-one relationship between a user and an blockchain private key (usually called an *address*). In a blockchain network users can have multiple private keys and each user can have multiple addresses. This creates anonymity within the network as otherwise one could scan the blockchain and determine which person is sending whom transactions. Digital signatures are often used to prove identities in the cybersecurity world. A blockchain's transaction signature verification process links transactions to the owners of private keys. This signature is not easily connectable with the real-world identities. Therefore blockchain technology is not a standalone identity management systems.

Labor for Nothing With Bitcoins's worldwide network it has enabled everyone to participate. Mining blocks and including transactions in blocks is possible for everyone with an Internet connection. Unfortunately Proof of Work (PoW) requires a huge amount of processing time and therefore electricity. The Proof of Work (PoW) consensus model is designed for a network where no or limited trust among users. The amount of energy used is immense. Estimations state that the Bitcoin blockchain network will use as much electricity as the entire country of Denmark by 2020 (Deetman: [14]). Even though software and hardware will improve, the mining difficulty is regularly adjusted to keep the mining time (not the resource usage!) roughly constant. Additionally every node during its creation uses many resources. Since the new node has to download most of the blockchains data in order to participate. This uses a lot of network bandwidth.

The Oracle Problem – Interacting with the Real World "The Oracle Problem" occurs once a blockchain network wants to interact with real world events. For example, if a blockchain network wants to record sensor values or record other noisy or error prone data this is not handled well. A blockchain network cannot record whether a shipment took place without relying on outside data sources. It might even be intentionally modified by a malicious actor. The blockchain cannot ensure the correctness of this information. *"Many projects have attempted to address the 'Oracle problem' and create reliable mechanisms to ingest external data in a way that is both trustworthy and accurate. For example, projects like 'Oraclize' provide mechanisms to take web API data and convert it into blockchain readable byte/opcode."*

(Yaga/Mell/Scarfone, 2018: [16]) Unfortunately, this creates a central instance again which offers attackers a single point of failure.

Blockchain Death A huge advantage over a centralized network is the constant availability of a decentralized network. Due to the copies of the blockchain throughout the system many parties can shut down without losing any information. However, as the number of nodes shrinks, participants with more computing power have more power over the entire blockchain. This attack is also known as the "51% attack". After a successful execution of this attack a single network participant is able to control the majority of the hash rate, potentially causing a network disruption. The attacker would have enough mining power to exclude or modify the order of transactions. (Li/Jiang/Chen, 2017: [49]) Therefore the attacker could prevent some or all transactions from being confirmed and prevent other miners from mining. Which is also known as mining monopoly.

Controlling a Blockchain "No one controls a blockchain!" is a typical statement regarding blockchain. However, it is not quite true. Permissioned blockchain networks are generally setup and run by an owner or consortium, which governs the blockchain network. They have the power to let parties join the network or even remove them. Additionally, they are controlling all sorts of software, guideline or smart contract changes. Permissionless blockchain networks are governed by network users, publishing nodes and software developers. The publishing nodes have significant control since they create and publish new blocks. The software developers can start a hard fork, giving the users the choice to live with unmaintained software, or accept changes they might not agree with to stay on the main fork. (Unknown, 2019: [48])

Trust and Immutability Issues One of the biggest misconceptions is that the absence of a trusted third party solves all kind of trust related issues. This is really far fetched. A blockchain network is just like every decentralized network. There might not be a third party with more rights, however the responsibilities are distributed throughout the network. Therefore, there is still a great deal of trust needed to work within a blockchain network. For example, cryptographic technologies are very important. A bug within an algorithm or a wrong implementation would tamper with the entire infrastructure. The trust among developers to produce bug-free software and not to include any selfish loopholes is very important. A smart contract might bring some more transparency on automated transactions, however it could also include malware. Additionally there is a certain amount of trust between all parties of this network. Since there are a few attacks that would enable a secret alliance to take over a part of the blockchain network. Even under the assumption that the provided software is bug-free and does not contain any malware, blockchain networks are still not completely tamper evident and tamper resistant. As mentioned before there are possible attacks to modify the blockchain network to ones advantages.

The chain of blocks itself cannot be considered completely immutable (Yaga/Mell/Robym/Scarfone, 2018: [16]). Since mining blocks onto the blockchain creates many forks some of the forks will have to be ignored. Bitcoin for example always considers the longest fork from the genesis block its main fork. Hence, all blocks that are on a different fork will be ignored. Those transactions will be invalid and therefore have never stopped pending. In order to get one of those stuck transactions completed they must be mined in a new block again and hopefully they end up on the longest path. Most blockchain network users wait several block creations before considering a transaction to be valid.

Malicious Users – Selfish Mining A blockchain network can vote on transaction rules and specifications, but it cannot enforce a user code of conduct. Permissionless blockchain networks therefore use incentives in form of rewards in a cryptocurrency to motivate users to act fairly. Unfortunately, this incentive does not stop a users from acting maliciously. Malicious behavior includes for example ignoring transactions from specific user group or refusing to transmit blocks to other nodes.

Another typical attack would be selfish mining (Cyril/Pérez-Marco, 2019: [13]). By mining a private fork without publishing it immediately miners can create a small time advantage. The malicious user can now mine the next block before the rest of the network to increase their chances of finding the next block first. They can then reap the mining reward. Software updates can prevent selfish mining, the implementation is up to the developers though.

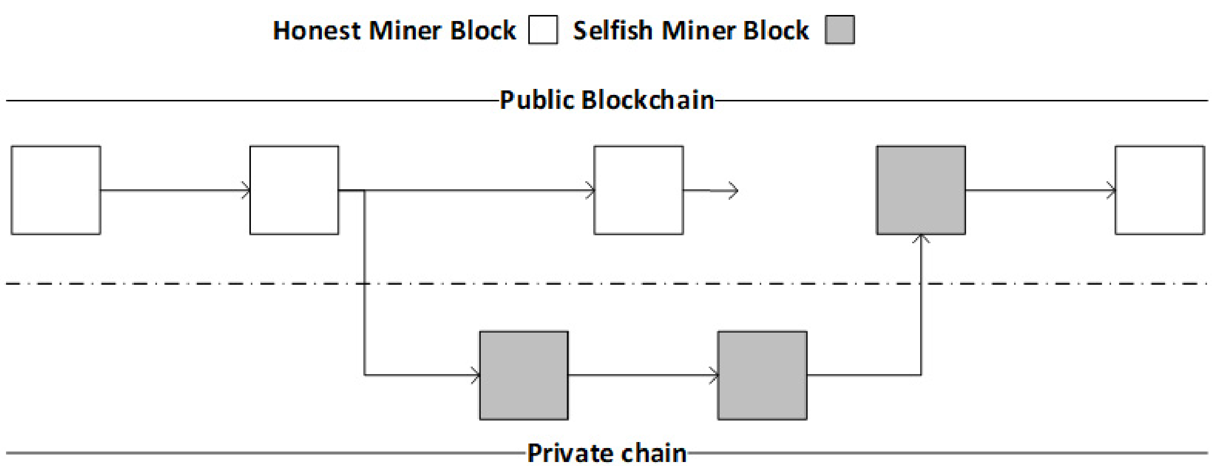


Fig. 10: Example of selfish mining

Source: own image

2.2.2 Blockchain for Different Industries

The cryptocurrency based blockchain model falls short on being a suitable host for requirements that many types of organizations would need for regulatory compliance when using blockchain and distributed ledger technologies. For instance, in the areas of financial services, healthcare, and government. Those specific requirements are presented below.

Food Industry Many companies like Nestlé and Walmart started to improve their supply chain with Blockchain technology already. The need for change, to reduce the spread of food-borne illnesses by pinpointing issues in the food chain is still not satisfied. Many other companies like Dole, Driscoll, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods and Unilever all started cooperating with IBM to introduce Blockchain technology (Gagliordi, 2018: [19]).

Hyperledger Sawthooth This business blockchain frameworks is used to build enterprise blockchains for a consortium of organizations, thus they are different than public ledgers like the Bitcoin or Ethereum. The Hyperledger frameworks include: (Jones, 2017: [31])

– An append-only distributed ledger
– A consensus algorithm for agreeing to changes in the ledger
– Privacy of transactions through permissioned access
– Smart contracts to process transaction requests.

Hyperledger Sawtooth, contributed by Intel and AWS Partner Network, is a blockchain framework that utilizes a modular platform for building, deploying, and running distributed ledgers. It provides a variety of consensus algorithms based on the size of the network. For instance it includes Proof of Elapsed Time (PoET) consensus algorithm, which provides the scalability of the Bitcoin blockchain without the high energy consumption of Proof of Work (PoW). Proof of Elapsed Time (PoET) allows for a highly scalable network of validator nodes, since after the elapsed amount of time publishing nodes is possible without completing any hard puzzle. Hyperledger Sawtooth supports both permissioned and permissionless deployments.

Hyperledger is a platform that is developing permissioned distributed ledger frameworks specifically designed for enterprises with strict regulatory compliance requirements (Jones, 2017: [31]). Special software for more scalability and more throughput is already in place. Even inter-operable identity modules for smoother transactions between multiple parties is accessible. The regulator can access all data in the ledger with reading rights and ensure compliance. Access is only permissioned to authorized parties. For better transparency every party has a copy of the same ledger. For secret information transactions are encrypted and only readable with the correct certificate. This secures all sorts of detailed transaction details between the transaction's explicit stakeholders. Just like in the initial blockchain this version also groups transactions into blocks and links them with hashes behind another. This creates a linked hash-list which is hard to tamper with. This concept enables backtracking through all records stored somewhere in the linked chain.

The Seafood Industry has already its own Blockchain based solution to record the journey of seafood from ocean to table. Sensors track fish and all kinds of information regarding those like possession, location, temperature, humidity, motion, shock, and so on. This software solution offers the final buyer to access the complete record of information and therefore offers a new level of transparency regarding our foods (Finan, 2018: [17]). Issues of the traditional seafood industry supply chain like laborious manual record keeping, improper food storage conditions or illegal, unregulated fishing practices are now easier to spot and prevent. This offers our food supply chain to more security and product quality while stabilizing the seafood industry's economy. Benefits of Sawtooth are the improvement of integrity between parties, rewards due to good practices and importantly more transparency for consumers and vendors.

TE-Food , "Food traceability on the blockchain" is the world's largest and most successful food traceability solution. *"The Vietnam/Hungary based company started in 2016 and serves 6000+ business customers, handles 400,000 transactions per day and reaches over 30 million people. Their commitment is to improve food safety, stave off corruption, and support fair trade while building trust between food supply chain companies, consumers and authorities."*(Thrill, 2018: [47]) TE-Food uses radio-frequency identification, seals and labeling stickers to track an entire life cycle of their products. With these technologies they are tracking livestock and fresh foods thoughtout the supply chain. With these data points a digital trail is traceable from farm to table. TE-Food is using their peer-to-peer app to trace to trace twelve thousand pigs, two hundred thousand chickens and 2.5 million eggs per day
(Thrill, 2018: [47]).

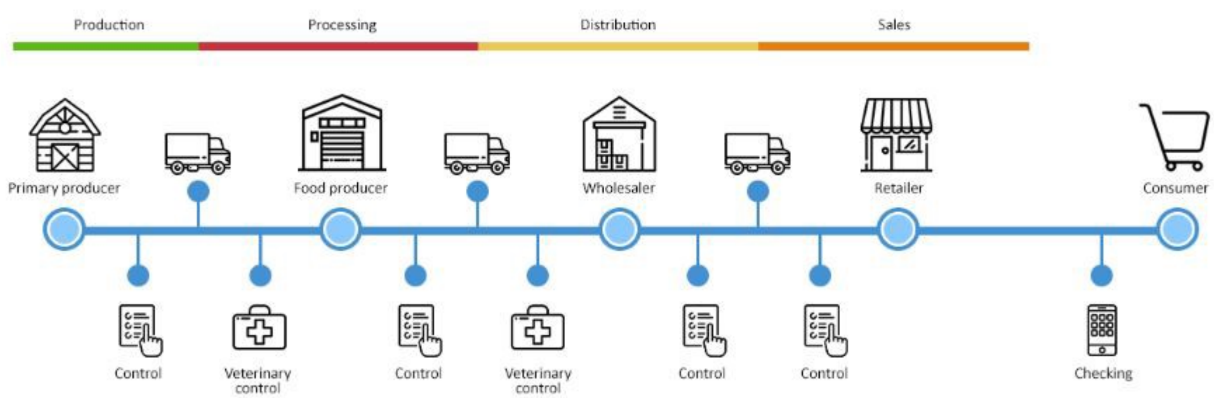


Fig. 12: Tracking a products lifecycle

Source: TE-Food traceability on the blockchain [47]

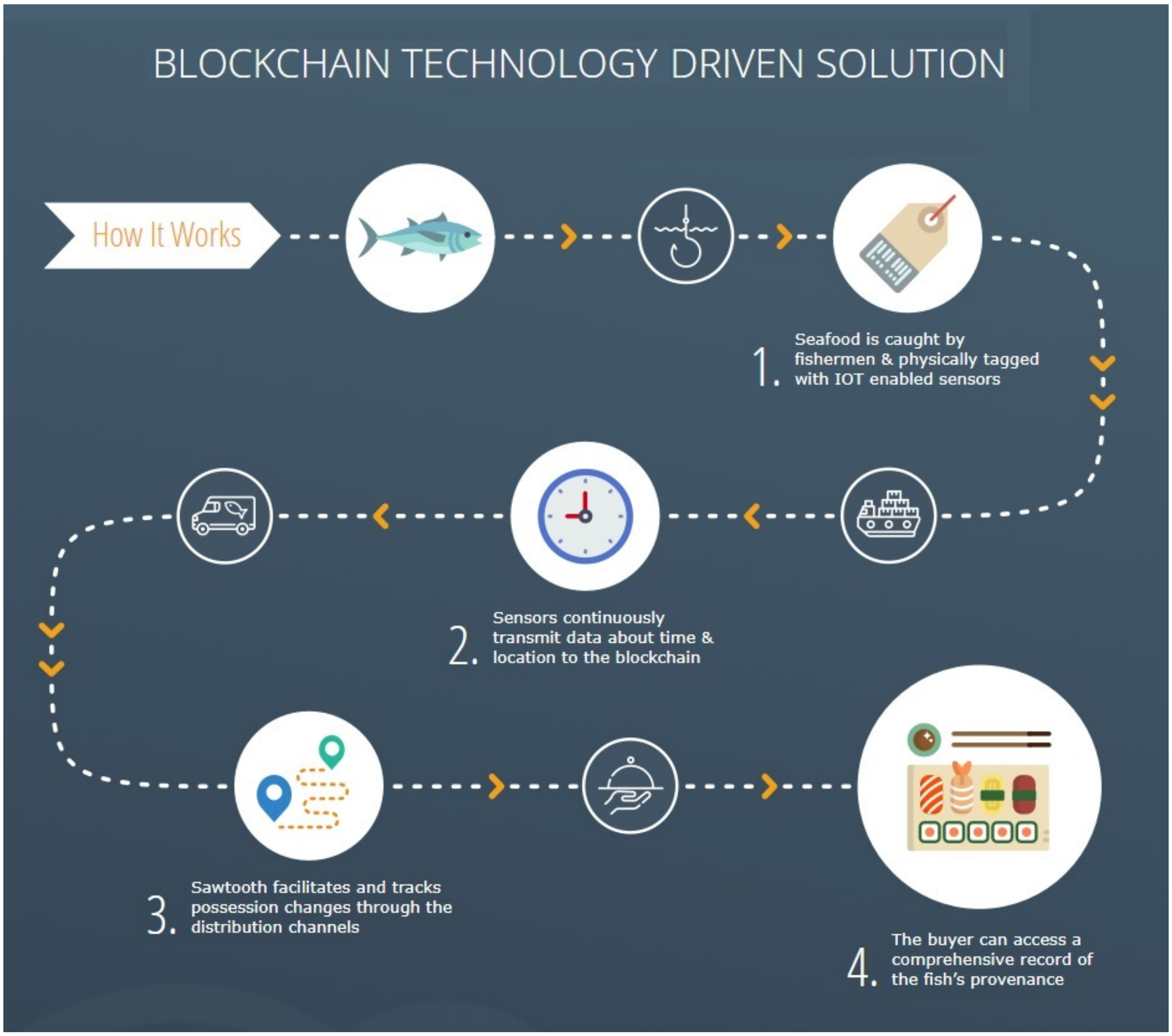


Fig. 11: Example of fish supply chain with blockchain technology

Source: A Modern Approach to Seafood Traceability with Blockchain Technology from Sawtooth [17]

Their payment solution works through a public network using ERC20 which is basically a TE-Food token. This token represents the identity and information data of the product. All information is published on a private blockchain with TE-Food tokens. In order to interact with this system two wallets are nessessary. With a TE-Food wallet and a public one filled with TFD tokens, tracing is possible. The traceability ledger uses TFD tokens for payment by the participants. This party provides information about treatments the product has undergone. E.g., if an animal has been treated with antibiotics, it is recorded on the ledger and can be checked throughout the supply chain. The company selling the product sets a price for this information and the buyer pays with TFD tokens via the wallet. All collected information can be analyzed, suppliers can even be rated on their products to enhance food safety.

Pharmaceutical Industry Many companies are already working on deploying blockchain technology within the pharmaceutical sector. Developed use cases and simulation models show the most important features can be realized within a blockchain based supply chain (Clauson/Breeden/Davidson, 2018: [33]). For instance, features like product identification could be contributed with a unique product identifier and validated in a off-chain. Product tracing is possible and allows enterprises to provide and receive tracing information. Even detecting and reporting counterfeit and unapproved drugs is possible. On this explicit issue is a company called BlockVerify (BlockVerify: [1]) currently involved in.

Farma Trust is a company developing a entire supply chain system based on blockchain technology for pharmaceutical products. It is not only suppose to track products in every production step its app also uses AI to predict the amount of requested pharmaceuticals for manufacturers to offer on demand production. (Farma Trust: [3])

LifeCrypter Life-Crypter is a prototype for a patient-empowering blockchain solution.
(Schöner, Kourouklis, Sandner, 2017: [35]) This prototype is suppose to bring integrity, traceability, and transparency to the global drug supply chain. The Life-Cypter app offers patients to trace their medical supply by themselves to check the origin of their products. Each product has an identification tag which offers the software to identify ownership in each supply chain step. A smart contract interacts with the blockchain and verifies its state. It also enables consensus for all parties involved. With this system and the power of patients the many lives lost due to counterfeit drugs is suppose to drop rapidly.

These and many other efforts in this field are however still at a Proof of Concept stage.
(Clauson/Breeden/Davidson, 2018: [33]) There is no doubt about the possibilities and opportunities for the health supply blockchain, however *"only time will tell if the highly regulated and complex healthcare*

sector can fully leverage all the possibilities blockchain technology has to offer."
(Clauson/Breeden/Davidson, 2018: [33])

Automotive Industry As we've seen in the previous section, using blockchain technology within the supply chain carries many advantages in a variety of industries. However, the automotive industry has not fully started exploring its possibilities. The reason behind this limited investment is *"the very same obstacles relating to coordination and trust that the technology would help the industry to overcome. That, in essence, is the industry's blockchain paradox."* (Schmahl/Mohottala/Burchardi, 2019: [44]) Blockchain technology in the supply chain could easily resolve some mistrust by solving transparency issues. For instance by using a public blockchain. However, in order to get enterprises to agree upon one technology for the entire supply chain a lot of trust is necessary in first place.

Companies Developing Blockchain Based Supply Chain Software *"According to a McKinsey study, blockchain is the core technology that now has the most potential to trigger the fifth wave of disruptive revolution after steam engines, electricity, information and Internet technology"*
(Mao/Wang/Hao, 2018: [15]). Due to this Blockchain hype, investors are keen to invest into transportation and logistic solutions. *"An analysis by BCG found that, since 2013, venture capital investors have poured approximately $300 million into startup companies offering blockchain solutions relevant to transport & logistics, including $53 million specifically in shipping and freight management, as well as in trading and shipping platforms."* (Schmahl/Mohottala/Burchardi, 2019: [44]). The future will show the success of those investments. Within the next years the transportation and logistic sector might change completely, if those solutions get accepted and adopted by all enterprises.

There are already a number of startups in this sector. On start-up including blockchain technology is Transport Alliance.*" BiTA is a member-driven organization. Members are primarily from the freight, transportation, logistics and affiliated industries. Alliance members share a common mission of driving the adoption of emerging technology forward. We accomplish this by developing industry standards; educating members and others on blockchain applications/solutions and distributed ledger technology and encouraging the use and adoption of new solutions. Thousands of companies have applied for membership. "* (BiTA: [5])

Volkswagen and IBM have build a blockchain powered system to track cobalt. This is used in many lithium-ion batteries, Volkswagen uses Cobalt for its electric vehicles. The IBM Hyperledger Fabric platform is suppose to *"increase efficiency, sustainability and transparency in global mineral supply chains."* (Khatri, 2019: [34]) Most Cobalt is produced in the Democratic Republic of Congo, by estimated two million miners under human rights violating circumstances. This new system aims to ensure transparency across the supply chain in near real-time. A few other companies like LG Chem and the Ford Motor Com-

pany have joined the platform. The group will expand also to other sectors of mineral using companies, like aerospace or electronics. By growing the platform manufacturers will not only have more transparency regarding their minerals but also an improved logistics and lower costs.
(Simms, 2019: [45])

Reasons for Lack of Action Even though these advantages and start-up ideas sound promising, there are a couple of reasons why many enterprises are highly critical about blockchain based systems.

Fragmented Value Chain Due to the many independent parties within an automotive supply chain blockchain would be a well-suited technology. However, this independency of another creates a difficulty in order to create a coordinated system. A blockchain based ecosystem would require many standards from software to specific licenses to suitable hardware. This lack of coordination creates a huge barrier for a final implementation of blockchain technology within the supply chain.

Limited Trust Because the automotive industry is a highly competitive industry, parties regularly chose not to share most of their information. The long lasting relationships between enterprises would now be replaced by technology. Many parties are unwilling to share their information further than their well established network. Due to these networks of convenience many companies are reluctant to abandon their traditional way of trading even though a blockchain solution might carry some other advantages for them.

In oder to overcome those issues a proper governance is required for the entire blockchain ecosystem.

Policies need to be considered. Laws, international privacy standards for shared data and a proof of identity must be developed. Data must be specified, what sort of information is required to publish and might be allowed to send as decrypted information.

Technical Elements have to be agreed upon. The blockchain type has to be agreed upon as well as other details. For example regarding data storage related information. For instance what sort of information can be stored in what way on the blockchain based system. What kind of tools are offered to every manufacturer and how can they use them.

Development Costs to design, implement and maintain the blockchain driven system. The costs should be shared among all parties.

The transportation and logistics sector would benefit from many advantages of blockchain technology. Stakeholders must consider whether receiving more trust and transparency within the entire supply chain is worth giving up the traditional convenient way of trading. Collaboration is necessary to enhance the current system. Only if a many stakeholders, governments and regulators are eager to develop a new way of trading this blockchain based system might revolutionize the automotive and many other industries.

2.3 Blockchain in a Traceability Supply Chain

2.3.1 Does a Supply Chain Need a Blockchain? Many companies tried very hard to use blockchain technology of any kind in order to follow the trend. Mostly those companies have no idea what a blockchain is actually good for. (Mitic, 2019: [38]) The pressure to use this technology is so immense, that a sort of anti-hype has developed. Many articles about proper use-cases for blockchain technology came forward. Additionally the United States Department of Homeland Security Science & Technology Directorate has been investigating blockchain technology and has created a flowchart, see figure 13 to determine the plausibility of using blockchain technology for specific projects.

Overall a couple of basic criteria for well-suited blockchain projects are easily explained:

- Many participants, the security of a distributed blockchain increases with the number of participants.
- No trusted third party, a blockchain would distribute all data among all participants.
- Transfer of digital assets or information between all parties with a full record history.
- Systems in need of a global digital identifier, e.g. blockchain can offer a secure system of ownership .
- Real time monitoring of activity between different parties.

If these criteria are not enough to decide a website "Do you need a blockchain?" (Hochstein, 2018: [24]) might be able to help. Regardless of the tool to determine a proper use of this technology most paths lead to *not a good idea*. This is not only because in most cases blockchain technology would be a waste of time and money. But also because there are many better already existing solutions out there that can solve most problems.

Coindesk, a technology website with focus on cryptocurrency and blockchain news have published an article "Don't use a blockchain unless you really need one." (Coindesk: [2]) The author explains how users are only supplying their data to huge siloed organizations. The largest benefit of blockchain technology is its decentralization. *"It's worth paying the cost when you need the decentralization, but it's not when you don't."* (Hochstein, 2018: [24])

The initial question remains. Does a supply chain need a blockchain based system? Well, a consistent data storage is definitely needed in order to support traceability. This data would also be added by multiple parties not only one manufacturer. Whether all data is supposed to be stored forever immutably is questionable. One big reason for a blockchain system in the supply chain is the distributed control of the data storage. At least if the implementation and maintenance is ignored. The tamper proof log of all writes onto the data storage system is also a nice advantage of blockchain.

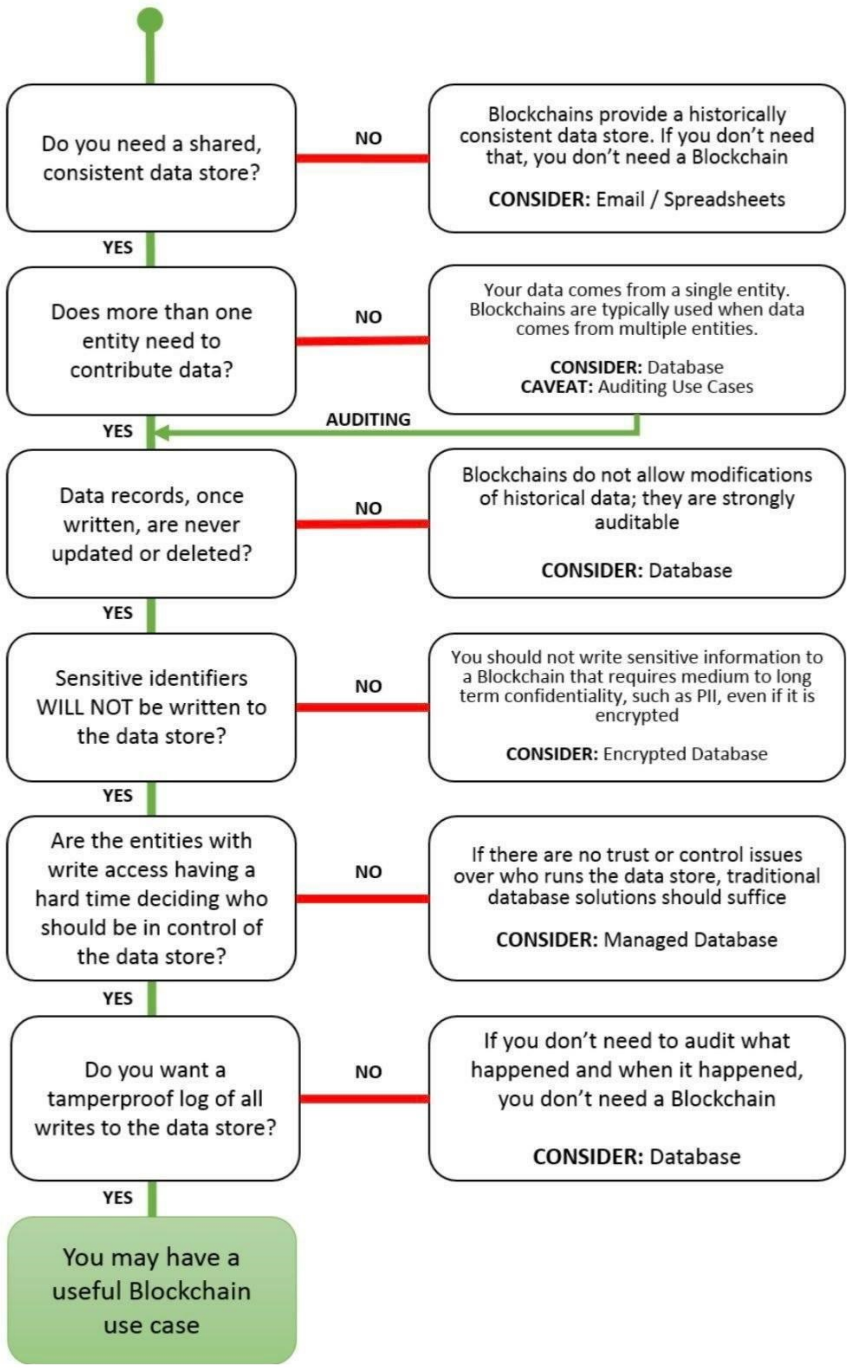


Fig. 13: Flowchart: do you need a blockchain?

Source: DHS Science & Technology Directorate (Hochstein, 2018: [24])

Hence, it is not a bulletproof blockchain use-case.In order to examine further advantages and disadvantages of this blockchain based supply chain the following chapter introduces possible features.

2.3.2 Features of a Blockchain Based Supply Chain A complete blockchain based traceability supply chain is supposed to work for every sector. It should cover the entire end-to-end production process. Every party throughout this process is supposed to be able to backtrack the components already included. Also every party should know where the product is sent next. In order to offer one system for all parties, many factors have to be covered.

Manufacturer Finance A payment of an importer can take several weeks or months until it is finally received by the manufacturer, because the process still contains a lot of paperwork. This is caused by the way traditional banks issue Letter of Credits or submit a Bill of Lading. A blockchain based system could help to make every transaction transparent to all involved parties and do those transactions within approximately an hour. Banking documentation would be completely digitalized and could be processed much faster.

Retail Sales, Service & Finance An auto finance provider has no trustworthy records of the cars history or the drivers behavior. A blockchain based system would enable driving patterns and service events to get sent to a shared platform that all parties have access to. Transparency about a vehicle's real driving history and parts would help the auto finance provider to more accurately value estimations.

Spare Parts & Warranty Many car manufacturer are concerned that service centers are installing counterfeit spare parts in their customer's vehicles. This can cause warranty costs, damage their reputation, and, in the worst case, accidents. A blockchain based system would enable the service center, the car manufacturer and the customer to trace the provided spare parts back.

Correct Data Input A blockchain based system offers immutable data storage. Unfortunately, this offers also no data correction. This is an obvious benefit regarding forgeries. Additionally, malicious hardware could still alter data before it is published within any kind of system. Offering a complete tamper-proof system would therefore require all software and hardware to be certificated. Even after this step, which again creates a central instance of certification, a guarantee of a complete secure system is infeasible.

Goods Origination Verifying provenance is currently mostly based on long-term trusted relationships, government certification or regulations. A blockchain based system could help to reduce these costs.

Registration onto the blockchain based system would allow analytical algorithms to verify a good trading partner for materials, parts, or products. This would also improve quality assurance and enable a transparent pricing system.

Ownership Certificates are like an official document that entitles ownership of a product. A blockchain based system can securely store relations of ownership by storing a physical number, like a serial number, onto a wallet of a certain user. A smart contract would ensure manipulation is not possible by a third party. Only the owner himself could transfer his ownership from himself to someone else.

Production Integration Each product has to be identifiable. In order to give products an identity some device must be approved to generate serial numbers and create digital ownership certificates. Additionally, products need to be identified. Thus some sort of hardware to scan serial numbers or QR code must be developed and distributed to all blockchain system parties to make entering malicious data onto the blockchain more difficult. Blockchain technology definitely experienced a big hype due to its involvement regarding cryptocurrencies.

Number of Participants One big factor of a useful use-case is how many parties are involved within its application. Blockchains security and its reliability is highly dependent on the size or the number of nodes involved. *"The technology is ideally suited for applications in complex supply chains, but less so where there are relatively few actors."* (Bateman, p. 9, 2015: [9]) Additionally, for blockchain to be effective parties from every sector within the supply chain have to be involved. Only sending products to authorized enterprises makes a complete tracking procedure possible.

Throughput A normal blockchain based system can only handle about 10 transaction per a second. However since each manufacturer within a supply chain has a lot of data to publish every second this might be a big disadvantage. Basically, this throughput is just like a very slow database which is especially for a new technology incredibly inefficient. (Hochstein, 2018: [24]) This slow throughput would not even be enough for selling popular concert tickets. Of course, this might change with some time but might never reach the speed of traditional databases.

Technological Consensus For a common blockchain based system all parties must agree not only to use the same application but also they have to agree on all rules. With a permissioned blockchain system a central organization could force all enterprises to one technology. However, most supply chain industries are highly competitive. Only a government policy could force them to one overall agreement.
(World Health Organisation, 2015, [6]) A permissionless system would therefore require all parties to agree on several issues discretely. Hence, this possible alliance is rather disputable.

Transparency This is a double sided sword. On the one hand side, transparency is the number one improvement from a centralized system to a decentralized blockchain based system. On the other side, this transparency can also be used to exploit dynamic pricing markets
(World Health Organisation, 2015, [6]). The competitiveness between parties could fade due to the lack of a constant trading for an improved margin.

User Experience and Interfaces Lastly a good user experience is important. Users themselves need an easy way to access information of their products. For example scanning a QR code and receiving all necessary information. Also interfaces for manufacturers are necessary. Not only for tracking backwards or forward. Also in order to publish new information onto the blockchain. Especially publishing information is important. Since all manufacturers do not want to spend time interacting with a hard to understand interface. Nor do manufacturers want to spend a lot of money training their staff use new software tools.
"Summing up user experience is key to obtaining acceptance from the user base." (Herings, 2017: [23])
There are multiple ways to implement a blockchain within a supply chain. To ensure certain properties of blockchains the following table 2 compares a permissioned blockchain from a permissionless one. A permissioned blockchain would act like a central authority. Therefore it would only bring little advantages over other traditional databases but a lot of disadvantages instead. (Lönnfält/Sandqvist, p. 50, 2018: [25]) A public blockchain however would enable more transparency.

Property of blockchains	Permissioned blockchain	Permissionless blockchain
Existing trust	High	Low
Secure against cyberattacks	Low	High
Tamper prove	Low	High
Transparent	Low	High
Traceable	Low	High
Easily scaleable	Low	High
Easily implemented privacy	Low	High
Easily implemented changes	Low	High
Cost of transactions	Low	High
Consensus power	High (Single authority)	Low (fully distributed)

Table 2: Comparison of properties in permissioned and permissionless blockchains

Source: Blockchains, the New Fashion in Supply Chains? (Lönnfält/Sandqvist, p. 50, 2018: [25])

Therefore, a permissionless blockchain based system would be more appropriate. Unfortunately, for this sort of implementation trust is required from all parties. All manufacturers would have to join the same system and share information that is currently kept confidential. Already existing systems offer many advantages. Lower costs, faster settling periods to fulfill contracts and fewer disputes between parties. (Jones, 2017: [31])

There is no turn-key solution to a blockchain based supply chain system yet. Due to the technologies possible impact on the supply chain strategies many investors and governments spend a lot of money in these research projects in hope of funding the next big technological breakthrough. *"The European Commission reported that it launched the EU Blockchain Observatory and Forum to further promote the awareness and engagement of blockchain technologies throughout European industries."*
(World Health Organisation, 2015, [6]) Are these false hopes or are future regulations in construction? Only time will tell, whether those regulation will solve issues regarding the lack of digitalization, trust and ownership of the system and its code.

3 Supply Chain Traceability Concept

The supply chain traceability concept developed for this thesis focuses on creating a fully transparent system for forward and backtracking data from every point within the supply chain.

3.1 Example Traceability Concept

This section explains an example product flow to showcase the traceability system. It describes a miniature flow of products from a single part to a vehicle and all information that will be stored to ensure its traceability.

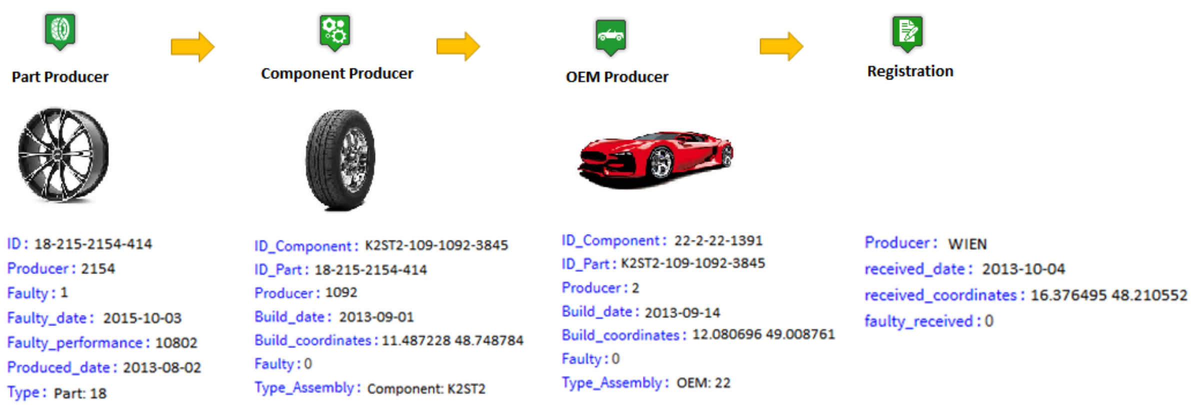


Fig. 14: Traceability system example: vehicle manufacturing

Source: own image

A product within this supply chain is built out of one part which is then integrated within two bigger objects. The part itself is manufactured within a “Part”-factory. This part has an ID and other information which is being tracked over its entire life time. After its creation it is shipped to a “Component”-factory where it gets integrated within another object. This so called “Component” gets a new ID. However from this ID all previous information are retrievable as well. With the new ID other information about the new component will be stored as well. From this factory the component is shipped to its final factory. The so called “OEM”-factory. Here the component is included into another object again. For the automotive industry this would now be the final car. The new produced car gets a new ID with again other information as well. After its final completion the car is ready-to-deliver and is send to its client.
Due to time and space limitations this concept is limited to these three intermediate stages. By design this concept is extendable to supply chains of realistic complexity.

3.2 Architecture and Infrastructure

This concept is uses R and SQLite, open source languages which are free of charge. The blockchain itself is a simple permissionless implementation in R by Johannes Mueller (Mueller, : [39]). For production use a different blockchain can be chosen.

As explained in section 2.3.2 there are multiple ways to implement a blockchain within a supply chain. Different implementations offer different advantages. In order to offer a free selection of the blockchain type this concept is not limited to any type of blockchain. The data stored on the blockchain could be decrypted by hashes 2.2.1 only accessible to a few selected producers or the blockchain could be only accessible to a selected amount of producers in first place.

For efficiency, the blockchain data is mirrored on each local node in a relational database. For the puproses of this thesis, SQLite is used, but any SQL engine can be substituted. The user interface is based on the R package Shiny.

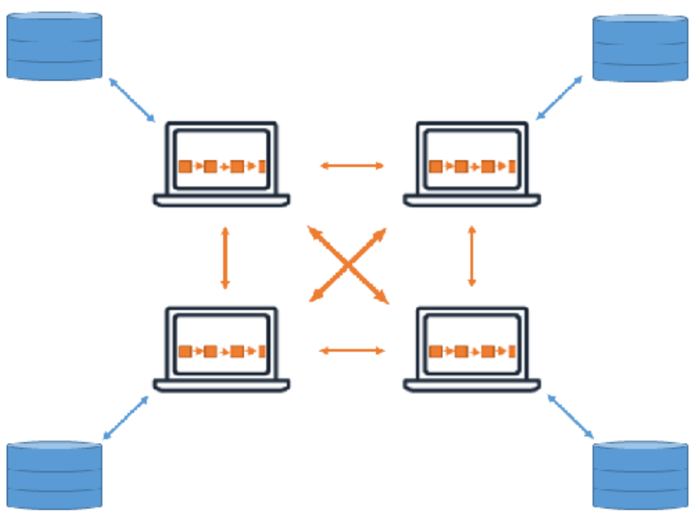


Fig. 15: Blockchain Based Architecture

Source: own image

Data consistency is ensured across nodes, due to the consensus algorithm deployed within the peer-to-peer network, and entrust access rights to the blockchain implementation. This plays to the strengths of the blockchain architecture for supply chains, as described in the previous section 3.2. Because of limitations in the performance, in particular around transaction speed and space efficiency, the data is mirrored on each node in a traditional relational database. Essentially, the blockchain is used as a distributed write-ahead log to implement trusted, tamper-proof data exchange on top of SQLite. This allows to leverage the performance of a relational SQL databases while using a blockchain as source of truth and data transport protocol.

This blockchain is a first draft implementation and does not contain the peer-to-peer networking necessary to distribute the data across a network, but could easily be switched for, e.g. Etherium, or another production-ready blockchain implementation.

To proof the transparency of this blockchain all data within this concept is currently completely unencrypted and visible to all users. Every user has access to the “Blockchain-Tab” 16 and can view the amount of blocks appended as well as the last block.

To limit the issues due to the oracle problem 2.2.1 this concept offers an easy to use user interface. This should limit the wrongly inserted information.

The architecture of this implementation is show in Figure 17.

Blockchain Architecture The architecture of the blockchain and its blocks is created with the assumption that within this supply chain all producers agreed on the following block types:

- Standard block,
- Sent block,
- Received block,
- Assembly block,

as well as a genesis block of the form as shown in Figure 18.

The different types of blocks represent the state of each step within the supply chain, and could of course be extended to model more complex work flows. The entire chain is implemented as a list of lists. Where each block is a list of attributes. Example blocks with filled in data would look like Figure 40

One supply chain blockchain list is attached within the appendix.

To make the transfer of block data into the database as simple as possible the SQL query is already stored in the block itself. Thus, loading a block in a database only requires to call one SQL query. Within the following section the schema of the database that captures the blockchain semantics is described.

Schema of the Database The schema of the database is dependent on the data within the blockchain. In our case the database has three tables: Part, Assembly and Transport 3

A part producer inserts its data into a “Standard-block” which corresponds to entries in the part table once synchronized. When sending an object from factory A to another factory B, the sender at A creates a “Sent-block” with their producer ID, date and their coordinates. Once synchronized this creates a row within the transport table.

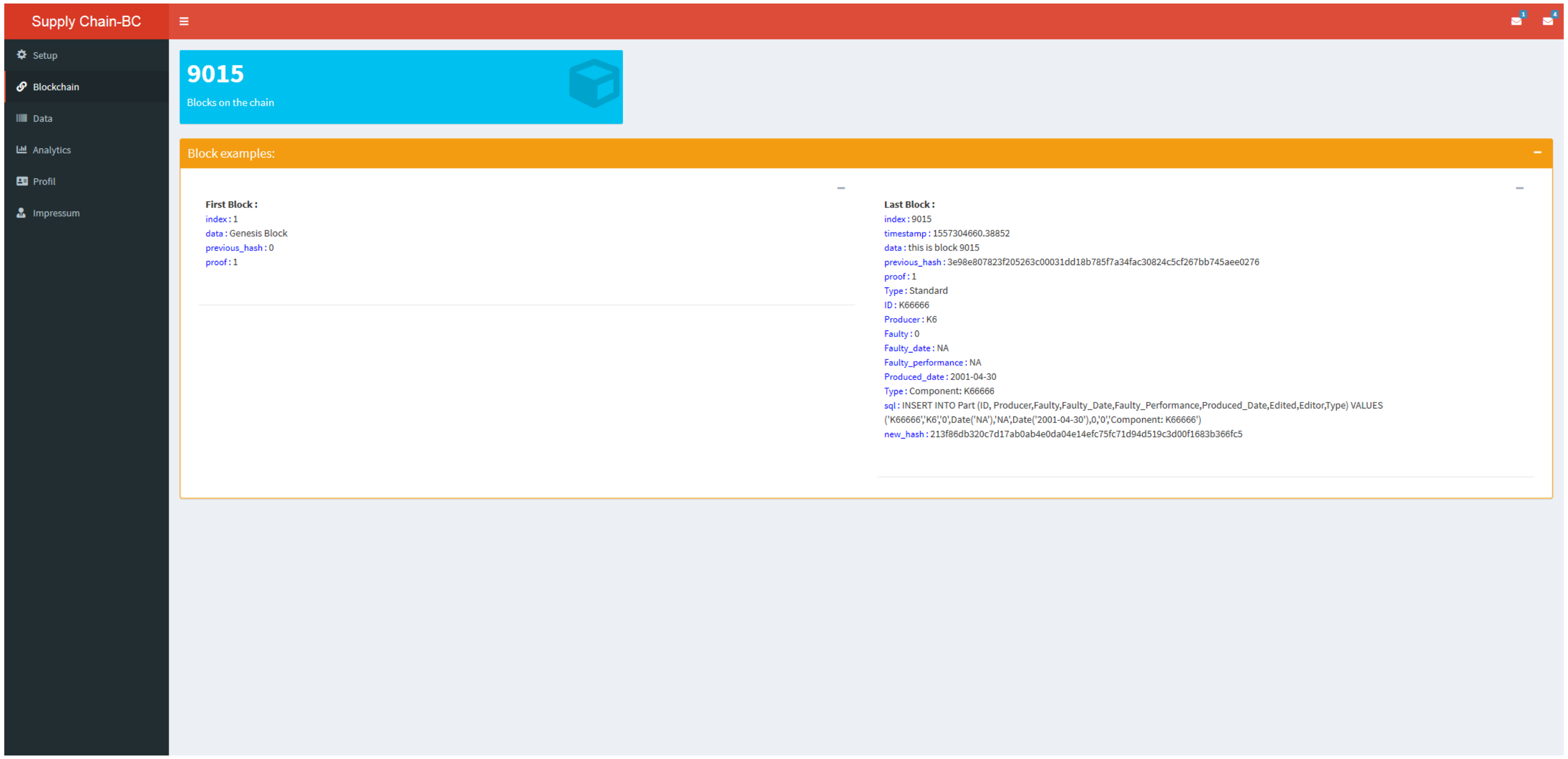


Fig. 16: Blockchain Tab

Source: own image

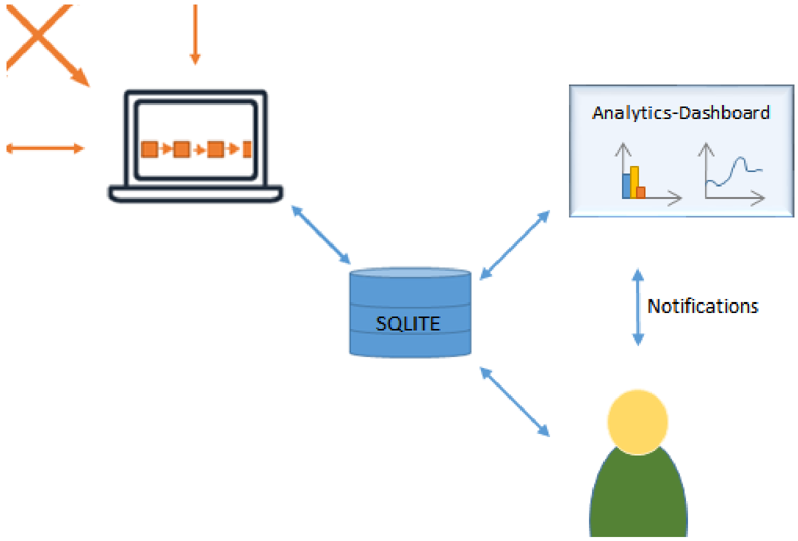


Fig. 17: Architecture of this concept

Source: own image

First Block :
index : 1
data : Genesis Block
previous_hash : 0
proof : 1

Fig. 18: Blockchain genesis block

Source: own image

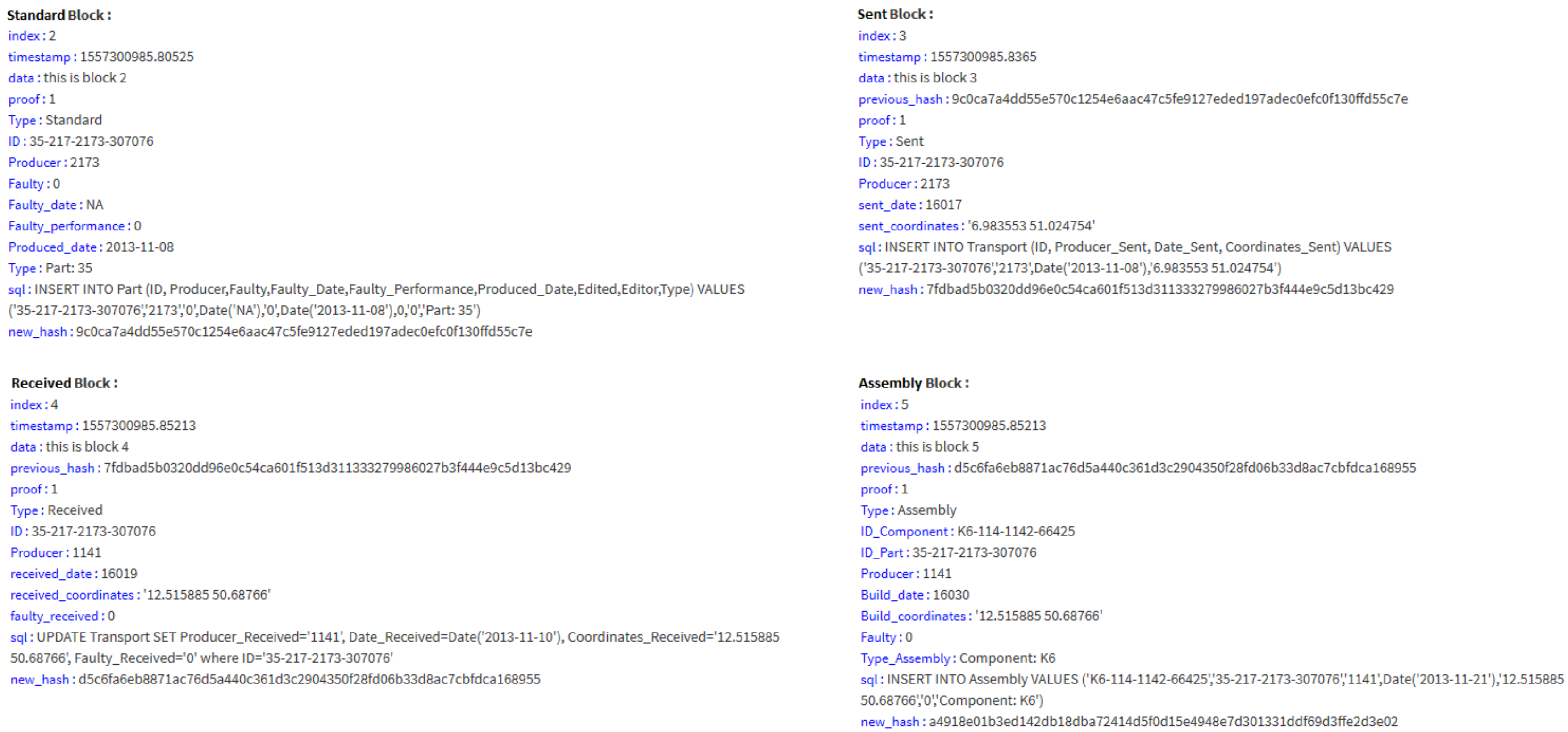


Fig. 19: Blockchain block types

Source: own image

Part	Assembly	Transport
ID Text	ID_Assembly Text	ID Text
Producer Text	ID_Part Text	Producer_Sent Text
Faulty Text	Producer Text	Producer_Received Text
Faulty_Date Date	Build_Date Date	Date_Sent Date
Faulty_Performance Text	Build_Coordinates Text	Date_Received Date
Produced_Date Date	Faulty Text	Coordinates_Sent Text
Edited Integer	Type_Assembly Text	Coordinates_Received Text
Editor Text		Faulty_Received Integer
Type Text		

Table 3: Database structure

Source: own image

As B receives the object, B creates a new "Received-block" with their ID, date, coordinates, and whether the object is still intact or faulty. This block would create an update function within the database and insert this data to the correct row within the transport table.

When assembling single parts together, a producer creates an "Assembly-block" and inserts the part ID, the new assembly ID and again a few other information. An "Assembly-block" triggers a new row within the assembly table.

For the explained supply chain simulated within this concept, figure 14 one vehicle would require nine blocks from a part producer to the final registration office. Figure 21 displays those necessary nine blocks. This trivial vehicle only contains 3 parts and is only shipped three times. However the amount of data it creates has to be logged and managed for analysis and possible recalls. The route of transportation for this specific example is displayed within figure 20.

3.3 Shiny-App

This application helps analyzing data from this blockchain based supply chain concept. From a given blockchain a database is created and from this data multiple tools are available depending on the user type.

The app is categorized into several tabs:

- Overview of the provided blockchain

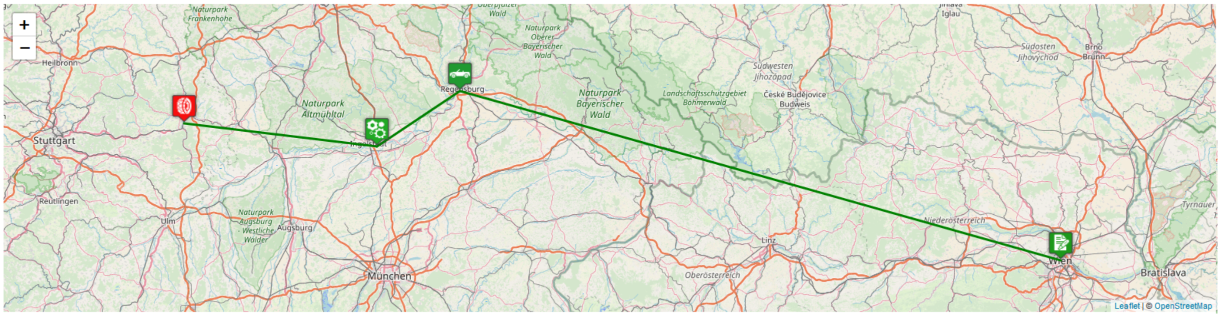


Fig. 20: Map of blockchain supply chain example

Source: own image

- Overview of the database tables
- Analyze Data of:
  - Own production
  - Suppliers
  - Shipments
- Own Profile
- Impressum

The "Blockchain-tab" 16 provides an overview of the provided blockchain and the "Database-tab" all tables extracted from the blockchain.
The "Analyzation-tab" is slightly different for all three types of users to show some examples of usage:

- OEM manufacturers can take a look at the entire supply chain of multiple vehicles 22 for which the final assembly takes place at their factory.
- Component manufacturers can examine all suppliers on a map 24.

The colors of icons depend on the amount of faulty products a manufacturer has produced. In this case if their faulty rate is above null their icon appears red. Are all produced products still functioning, is the icon green.
The line color depends on the transportation process. Is the shipped item still in tact after arriving at its destination so is the line between icons green. Are there faulty items so appears a red line.

Other functionalities provided for all users are the "Own production" tab as well as the "Shipment" tab. Boxes display the amount of faulty build and faulty shipped products. Additionally the destination where those faulty items are shipped are displayed. This enables producers to take action and inform their business partners.

Type : Standard
ID : 18-215-2154-414
Producer : 2154
Faulty : 1
Faulty_date : 2015-10-03
Faulty_performance : 10802
Produced_date : 2013-08-02
Type : Part: 18

Type : Sent
ID : 18-215-2154-414
Producer : 2154
sent_date : 2013-08-02
sent_coordinates : 10.104846 48.856811

Type : Received
ID : 18-215-2154-414
Producer : 1092
received_date : 2013-08-02
received_coordinates : 11.487228 48.748784
faulty_received : 0

Type : Assembly
ID_Component : K2ST2-109-1092-3845
ID_Part : 18-215-2154-414
Producer : 1092
Build_date : 2013-09-01
Build_coordinates : 11.487228 48.748784
Faulty : 0
Type_Assembly : Component: K2ST2

Type : Sent
ID : K2ST2-109-1092-3845
Producer : 1092
sent_date : 2013-09-01
sent_coordinates : 11.487228 48.748784

Type : Received
ID : K2ST2-109-1092-3845
Producer : 2
received_date : 2013-09-14
received_coordinates : 12.080696 49.008761
faulty_received : 0

Type : Assembly
ID_Component : 22-2-22-1391
ID_Part : K2ST2-109-1092-3845
Producer : 2
Build_date : 2013-09-14
Build_coordinates : 12.080696 49.008761
Faulty : 0
Type_Assembly : OEM: 22

Type : Sent
ID : 22-2-22-1391
Producer : 2
sent_date : 2013-10-01
sent_coordinates : 12.080696 49.008761

Type : Received
ID : 0
Producer : WIEN
received_date : 2013-10-04
received_coordinates : 16.376495 48.210552
faulty_received : 0

Fig. 21: Blockchain supply chain example

Source: own image

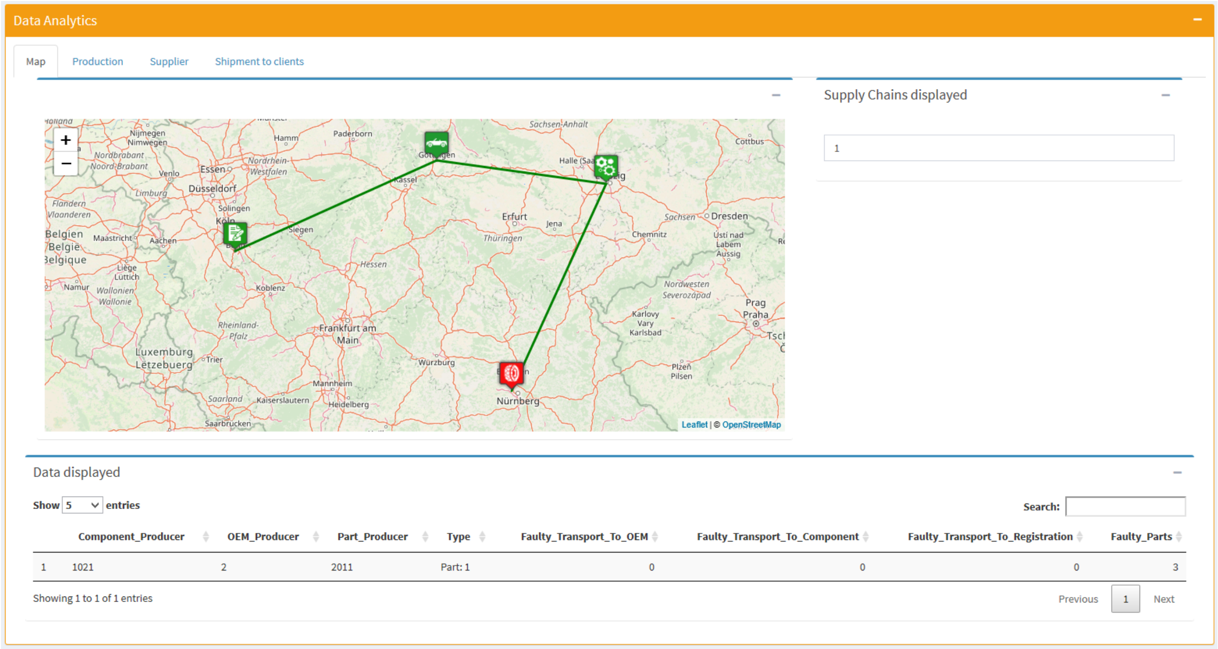


Fig. 22: Map analysis of backtracking one vehicle

Source: own image

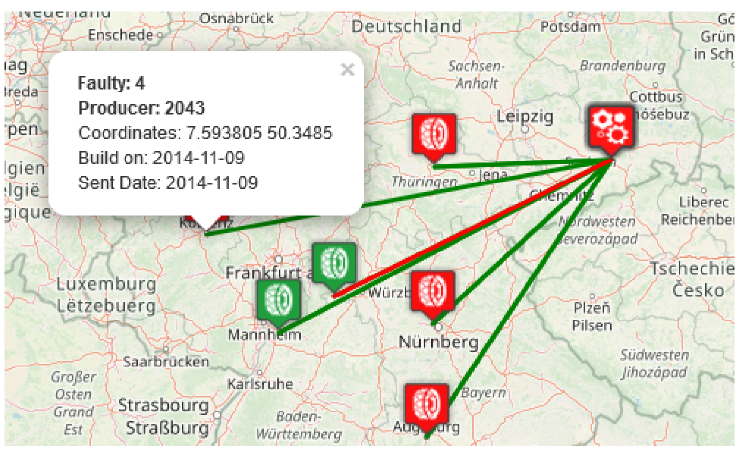
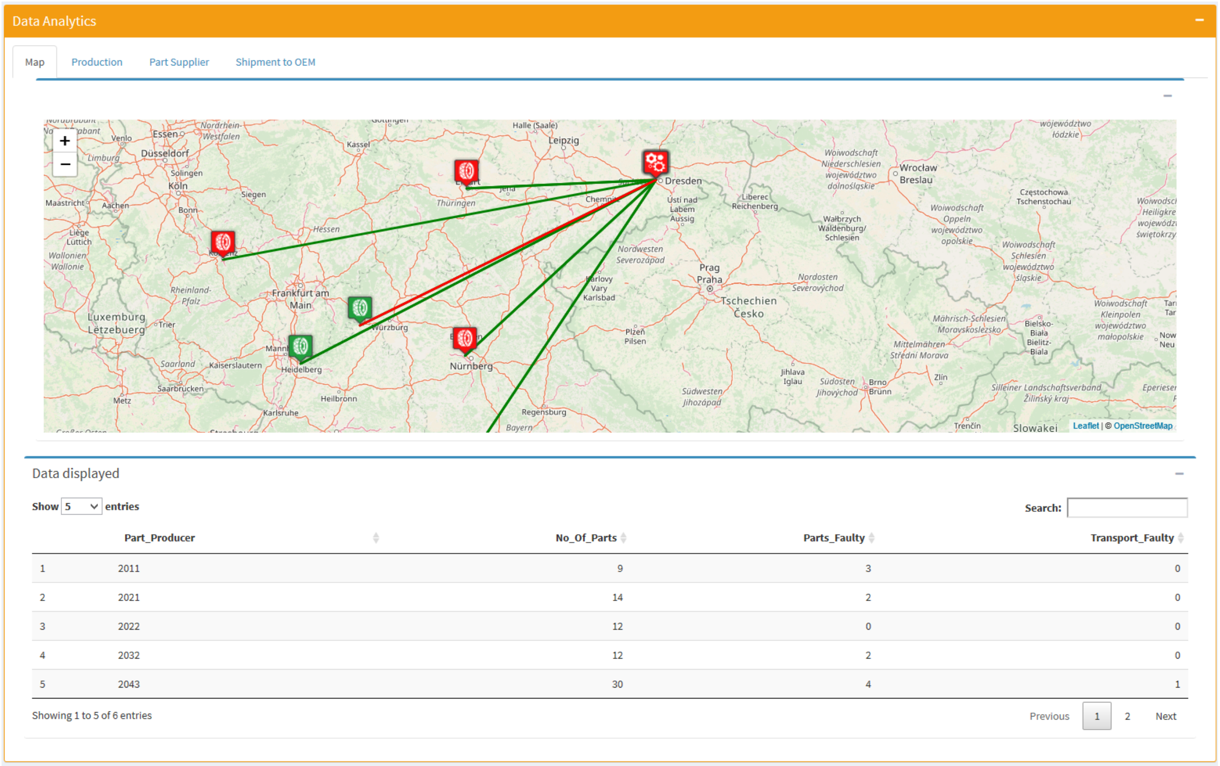


Fig. 23: Map analysis of part suppliers of component producer

Source: own image



	Part_Producer	No_Of_Parts	Parts_Faulty	Transport_Faulty
1	2011	9	3	0
2	2021	14	2	0
3	2022	12	0	0
4	2032	12	2	0
5	2043	30	4	1

Fig. 24: Backtracking supplied parts

Source: own image

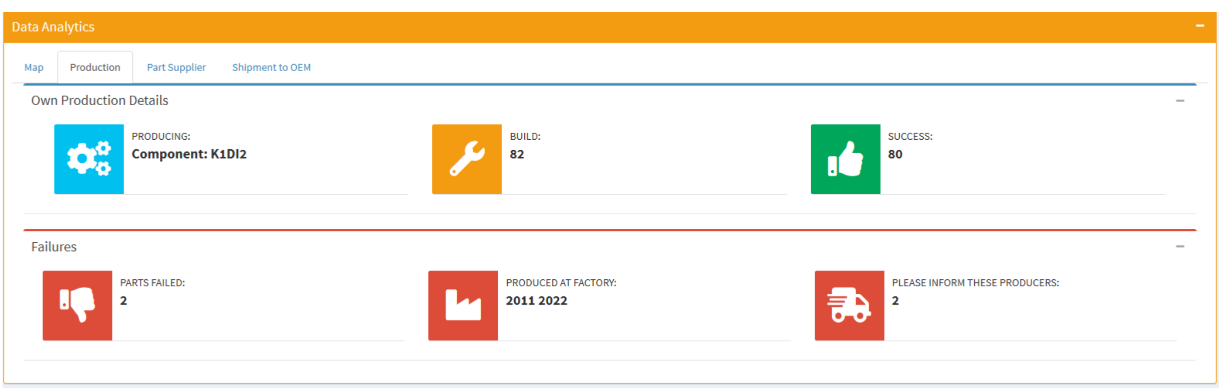


Fig. 25: Analysis of own component production

Source: own image

3.4 Evaluating the Concept

This blockchain-based traceability concept tackles the primary challenges transparency, traceability, and trust. Trust between many different suppliers can be established by agreeing on one blockchain architecture. By doing that an immediate improvement of data quality is archived.

Transparency and traceability is managed by committing blocks onto the blockchain, with all necessary information available to all participants. Hence the risk of failure within the supply chain can be lowered and a higher product quality can be raised due to an improved transport system and its security.

The costs for developing a fully functional version of a blockchain based supply chain are a large investment, however the savings on average recall costs and their waste in resources are higher. The high costs can be lowered by using already existing open source software.

Customer have fewer issues with unnecessary recalls and can be ensured their product has a certified history of production. Locating of a single part is handled within a few seconds. Also spotting possible reasons for its failure is manageable by analyzing other shipments of the same type.

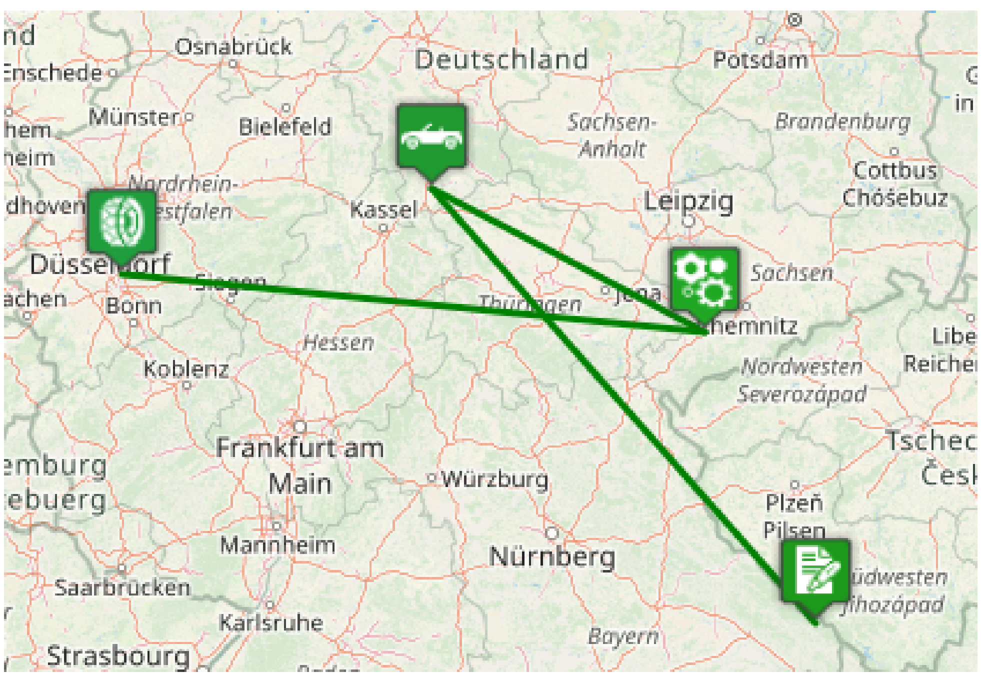


Fig. 26: Supply Chain of a Clients Vehicle

Source: own image

However, a few issues do remain. R itself is not fast enough to handle the amount of calculations needed to support a blockchain and hence a system like this. This can be solved by binding to blockchain library written in a different language. In any case, the tool to interact with a database could be written in R. Therefore all data analysis tools created within this concept could still be used.

Introducing a blockchain based supply chain requires all manufacturers to have access to servers and they need enough data storage to manage their own blocks and their own data. Unfortunately, the digitalization of factories are quite different in the speed of development.
Regardless of their current digitalization state the “Oracle problem” will require even more expenses. Since the tracking of physical objects requires expensive tools to create a bridge between the physical and the digital world.

4 User Manual

This User Manual contains all essential information fully use this blockchain technology based supply-chain system. It includes a description of the systems functionalities. Step-by-step procedures will guide through the systems mode of operations.

In order to get started the supply-chain tool requires a blockchain rds and a database sqlite file. The default blockchain contains 9015 blocks of data. The provided database is loaded from those blocks. This guide is based on this default data and hence the type of users and their analytical tools could fail with a wrongly implemented blockchain. A change of blockchain, and therefore the database, is possible and will be described in a further chapter.

```
con <<- DBI::dbConnect(RSQLite::SQLite(),"./mydb_new.sqlite")
blockchain_filename <-  "./DB/blockchain_start.rds"
blockchain <<- readRDS(file=as.character(blockchain_filename))
```

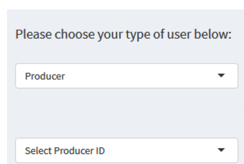


Fig. 27: User login

Source: own image

This tool starts with the user selection. 27 There are four different type of users within this concept:

- OEM Manufacturer
- Component Manufacturer
- Part Manufacturer
- Client

With the chosen user come different analytical functionalities which are implemented to show possible data analytical tools. Depending on the loaded blockchain a user producer has to provide its manufacturing number as well. The drop down menu offers several options. After the successful authentication the menu bar appears:

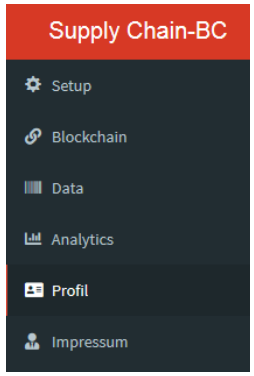


Fig. 28: Sidebar menu

Source: own image

Regardless of the chosen user the blockchain and therefore also the database are containing the same data. Since all users have access to the same blockchain. This is also visible within the "Blockchain" 29 and the "Database" tab 30.

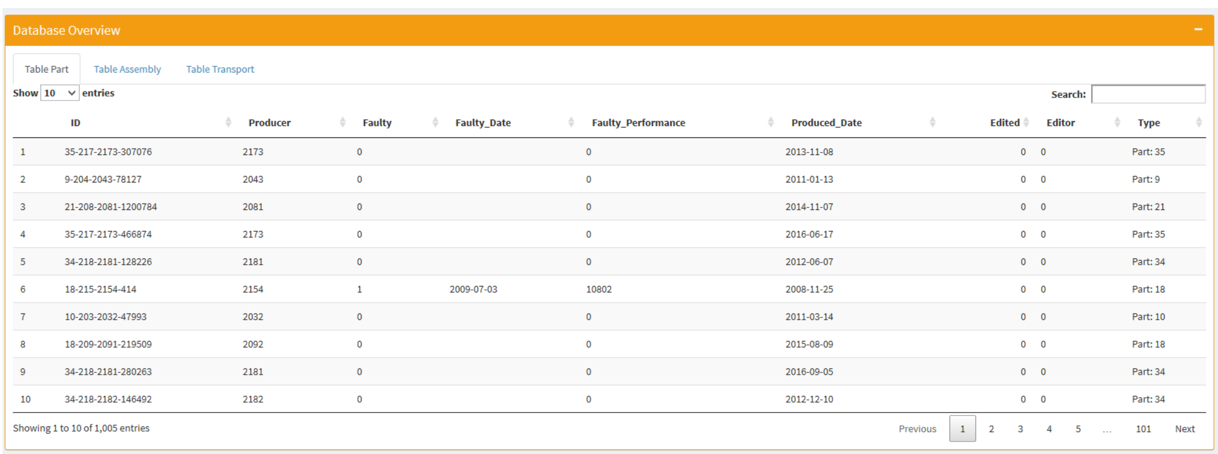

Database Overview

Table Part | Table Assembly | Table Transport

Show 10 entries

Search:

	ID	Producer	Faulty	Faulty_Date	Faulty_Performance	Produced_Date	Edited	Editor	Type
1	35-217-2173-307076	2173	0		0	2013-11-08	0	0	Part: 35
2	9-204-2043-78127	2043	0		0	2011-01-13	0	0	Part: 9
3	21-208-2081-1200784	2081	0		0	2014-11-07	0	0	Part: 21
4	35-217-2173-466874	2173	0		0	2016-06-17	0	0	Part: 35
5	34-218-2181-128226	2181	0		0	2012-06-07	0	0	Part: 34
6	18-215-2154-414	2154	1	2009-07-03	10802	2008-11-25	0	0	Part: 18
7	10-203-2032-47993	2032	0		0	2011-03-14	0	0	Part: 10
8	18-209-2091-219509	2092	0		0	2015-08-09	0	0	Part: 18
9	34-218-2181-280263	2181	0		0	2016-09-05	0	0	Part: 34
10	34-218-2182-146492	2182	0		0	2012-12-10	0	0	Part: 34

Showing 1 to 10 of 1,005 entries

Previous 1 2 3 4 5 … 101 Next

Fig. 30: Database overview

Source: own image

Another informative page is the "Profile Tab" figure 31. Here is all necessary information about the chosen user displayed. Additional fun facts like the amount of different blocks created in the name of this producer is shown.

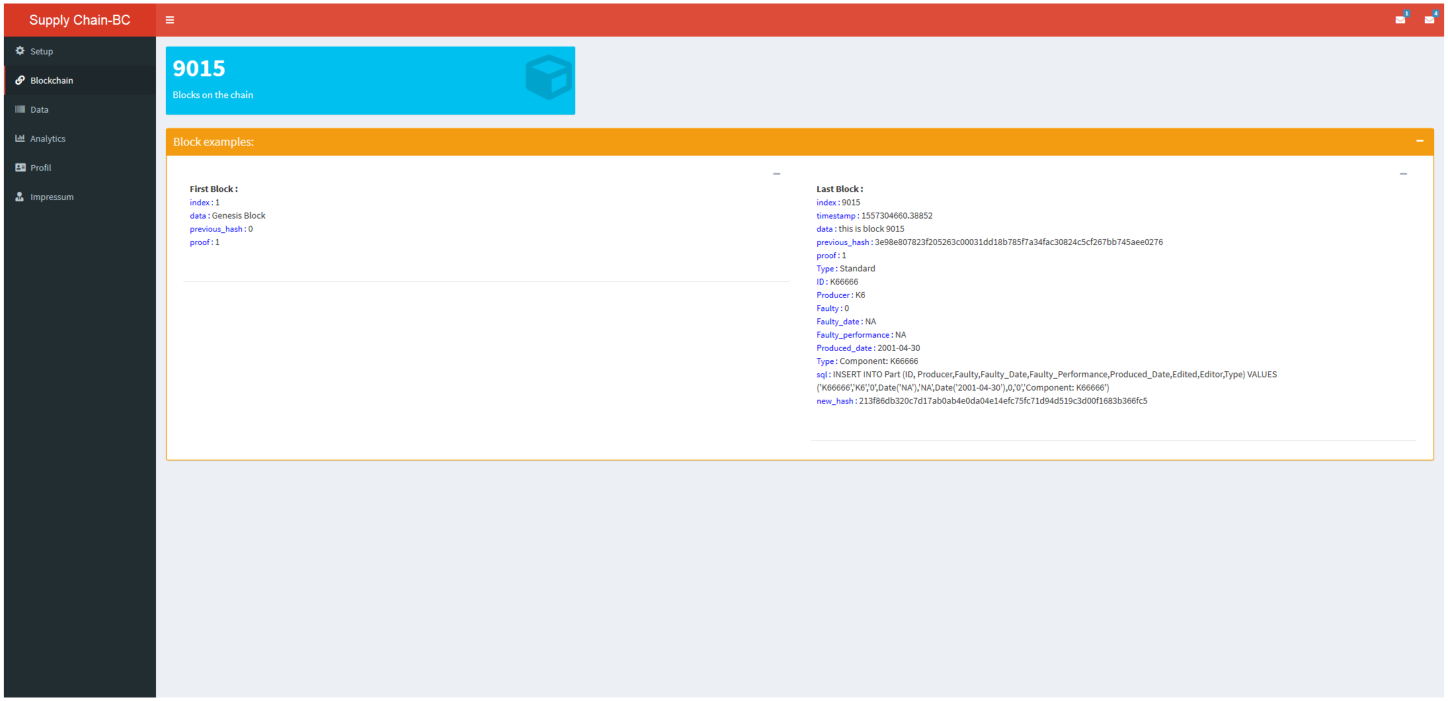


Fig. 29: Blockchain setup

Source: own image

4.1 Different User Types

User: OEM Manufacturer

This user has the most functionalities in terms of analyzing data of parts supplied by other manufacturers. For an OEM Manufacturer it is really important to be able to forward and backtrack all parts included within a vehicle. Parts that are already marked as faulty should not be included within a new car.
A visualization of supply chains to the OEM manufacturer is created within the "Map" tab figure 32. It offers the possibility to display a selected amount of supply chains. The origin of each single part is visualized as well as their faultiness. If a part turned out to be faulty the icon would be red as displayed in 32.

As OEM manufacturer, the last instance before delivering the product to the client all steps possible should be taken to ensure a safe product.
Therefore a traceable system is required. With this tool the suppliers can be easily analyzed. Based on that data the own production can be highly influenced. Hence there is an own production tab, figure 33, available to warn about faulty parts build in an own product.

In order to take a closer look at the suppliers and who is actually sending faulty products the "Supplier" tab can help, figure 34. There are multiple charts displaying numbers of products produced at part manufacturers as well as delivery times. To take a closer look at specific manufacturers a sign on the right side displays who is supplied with faulty products.

To guarantee perfect functional products produced by the own manufacture there must also be a warning if a faulty product leaves the own factory. Hence the "Shipment to client" tab, figure 35, provides information about the numbers of faulty products produced and where they are getting shipped of to. Due to this notification quick actions can be taken to ensure the clients safety.

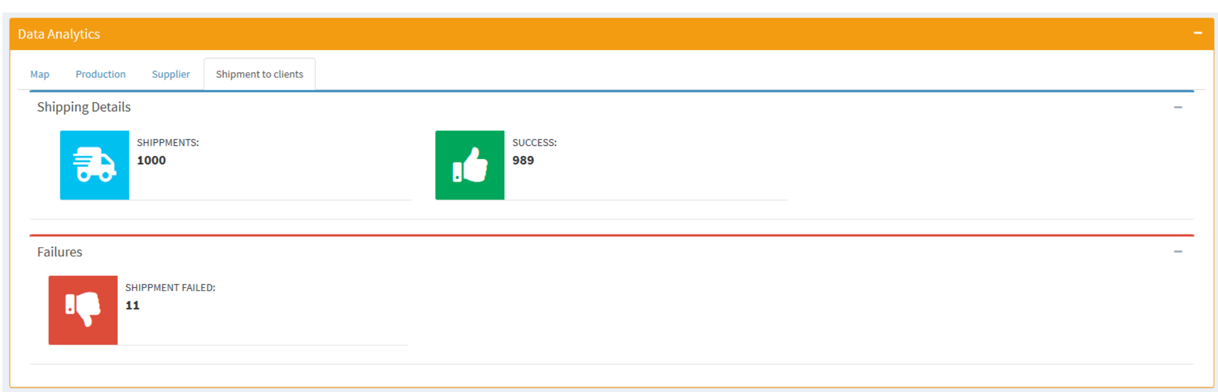


Fig. 35: Shipments to clients from OEM producer

Source: own image

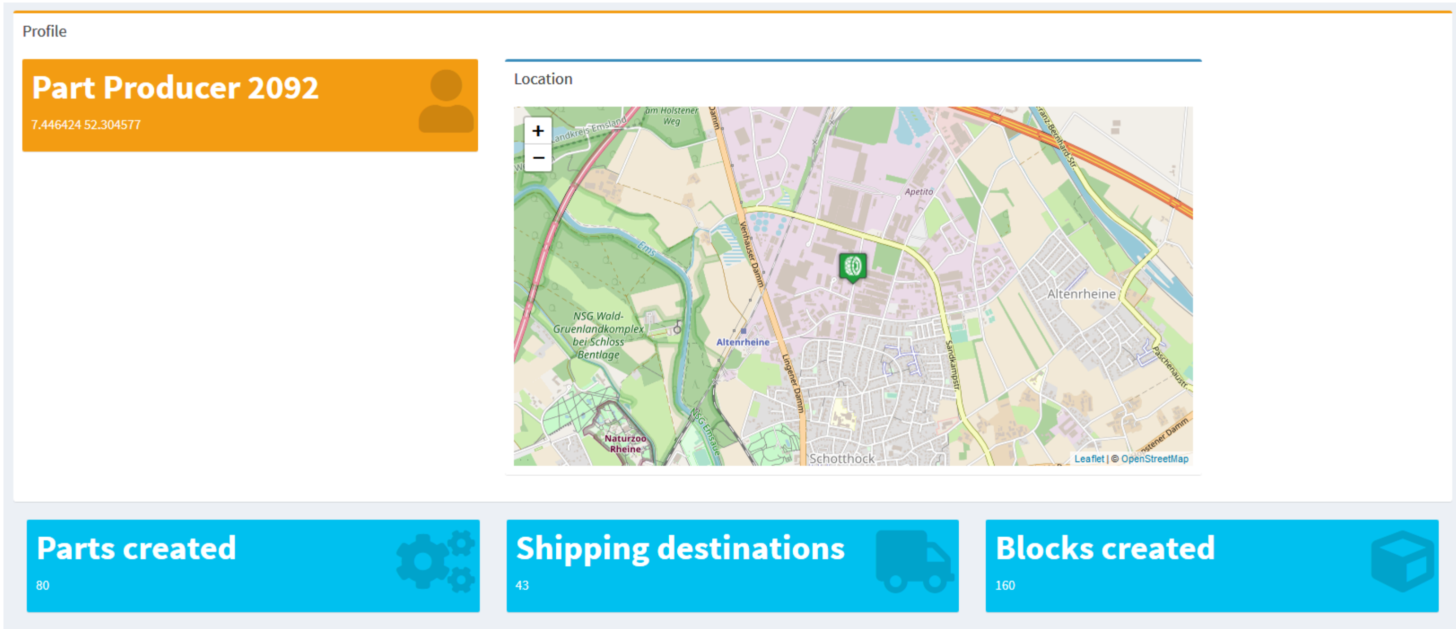


Fig. 31: Profile tab

Source: own image

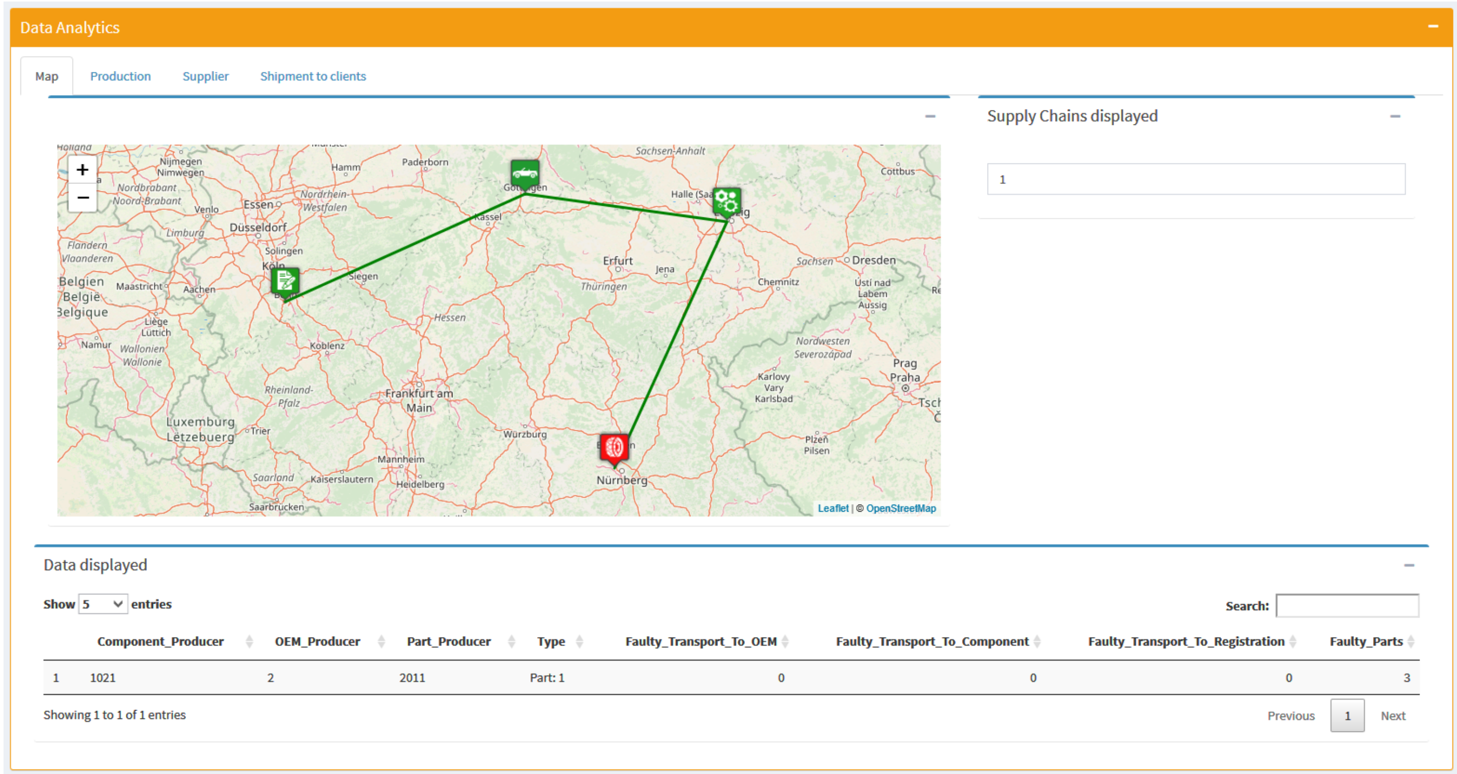


Fig. 32: Map of multiple supply chains of OEM producer

Source: own image

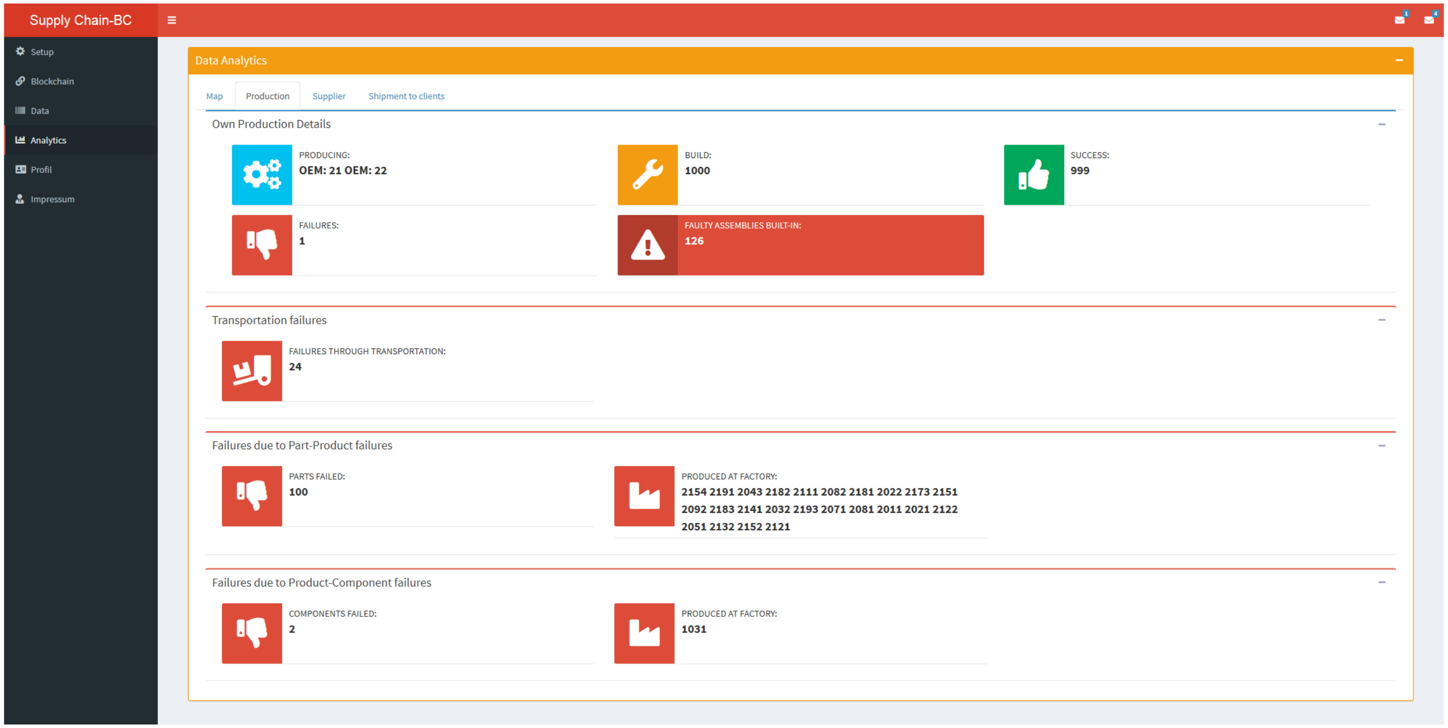


Fig. 33: Analyzing own Production of OEM producer

Source: own image

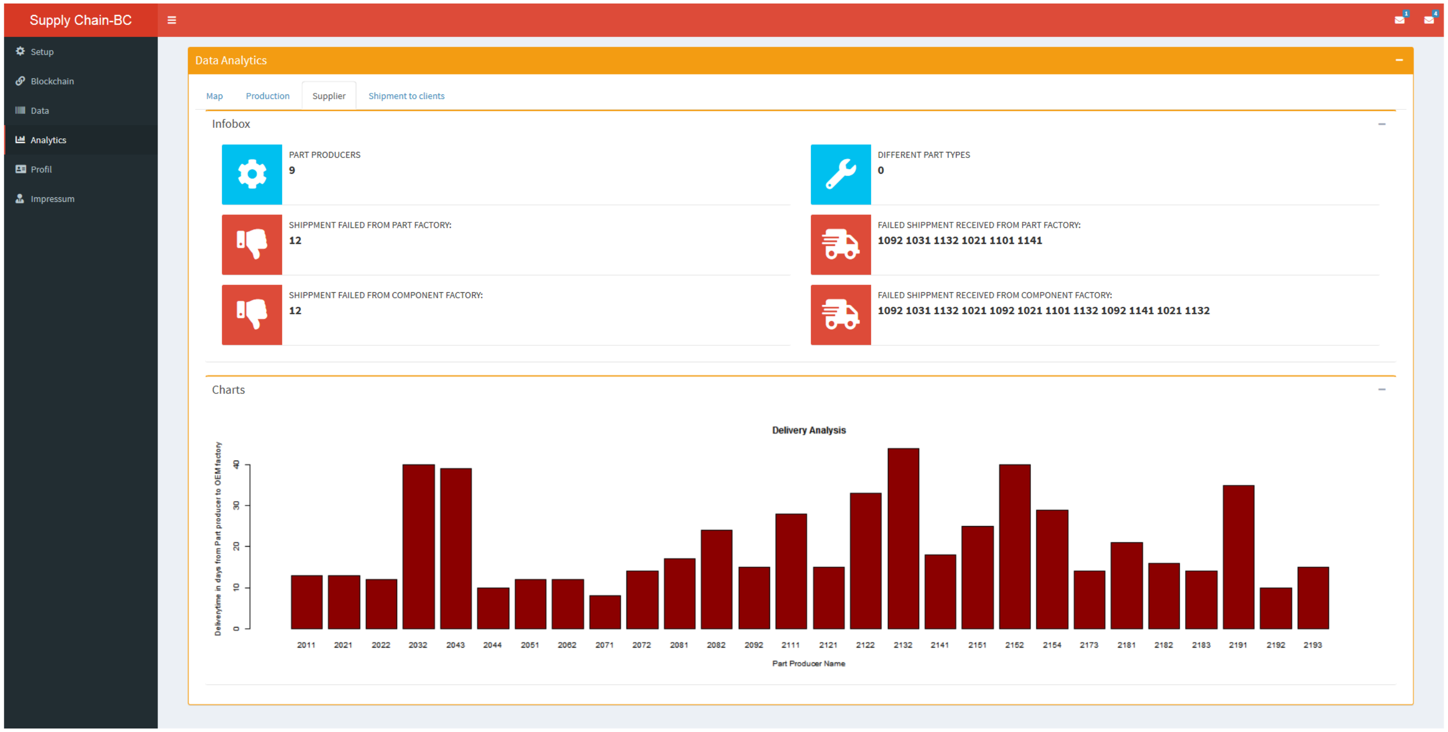


Fig. 34: Analyzing faulty imports of OEM producer

Source: own image

User: Component Manufacturer

The component manufacturer has multiple tabs as well. On his first analytical tab is a map 36, displaying all his suppliers. The icon color depends on the faulty parts each supplier transports taught the component manufacturer. And each line color shows whether the component producer received faulty parts due to lack of caution during its transportation.

An additional analysation of all incoming parts is shown in the third tab 37. It shows multiple charts with all part types this component producer receives. As well as an analysis of faulty parts. Since some part producers are more likely to produce working parts than other.

Just like the OEM manufacturer the component producer has to ensure quality in his own products as well. Hence the "Own production" tab, figure 38, displays again an overview of how many faulty parts are getting produced and where some have been delivered to.

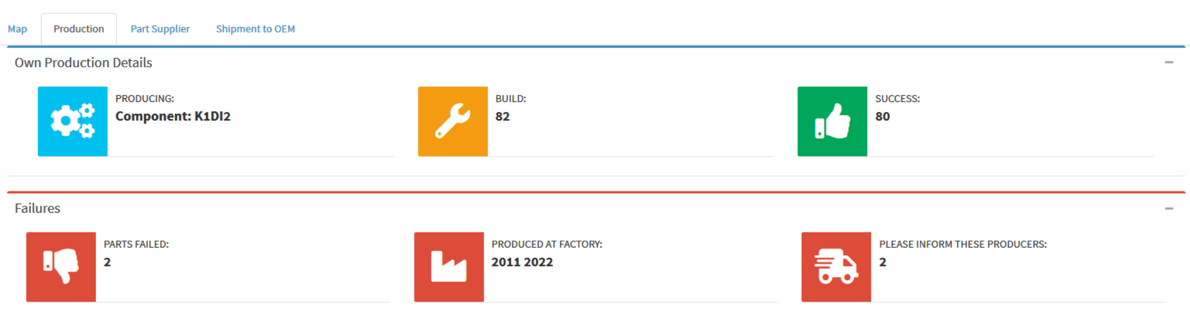


Fig. 38: Analysis of own production of component producer

Source: own image

A save delivery has to be ensured as well. Therefore provides the "Shipment to OEM" tab, figure 39, an overview of the current statistics. Also an number of faulty shipments are displayed as well as where they have been sent off to.

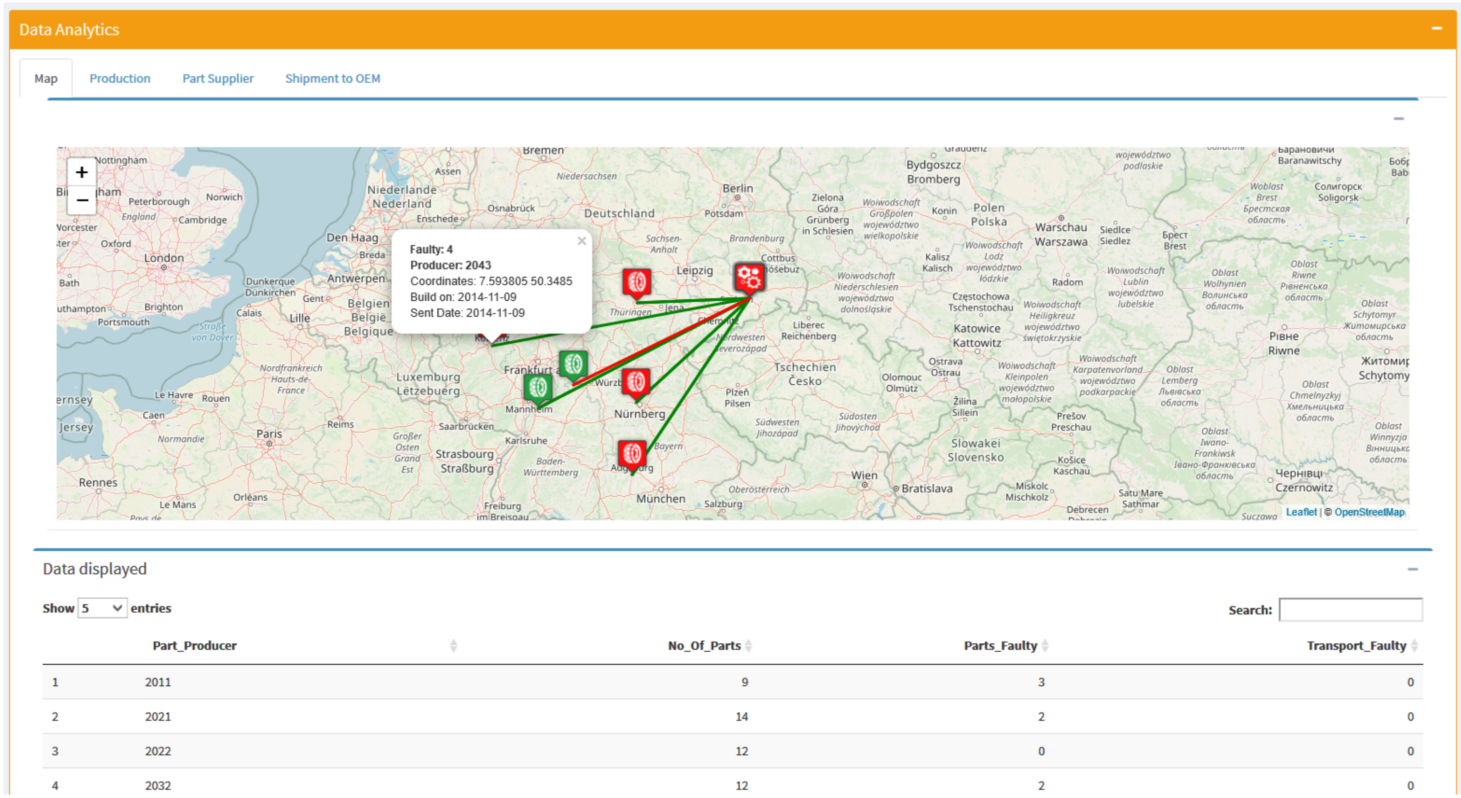


Fig. 36: Map analysis of part suppliers of component producer

Source: own image

Fig. 37: Analysis of part suppliers of component producer

Source: own image

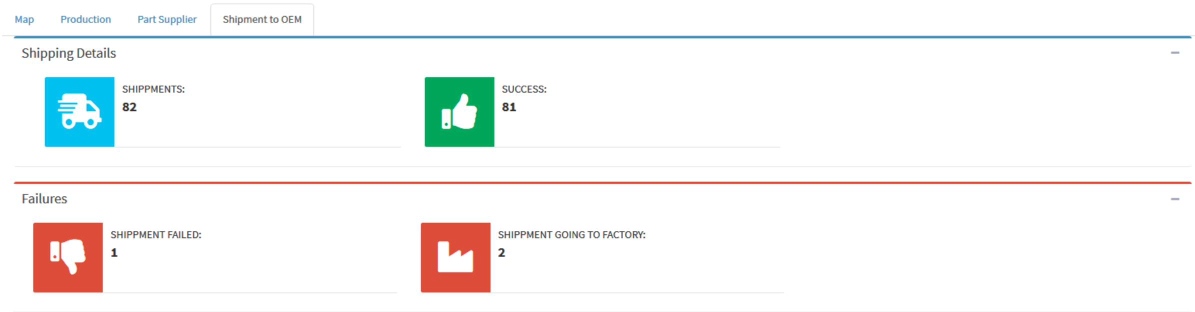


Fig. 39: Analysis of shipments to OEM producers

Source: own image

User: Part Manufacturer

As a part manufacturer the products build have no assemblies build within itself. Hence this is where the initial supply chain starts. The analysation tools are therefore mainly build to take a closer look at the own production and to forward track the parts produced.

The tab of "Own production" figure 40, shows how many part have been build and the faulty rate. Again it is also displayed where those faulty parts are getting shipped to.

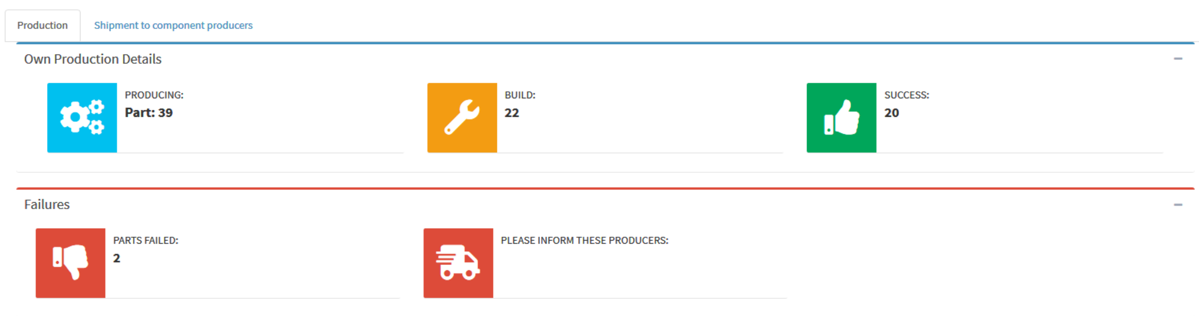


Fig. 40: Analysis of produced parts of part producer

Source: own image

Since shipments are likely to destroy parts the "Shipment to Component" tab 41 takes a closer look at those faulty shipments in oder to reduce useless costs.

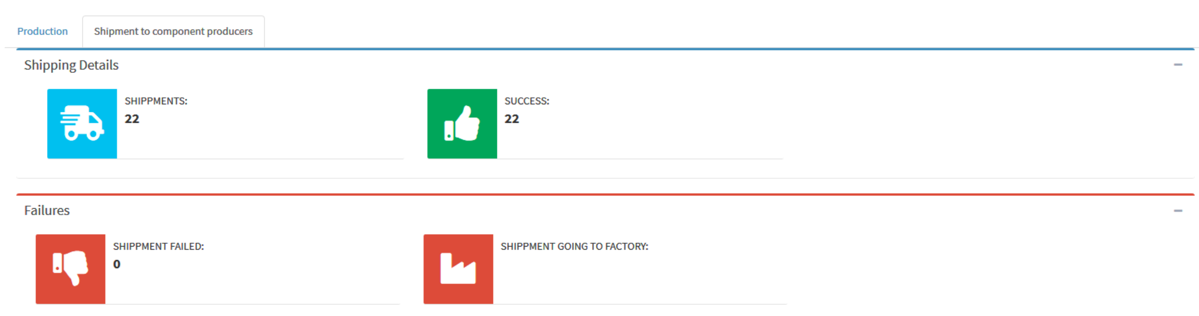


Fig. 41: Analysis of shipments from a part producer

Source: own image

User: Client

The Client is implemented with restricted access to the blockchain and the database. Theoretically this could also be completely transparent, however this version should be satisfying to ensure safe parts within the clients vehicle.

With a given vehicle number the client can now take a look at the supply chain which created this vehicle. This supply chain shows each single producer with either a green or a red icon and the road between those with either a green or a red line. If one single item appears red it would be advisable to visit a repair shop. Since then a part produced at this factory has some sort of malfunctioning.

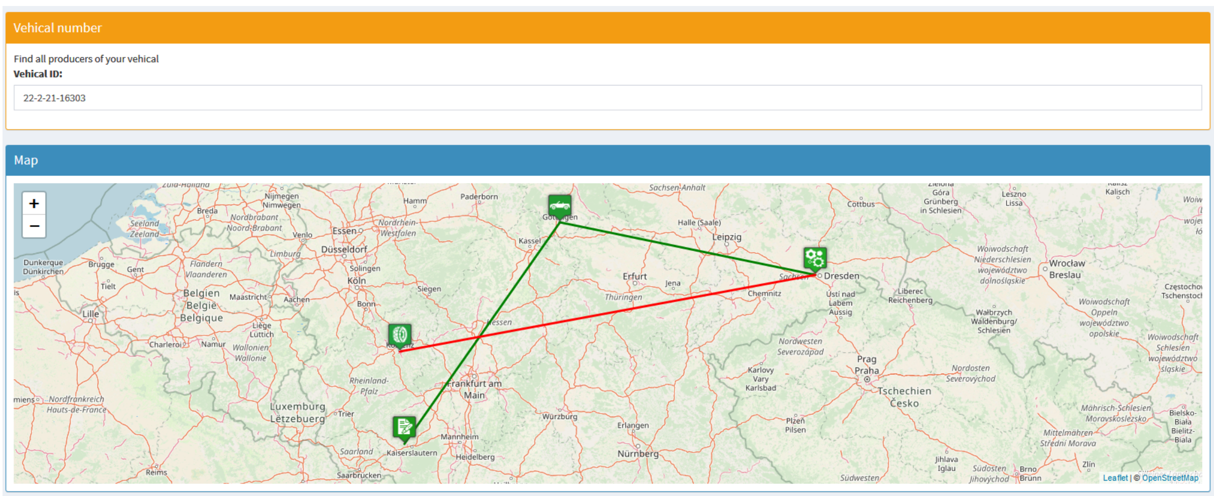


Fig. 42: Supply chain of vehicle

Source: own image

4.2 Different Blockchain

A change of blockchain and hence a change of the entire dataset is possible by changing the first lines within the code. Here the path of the existing “rds” file needs to be inserted. If the blockchain is correctly formated a new database will be created based on the data on the blockchain. This might take a while depending on the size of the file. Once done, all tools are ready to use.

If a blockchain “rds” file as well as the matching database already exists the first lines should be altered to:

```
con <<- DBI::dbConnect(RSQLite::SQLite(),"./mydb_new.sqlite")
```

```
blockchain_filename <-  "./DB/blockchain_start.rds"
blockchain <- readRDS(file=as.character(blockchain_filename))
```

Here a database as well as the blockchain is loaded and used within the program.

If a blockchain "ṙds" file exists but no matching database the first lines should be altered to:

```
con <- DBI::dbConnect(RSQLite::SQLite(),"./mydb_new.sqlite")
new_database(con)


blockchain_filename <-  "./DB/blockchain_start.rds"
blockchain <- readRDS(file=as.character(blockchain_filename))
from_BC_into_DB(con, blockchain)
```

Here a new database is created at the given path "/DB/blockchain_startṙds". The database will contain the following tables: Part, Transport, Assembly. Based on the loaded blockchain the method called "from_BC_into_DB" loads all data from all blocks into the database.

Behind the scene the schema for all three tables are visible. As well as the procedure how each single block is on-boarded onto the blockchain.

```
new_database <- function(con){
    try(dbSendQuery(conn=con,
        "CREATE TABLE Part
                 (ID Text,
                 Producer Text,
                 Faulty Text,
                 Faulty_Date DATE,
                 Faulty_Performance Text,
                 Produced_Date DATE,
                 Edited Integer,
                 Editor Text,
                 Type Text)"
        ))

  try(dbSendQuery(conn=con,
        "CREATE TABLE Transport
                (ID Text,
                Producer_Sent Text,
                Producer_Received Text,
```

```
                Date_Sent DATE,
                Date_Received DATE,
                Coordinates_Sent Text,
                Coordinates_Received Text,
                Faulty_Received Integer)"
        ))

  try(dbSendQuery(conn=con,
        "CREATE TABLE Assembly
                (ID_Assembly Text,
                ID_Part Text,
                Producer Text,
                Build_Date DATE,
                Build_Coordinates Text,
                Faulty Text,
                Type_Assembly Text)"
        ))
}

from_BC_into_DB <- function(con, public_blockchain){
        i=2
        for(i in 2:length(public_blockchain)){
                dbSendQuery(con,public_blockchain[[i]]$sql)
        }
}
```

5 Future Work

The concept presented in this thesis still has some shortcomings and missing features that can be adressed in future work. For one it is not using a production ready blockchain, but a simple implementation in R. Since R is not a very performant language, an implementation in an external library should be used instead. In a future extension Sawtooth or Etherium should be used together with smart contracts instead of this demo implementation.

Additionally, there are a few trust improvements that could ensure more safety. For a more secure data transfer and hence better data quality, the blockchain should include end to end encryption for manufacturers. Furthermore, in the current implementation each producer can publish new blocks. This could be denied by letting each manufacturer sign their blocks with a special key.

Apart from these trust enhancements more features are necessary for implementing this concept in the industry. An additional money transfer service for example could make paying invoices easier.

6 Conclusion

Blockchain technology has the ability to bring supply chain systems into a more modern stage. Blockchains are capable of creating digital ownership certificates, production integration, a more transparent information storage, enhance the current payment system, and lastly guarantee traceability.

A system based on a centralized database or a blockchain based supply chain have both advantages and a which one to favor is debatable. A centralized system could offer almost every aspect blockchain technology is able to offer. Traditional databases are more efficient. An improven payment system could be implemented by paying with Bitcoin or some other cryptocurrency that is faster and more transparent on its current status than a traditional bank. A centralized system could also reduce erroneous orders and lower recalls. Tracking and data analysis would be possible if enterprises would find some technical consensus on what software to use. However this is an issue regardless of the choice of traceability system.

The biggest advantage of blockchain technology is its decentralization (Hochstein, 2018: [24]) and its transparency. Which enables a new way to ensure data quality and traceability. However, running the entire supply chain on a blockchain also brings a couple of difficulties with it. For example, its current inefficiency and lack of throughput. Future improvements such as Proof of Stake, or the option of using a local database as intermediate store as in this thesis, can ameliorate these problems.

The strength of trust within a blockchain based system is always dependent on the number of participants. Currently, only a few companies are stepping forward and start a blockchain implementation within their ecosystem. Being among the first few companies and thereby leading in this new technology is essential for further advancements through digitalization and might lead to a advantage over competitors. But early adopters also have to bear the costs and risks of development in an immature ecosystem. This choice has to be evaluated by each company individually.

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A

Appendix: Blockchain example

```
[[1]]
[[1]]$index
[1] 1

[[1]]$timestamp
NULL

[[1]]$data
[1] "Genesis Block"

[[1]]$previous_hash
[1] "0"

[[1]]$proof
[1] 1



[[2]]
[[2]]$index
[1] 2

[[2]]$timestamp
[1] "2019-05-08 09:36:25 CEST"

[[2]]$data
[1] "this is block 2"

[[2]]$previous_hash
NULL
```

```
[[2]]$proof
[1] 1


[[2]]$Type
[1] "Standard"


[[2]]$ID
[1] "35-217-2173-307076"


[[2]]$Producer
[1] "2173"


[[2]]$Faulty
[1] "0"


[[2]]$Faulty_date
[1] NA


[[2]]$Faulty_performance
[1] "0"


[[2]]$Produced_date
[1] "2013-11-08"


[[2]]$Type
[1] "Part: 35"


[[2]]$sql
[1] "INSERT INTO Part
(ID, Producer,Faulty,Faulty_Date,Faulty_Performance,Produced_Date,Edited,Editor,Type)
VALUES
('35-217-2173-307076','2173','0',Date('NA'),'0',Date('2013-11-08'),0,'0','Part: 35')"
```

```
[[2]]$new_hash
[1] "9c0ca7a4dd55e570c1254e6aac47c5fe9127eded197adec0efc0f130ffd55c7e"


[[3]]
[[3]]$index
[1] 3

[[3]]$timestamp
[1] "2019-05-08 09:36:25 CEST"

[[3]]$data
[1] "this is block 3"

[[3]]$previous_hash
[1] "9c0ca7a4dd55e570c1254e6aac47c5fe9127eded197adec0efc0f130ffd55c7e"

[[3]]$proof
[1] 1

[[3]]$Type
[1] "Sent"

[[3]]$ID
[1] "35-217-2173-307076"

[[3]]$Producer
[1] "2173"

[[3]]$sent_date
[1] "16017"

[[3]]$sent_coordinates
```

```
[1] "'6.983553 51.024754'"


[[3]]$sql
[1] "INSERT INTO Transport
(ID, Producer_Sent, Date_Sent, Coordinates_Sent)
VALUES
 ('35-217-2173-307076','2173',Date('2013-11-08'),'6.983553 51.024754')"


[[3]]$new_hash
[1] "7fdbad5b0320dd96e0c54ca601f513d311333279986027b3f444e9c5d13bc429"



[[4]]
[[4]]$index
[1] 4


[[4]]$timestamp
[1] "2019-05-08 09:36:25 CEST"


[[4]]$data
[1] "this is block 4"


[[4]]$previous_hash
[1] "7fdbad5b0320dd96e0c54ca601f513d311333279986027b3f444e9c5d13bc429"


[[4]]$proof
[1] 1


[[4]]$Type
[1] "Received"


[[4]]$ID
[1] "35-217-2173-307076"
```

```
[[4]]$Producer
[1] "1141"

[[4]]$received_date
[1] "16019"

[[4]]$received_coordinates
[1] "'12.515885 50.68766'"

[[4]]$faulty_received
[1] "0"

[[4]]$sql
[1] "UPDATE Transport
SET Producer_Received='1141',
Date_Received=Date('2013-11-10'),
Coordinates_Received='12.515885 50.68766',
Faulty_Received='0'
where
ID='35-217-2173-307076'"

[[4]]$new_hash
[1] "d5c6fa6eb8871ac76d5a440c361d3c2904350f28fd06b33d8ac7cbfdca168955"


[[5]]
[[5]]$index
[1] 5

[[5]]$timestamp
[1] "2019-05-08 09:36:25 CEST"
```

```
[[5]]$data
[1] "this is block 5"


[[5]]$previous_hash
[1] "d5c6fa6eb8871ac76d5a440c361d3c2904350f28fd06b33d8ac7cbfdca168955"


[[5]]$proof
[1] 1


[[5]]$Type
[1] "Assembly"


[[5]]$ID_Component
[1] "K6-114-1142-66425"


[[5]]$ID_Part
[1] "35-217-2173-307076"


[[5]]$Producer
[1] "1141"


[[5]]$Build_date
[1] "16030"


[[5]]$Build_coordinates
[1] "'12.515885 50.68766'"


[[5]]$Faulty
[1] "0"


[[5]]$Type_Assembly
[1] "Component: K6"
```

```
[[5]]$sql
[1] "INSERT INTO Assembly
VALUES
('K6-114-1142-66425','35-217-2173-307076','1141',Date('2013-11-21'),
'12.515885 50.68766','0','Component: K6')"

[[5]]$new_hash
[1] "a4918e01b3ed142db18dba72414d5f0d15e4948e7d301331ddf69d3ffe2d3e02"



[[6]]
[[6]]$index
[1] 6

[[6]]$timestamp
[1] "2019-05-08 09:36:25 CEST"

[[6]]$data
[1] "this is block 6"

[[6]]$previous_hash
[1] "a4918e01b3ed142db18dba72414d5f0d15e4948e7d301331ddf69d3ffe2d3e02"

[[6]]$proof
[1] 1

[[6]]$Type
[1] "Sent"

[[6]]$ID
[1] "K6-114-1142-66425"

[[6]]$Producer
```

```
[1] "1141"


[[6]]$sent_date
[1] "16030"


[[6]]$sent_coordinates
[1] "'12.515885 50.68766'"


[[6]]$sql
[1] "INSERT INTO Transport
(ID, Producer_Sent, Date_Sent, Coordinates_Sent)
VALUES
('K6-114-1142-66425','1141',Date('2013-11-21'),'12.515885 50.68766')"


[[6]]$new_hash
[1] "950eb1cfd03c5ebc6ce701f46809194384b98a3a06d2bd1c0c5e1162da5f5c3c"



[[7]]
[[7]]$index
[1] 7


[[7]]$timestamp
[1] "2019-05-08 09:36:25 CEST"


[[7]]$data
[1] "this is block 7"


[[7]]$previous_hash
[1] "950eb1cfd03c5ebc6ce701f46809194384b98a3a06d2bd1c0c5e1162da5f5c3c"


[[7]]$proof
[1] 1
```

```
[[7]]$Type
[1] "Received"

[[7]]$ID
[1] "K6-114-1142-66425"

[[7]]$Producer
[1] "2"

[[7]]$received_date
[1] "16031"

[[7]]$received_coordinates
[1] "'9.932804 51.535703'"

[[7]]$faulty_received
[1] "0"

[[7]]$sql
[1] "UPDATE Transport
SET
Producer_Received='2',
Date_Received=Date('2013-11-22'),
Coordinates_Received='9.932804 51.535703',
Faulty_Received='0'
where
ID='K6-114-1142-66425'"

[[7]]$new_hash
[1] "69e00586dfb134bd933107c42f5dafca8c56fd58d7469f26ec00a5709dcdb058"
```

```
[[8]]
[[8]]$index
[1] 8

[[8]]$timestamp
[1] "2019-05-08 09:36:25 CEST"

[[8]]$data
[1] "this is block 8"

[[8]]$previous_hash
[1] "69e00586dfb134bd933107c42f5dafca8c56fd58d7469f26ec00a5709dcdb058"

[[8]]$proof
[1] 1

[[8]]$Type
[1] "Assembly"

[[8]]$ID_Component
[1] "21-2-21-322776"

[[8]]$ID_Part
[1] "K6-114-1142-66425"

[[8]]$Producer
[1] "2"

[[8]]$Build_date
[1] "16045"

[[8]]$Build_coordinates
[1] "'9.932804 51.535703'"
```

```
[[8]]$Faulty
[1] "0"

[[8]]$Type_Assembly
[1] "OEM: 21"

[[8]]$sql
[1] "INSERT INTO Assembly
VALUES
('21-2-21-322776','K6-114-1142-66425','2',Date('2013-12-06'),
'9.932804 51.535703','0','OEM: 21')"

[[8]]$new_hash
[1] "2e117aa402e9b93d3bcf5d0ebe25c2bc6b5a3c96f57bfd5ea58c96754247c0c6"


[[9]]
[[9]]$index
[1] 9

[[9]]$timestamp
[1] "2019-05-08 09:36:25 CEST"

[[9]]$data
[1] "this is block 9"

[[9]]$previous_hash
[1] "2e117aa402e9b93d3bcf5d0ebe25c2bc6b5a3c96f57bfd5ea58c96754247c0c6"

[[9]]$proof
[1] 1
```

```
[[9]]$Type
[1] "Sent"


[[9]]$ID
[1] "21-2-21-322776"


[[9]]$Producer
[1] "2"


[[9]]$sent_date
[1] "16045"


[[9]]$sent_coordinates
[1] "'9.932804 51.535703'"


[[9]]$sql
[1] "INSERT INTO Transport
(ID, Producer_Sent, Date_Sent, Coordinates_Sent)
VALUES
('21-2-21-322776','2',Date('2013-12-06'),'9.932804 51.535703')"


[[9]]$new_hash
[1] "60c21040fc46dcad6b40a4ffa1601e2ccfd31cf13fdeb35085a5c6652bac67a0"



[[10]]
[[10]]$index
[1] 10


[[10]]$timestamp
[1] "2019-05-08 09:36:25 CEST"


[[10]]$data
```

```
[1] "this is block 10"


[[10]]$previous_hash
[1] "60c21040fc46dcad6b40a4ffa1601e2ccfd31cf13fdeb35085a5c6652bac67a0"


[[10]]$proof
[1] 1


[[10]]$Type
[1] "Received"


[[10]]$ID
[1] "21-2-21-322776"


[[10]]$Producer
[1] "MAUTH"


[[10]]$received_date
[1] "16082"


[[10]]$received_coordinates
[1] "'13.583714 48.886789'"


[[10]]$faulty_received
[1] "0"


[[10]]$sql
[1] "UPDATE Transport
SET
Producer_Received='MAUTH',
Date_Received=Date('2014-01-12'),
Coordinates_Received='13.583714 48.886789',
Faulty_Received='0'
```

```
where
ID='21-2-21-322776'"

[[10]]$new_hash
[1] "a0e3081b120fbf006a80cf830d0ed9abdf7cc66e9a08d25b78e4c4c2659265b1"
```