Traceability Blockchain Prototype for Regulated Manufacturing Industries

Traceability Blockchain Prototype for Regulated Manufacturing Industries

Utkan Eryilmaz
Department of IE & IS
Eindhoven University of Technology
The Netherlands
u.eryilmaz@tue.nl

Remco Dijkman
Department of IE & IS
Eindhoven University of Technology
The Netherlands
r.m.dijkman@tue.nl

Willem van Jaarsveld
Department of IE & IS
Eindhoven University of Technology
The Netherlands
w.l.v.Jaarsveld@tue.nl

Wouter van Dis
Fokker Services B.V.
Hoeksteen 40, Hoofddorp
The Netherlands
wouter.vandis@fokker.com

Kaveh Alizadeh
Fokker Services B.V.
Hoeksteen 40, Hoofddorp
The Netherlands
kaveh.alizadeh@fokker.com

ABSTRACT
Blockchain emerged as a peer-to-peer trust platform for trading virtual currencies and evolved to be used for different problems including supply chain provenance. Due to stringent requirements of safety, regulated manufacturing and service industries such as aerospace, healthcare, and transportation require regulated traceability for parts, from source to the last customer, with detailed information requirements for each handover and operation. In this research, we analyzed the current traceability problem and list use cases of a traceability blockchain platform. A prototype platform is developed for the aerospace industry where every single part is required to have source and path traces recorded by certified supply chain actors. We evaluate the efficiency benefits of the platform in terms of duration and address future research topics.

CCS Concepts
• **Applied computing→ Enterprise computing→ Enterprise interoperability→ Enterprise application integration**

Keywords
Blockchain; supply chain; traceability; smart contracts; master data

1. INTRODUCTION
Traceability of parts and products is of major importance for manufacturing companies in different sectors to ensure important product characteristics, such as safety, reliability, and efficiency. In safety-critical industries, including healthcare, transportation and aerospace, traceability is even mandated by regulatory bodies. Blockchain and distributed ledger technology (DLT) recently utilized for use cases in various domains, including supply chains, cross border trade, healthcare, and additive manufacturing.

Several studies exist that introduced blockchain technology [1] [2] to supply chains. One of the first studies was by Tian [4] which used blockchain and radio frequency identification (RFID) for traceability in food supply chains. Blockchain is used to store and communicate authentic supply chain data to increase food safety. A comprehensive system, food trust, for multiple actor food supply chains was developed by IBM [5] using consortium blockchain Hyperledger Fabric [7]. Apart from food safety, IBM food trust is used to differentiate food based on quality, reduce waste and comply with standards. One of the major advantages of using a blockchain platform for food safety is timely product recalls. Other applications of blockchain for recording and checking the authenticity of products exist [9]. The origin tracking for sustainability and ethical compliance are two other areas addressed by these applications. Although there are plenty of blockchain platforms and applications [6] [9] [17], the technology is at infancy for supply chain applications. More research is needed to understand the transformative aspect of blockchain technology for different use cases, governance, digitalization, and trust [10] [11]. The benefits of the blockchain reside in distributed control and data which is not often the case for existing business and trade processes.

The studies dealing with other industries such as manufacturing seem to be at an early stage[14]. Recently, Honeywell introduced a blockchain supported trade platform [12]; however, this seems to be a private blockchain platform controlled by a single company.

In an ongoing research project (ITOPP), we are investigating the application of the blockchain approach for traceability problem in the regulated industry. The traceability in regulated industries differentiates from the food and other supply chains. First, the supply chain of regulated industries involves production, trade, installation and maintenance of complex parts that may include up to hundreds of thousands of different parts. Second, the traceability requirements are more formal for some of the industries such as aerospace as all the parts are required to have a complete trace. Third, the market structure is different as the actors in regulated industries are certified, audited and may have exclusive contractual agreements. Fourth, while the particular food can easily be spoiled because of the environmental conditions, the regulated parts are generally less effected, causing traceability information to have long term validity and value. In this work, considering specific aspects of the regulated industries, we explored the traceability problem, defined use cases and developed a prototype blockchain platform. We also evaluate the foreseen efficiency benefits of the blockchain traceability platform compared to current practice.

BIOTC'20, July 8–10, 2010, Singapore.

DOI: http://dx.doi.org/10.1145/12345.67890

Against this background, the remainder of this paper is structured as follows. In the second section, we describe the traceability problem in regulated industries and briefly introduce blockchain for the supply chain. In the third section, we provide the use cases of a traceability blockchain platform, the prototype design, and implementation. Finally, in the fourth section, we evaluate the prototype platform and list some of the challenges for further development.

2. BACKGROUND

2.1 Traceability in Regulated Manufacturing

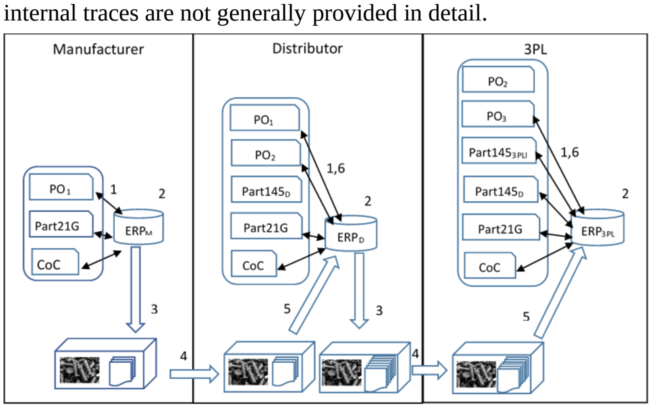
Traceability is defined in the supply chain literature [3] as *"an ability by which one may track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales (read: 'chain traceability'), or internally in one of the steps in the chain, for example the production step (read: 'internal traceability')"*. The requirements of traceability vary from industry to industry for different aspects, namely the scope of traceability (the products to be traced), product identification, the required steps of history information, and the level of detail. In the aerospace sector, every part that is installed in an aircraft has extensive conformity requirements and should be accompanied by extensive back to birth (BTB) trace. In the literature, the term Traceable Resource Unit (TRU) [10] is used to define a collection of parts of the same type that has the same trace back to the origin. Traceable item [13] or TRU [10] is advised to be identified uniquely for querying the associated trace.

To determine that a part conforms to specification, two kinds of information are used:

a. The part is produced, assembled, or disassembled in a standard way by an accredited organization. This is evidenced by a Certificate of Conformity (CoC) and manufacturer certification.

b. The part (and the corresponding information) is handled by accredited organizations. These organizations have been certified to have the necessary processes to handle the part, evidenced by a supplier certification.

For a traceability system to work properly, the most important is recording the operation(s) on parts and handover(s) of the parts. In the case of the aerospace industry, having a chain trace with supporting certification information guarantees that the part is conformant. We conclude that the focus of the traditional traceability systems is on getting the chain trace and CoCs thus internal traces are not generally provided in detail.



(3PL: Third Party Logistics Provider, PO: Purchase Order, Part 21G: EASA Part 21G Company Certificate, CoC: Certificate of Conformance, Part145: EASA Part 145 Company Certificate, ERP: Enterprise Resource Planning)

Figure 1. Traditional Traceability Approach Data Flow

The traceability process is analyzed for the aerospace industry and the process steps and related data elements are presented in Figure 1. We note that currently the actors in the supply chain store data in their own systems. First, the traceability data should be gathered from the enterprise resource planning (ERP) of the producer (steps 1 and 2). Then different files should be gathered and transformed into a single package that is attached to the product and/or transmitted digitally. The files and information should then be controlled manually for integrity. During each step shown in Figure 1 following actions are performed.

1. Purchase order number or other intermediary data (shipping number etc.) is used to reference and access the traceability data. This data does not identify TRU globally.
2. The trace data should be extracted and checked. The integrity of intercompany reference (purchase order number) and integrity of trace data should be controlled separately.
3. Data should be packaged and sent digitally or printed and attached to the physical part.
4. The data is transmitted with the shipment or digitally to the ordering entity. The data is not encrypted and sent via a secure channel and can be intercepted.
5. The validity of part and organizational certificates of all upstream actors should be controlled by the distributor.
6. The data should be digitalized and information should be mapped to the orderer's ERP data. Missing information may be added manually. The consistency of the links should be verified (repeat step 1).

The data is kept by the distributor and data integrity is the responsibility of the distributor. When a Third Party Logistics (3PL) provider makes an order from the distributor, the same process is repeated with more effort, resulting in a series of data acquisitions, transformation, non-secure communication, data integrity checks, certificate controls, utilizing different identifiers such purchase order numbers, shipping references, company-specific internal IDs. All the data of chain trace is accessed through purchase order numbers and the internal trace of the batches can be obtained through manual inspection of the files.

Traceability data can also be classified as master and event data. Master data refers to more consistent, static data on actors, places, and parts. Event data is related to actions and accumulates as a part moves through the supply chain. For the case of regulated industries, the suppliers may provide the master data about the part including producer, part number, CoC before or during the ordering process. Trace data is communicated to the orderer digitally or attached to the actual part as documents. Considering the process and data communication, we can make a shortlist of improvement areas for the current process:

a) Data transformation and storage of traceability data by each actor causes inefficiency (step 1, 2, 5 and 6). The process is also error-prone.

b) The communication between actors is not via a secure channel (step 4), it is prone to attacks and errors.

c) Increased effort is needed in the downstream as product and organizational certificates are checked manually (step 5). The previous checks by the former parties are not used as an indication for validity.

d) Whenever incompleteness or inconsistency is present, the information is communicated to one upstream level by transaction IDs (dispute resolution process). This involves many different systems working together (ERP, CRM, intercompany communication) and leads to manual work and inefficient resource use.

e) As there is no coherent unique identification of TRUs by all actors, the access to records is not automated. In the event of a disagreement, it takes time and effort to determine the root cause of the issue (all steps).

Besides these apparent issues, lack of globally identifiable, agreed, immutable records have some further side effects which is in the current practice remedied by following additional measures:

a) Every actor should be periodically audited by certification authorities such as the European Aviation Safety Agency (EASA). The audit ensures that the organization has necessary trace data for the currently or previously owned parts, thus guarantees part conformance.

b) The process provides no automated means of control for preventing the introduction of fake data and noncompliant products. Other measures such as approved supplier lists and manual quality inspections are used to ensure parts are compliant.

As a result, we conclude that the benefits are not limited to more efficient operation, there is a potential for transforming the current practice to a one with built-in continuous efficiency and possible safety improvements.

The audit process will certainly benefit from improved traceability as all trusted data of the audited organization even part of consortium data will be directly available and accessible. We left this aspect out of the scope of this study as it involves significant transformation for the audit process and has to deal with variations among industries.

2.2 Blockchain as a Traceability Platform

Blockchain was introduced as an innovative technology supporting peer-to-peer digital currency [1]. The building blocks were cryptographically sound, private-public key based transaction mechanism, decentralized proof-of-work consensus for adding hash interconnected blocks and incentive proposal for participation in transaction processing. Public blockchains such as Bitcoin [1] and Ethereum [2] network are fully decentralized but has limitations of scale and constraints on real-time operation.

Novel platforms such as Hyperledger Fabric [7] emerged that address the weaknesses of the public blockchain platforms, which are sometimes called Blockchain 3.0. While the first wave of blockchain technology like Bitcoin address solely public digital currency creation, the later provides mechanisms for access control, security, modularization, and flexible smart contracts. Hyperledger Fabric uses permissioned voting-based consensus protocol coupled with an orderer that provides near real-time performance [15]. Blockchain and Hyperledger Fabric is increasingly used as a provenance platform [9]. Different from the public blockchain, only authenticated peers participate in a permissioned blockchain such as Hyperledger Fabric. As trust in the participants is higher, the consensus mechanism is simpler. After the transactions are
Security

simulated and results are agreed upon by a predefined number of authenticated peers of the blockchain, results are ordered and written to the peers. The distributed ledger can attain performance required by the business application in terms of number of transactions and transaction verification delay. Hyperledger Fabric has three main components enabling secure, immutable recording of transactions. These are the *smart contract engine*, the *ledger*, and the *world state*. The *world state* and *ledger* are updated only through the *smart contract engine* that orders the transactions (satisfy endorsement conditions) and checks other conditions. Each transaction is recorded to the *ledger* entries which are formed into cryptographically linked blocks to prevent illegal updates.

We should underline the differences of the consortium blockchains with public blockchains. Public blockchains use consensus mechanisms that are far more resource consuming, sophisticated and complex than consortium blockchains. The consortium blockchains such as Hyperledger Fabric [7] built on the assumption that each actor is identified and authenticated. With the assumptions of good governance by actors and well-defined contracts reflecting the business rules, the consortium blockchains act as a trusted medium. Blockchains such as Hyperledger Fabric provide near real-time performance by limiting the work during consensus. Recent research and developments aiming increased performance [15], making them a viable alternative for supply chain transactions.

We illustrate the updated process by utilizing the blockchain in Figure 2. Each actor has a peer (PN) which is a part of the blockchain and every operation is recorded to the blockchain. The traceability is enabled with blockchain in the following way.

1. The parts are registered as they are produced. The production is registered to the blockchain and is uniquely identified afterward.

2,3,4. The data is stored in the blockchain and can be accessed by all the actors in the downstream as needed. There is no need to extract and check trace from different information systems (step 2), prepare the data and send it in printed form or digitally (step 3).

5. If the data is released to an actor, he may get the trace by using the unique identifier (#TRUID).

6. The data is controlled and made available to the ordering actor using blockchain.

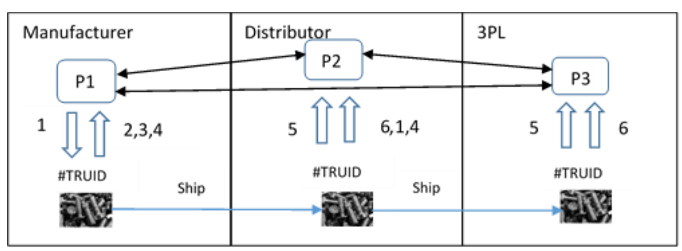


Figure 2. Blockchain as a Traceability Platform

The peer-to-peer architecture can be realized by a consortium blockchain such as Hyperledger Fabric [7]. All the operations are written in a secure, immutable distributed ledger. In the end, we have a trustable source for traceability information. By using the traceability blockchain security, immutability and trust are supported as follows.

Security
Each transaction proposal is signed by the client with her own certificate and selected peers sign the proposal of each transaction. The communication between the peers is authenticated. Furthermore, the transactions may be access-controlled based on the role of the actor or world state of the blockchain.

Immutability
The transactions are finalized and written to the ledger if only if the peers' evaluations of transaction proposals agree. The result is recorded by every peer and the blocks containing the records are cryptographically linked, therefore it is not possible to update or insert an entry into the ledger.

Trust
World state, transaction history, and private data are checked during the world state updates. By design, only relevant transactions are enabled at a particular world state. Furthermore, only with the predefined number of endorsements of the peers, the world state is updated. So the immutable history, with a consensus mechanism for authenticated actors provides a distributed ledger with a trusted world state and ledger.

3. TRACEABILITY BLOCKCHAIN PROTOTYPE

The development of the prototype is done in close collaboration with the implementation partner which is an aerospace service company. The design and development tasks are done mainly by the researchers in close collaboration with industry experts. Industry experts provide valuable insights and design inputs over the traceability process and use cases. In summary, traceability blockchain prototype development involved the following steps:

1. The traceability process for standard parts was defined with the user group. Problems within the existing process were identified and discussed with the user group. We evaluated the blockchain suitability for the application using an existing approach [16].

3. Considering the existing problems and the additional functionality offered by the blockchain technology, the first version of use cases was drafted and discussed with the user group. An agreement was reached on the functionality of the prototype.

3. The master data model and transactions were defined and shared with the user group. Based on user group suggestions the data model was updated. Transactions are mapped to existing ERP operations to guarantee mutual consistent operation.

4. Graphical user interface (GUI) and functions were presented and feedback was taken for further additions and improvement.

5. Test cases for the operation were defined by the user group. Test cases involve a sequence of operations corresponding to normal operation and anomaly cases.

6. Test cases were executed and the facilities provided by the use cases were examined.

We describe the blockchain prototype including the use cases, architecture, smart contract transactions and GUI in this section.

3.1 Use Cases

The initial use cases of the traceability system are determined iteratively during the prototype development with the collaboration of the project partners. Initial use cases focus on the initial implementation and short term benefits of the blockchain by avoiding the manual process and paper trail.

Use Case 1: Trustable, One Click, Back to Birth (BTB) Trace
The system should provide the user with a full trace and accompanying data in one click. This includes a BTB trace of a TRU, starting from the production of the batch (CoC, certificates and other attributes), splits (split batch trace), assemblies (CoC as needed, the parts list), handovers (organizational certificates and other information) will be provided on a timeline with links to detailed data and files. The blockchain based platform streamlines the use of manual operations and inspections. The blockchain will store the information iteratively by actors through time in the secure immutable distributed ledger and as the global asset ID is available to the participants, the owner displays it with one click.

Use Case 2: Dispute Resolution through Common Trace
The trace of the part should be totally consistent for different actors. This will be enabled through the records of immutable DLT records. Further steps resulting from forming the BTB trace through various systems and files will be eliminated. Two parties of the supply chain will have consistent data and visualization of the trace referenced by global asset ID. All data can be either accessed directly or decrypted or validated by the transaction hashes.

Use Case 3: Access Controlled Built-in Trusted Trace Data
Data becomes validated as it is inspected and communicated by downstream organizations. In Figure 3, we illustrate two cases where blockchain transforms the traceability process in this way using shared data. In the first case, trace entries and data that are written to the blockchain by previous organizations (org1, org2) become validated as it moves downstream. The current or candidate owner (org4) should only check the unchecked data (org3's trace entries). The previously validated data is presented to the user using the validation cues explained in the user interface section.

For the second case, the information validation is more indirect, in the sense that it is enabled through participating consortium members. If the information for a split batch is validated (org1:tru1), the split TRU (org1:tru2) is also validated. The downstream organization (org3) has information about the validity beforehand.

In this way, the burden of the manual or semi-automated process of going through upstream trace elements is greatly reduced. The focus is now on the integrity of the part with blockchain data and the quality of the part. As secure, immutable and integral trace data is available, the focus of the inspection process will be checking the data referring to the physical part and part quality.

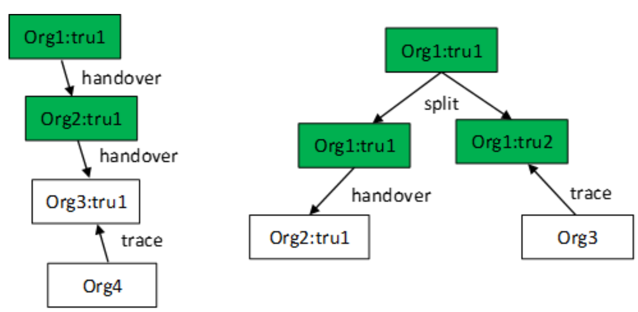


Figure 3. Downstream Flow of Trace Validity Information

3.2 Architecture

Using a blockchain as a provenance platform requires the distributed ledger as an infrastructure (peers and orderer), the software development kit (SDK) to interact with the infrastructure, the user interface to present the blockchain information in a clear, concise and familiar way to the user and facilities to interact efficiently. The major components of the system are shown in Table

1. The peer application forms the backend and runs the smart contract. The server is developed using Hyperledger Fabric SDK and provides a software interface to the backend for the client application. Functions for enrolling users, connecting to blockchain and signing transactions exist in the server. The client application provides the user interface and controls for the user. Orderer communicates with the peers and is responsible for ordering and validating the transactions.

Table 1. Components of the Prototype

Component	Function
Client Application	UX, company specific policy, assetID mapping(optional)
Server and SDK	Enroll Users, Connect Gateway, Submit Transactions
Peer	Smart contract engine, World state, Ledger
Orderer	Ordering and validating

3.3 Master Data and Access Control

Master data is stored in four tables as key, value pairs. The data elements for supply chain actor (SCA), traceable resource unit (TRU), ownership (OWN), trace (TRACE), their keys, values and relations are shown in Figure 4. Supply chain actors (SCA) is referenced by unique organizational key (*OrgID*) and TRUs are access by global asset identifier (*TRUID*). An ownership table is used to store the current owner of each TRU referenced by a key (*OWN:OrgID:TRUID*). The actors have access to trace information referring to specific TRUs they own (*TRACE:OrgID:TRUID*).

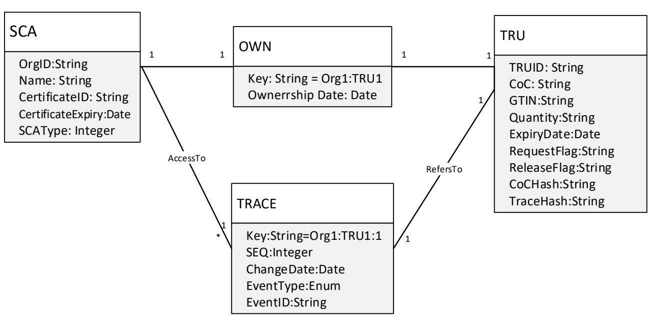


Figure 4. Master Data Model

TRU table involves production data, CoCs, expiry date. If no anomaly occurs this data stays unchanged through the lifetime of a TRU, only copied if split operation takes place (see smart contract and transactions). Every TRU has an immutable, trusted trace to the source. The SCA data is also public so that every member of the blockchain can see the organization names, certificates, and validity dates. The ownership relation can be public or encrypted.

Trace information may include company-specific information such as purchase order, shipment numbers so it is also kept private. It is communicated to the new owner during ownership change. The files such as CoC and manufacturer or handler certificates that will introduce significant data burden to the system is stored as private data by the peers. The hashes of the private data are still in public ledger for validation purposes. Note that information such as quantity can be used to infer about the supply by the manufacturers. Therefore, it can be encrypted or private if this effects pricing.

Table 2. Data Elements

Data Class	Access Type	Rationale
TRU (Production data)	Public	TRU information is available for the customer before order.
TRU (Current state)	Private	Information related to TRU such as price is only available for the current owner.
Supply Chain Actor	Public	Members of the consortium have their organizational information available for discovery.
Ownership	Public or Encrypted	Ownership data can be public or private based on the requirements.
Detailed Trace	Public, Encrypted or Private	Trace entries can be public, encrypted or private based on the requirements of actors.
Files (certificates, CoCs)	Private	Public storage of files cause replication by peers and form a burden for scaling.

3.4 Smart Contract and Transactions

The process model formed the basis for defining the smart contract transactions. We define the main actors, transactions, using the process model description, ensuring that no gap exists supporting the current business process. The process flow, the data mapped to specific transactions are shown in Figure 5.

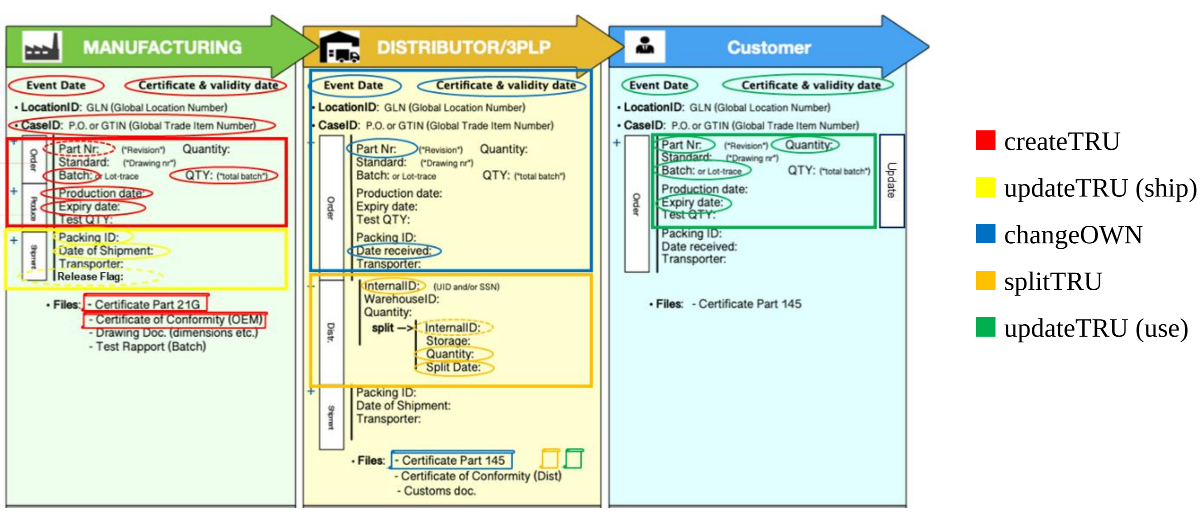


Figure 5. Process Data Mapped to Transactions

createTRU: This transaction is called when a manufacturer introduces a new lot to the system. All the part and CoC information are submitted and written to the blockchain. A new key for unique identification (TRUID) is assigned to the new TRU and all the information is stored. The TRU is owned by the organization submitting the transaction.

updateTRU: This transaction is called when there is an update of a part attribute. It is also executed when a part is ordered, shipped (released to the new owner) and commissioned. The TRUID, the attribute to be updated and the new value should be specified.

splitTRU: This transaction is called when an existing TRU is split and a new TRU with the same product attributes and CoC is introduced. The existing TRUID and the quantity of the new TRU should be specified. The new quantity is assigned to new TRU and old TRU has the remaining amount. In this way, no new part is introduced via smart contract except the *createTRU* transaction.

changeOWN: This transaction is used to get ownership of a TRU. It is called by specifying the TRUID. The client submitting this transaction should be part of the organization to which the TRU is released. The intermediate steps of this transaction are presented in Figure 6. As all other transactions, at first, the transaction context is obtained and checked. Then the ledger is read and the condition is checked to guarantee that the old owner released the TRU for the new owner and trace entries belonging to the new owner is written by copying the old owners' trace and resetting necessary parameters. Finally, the records are submitted to be written to the world state.

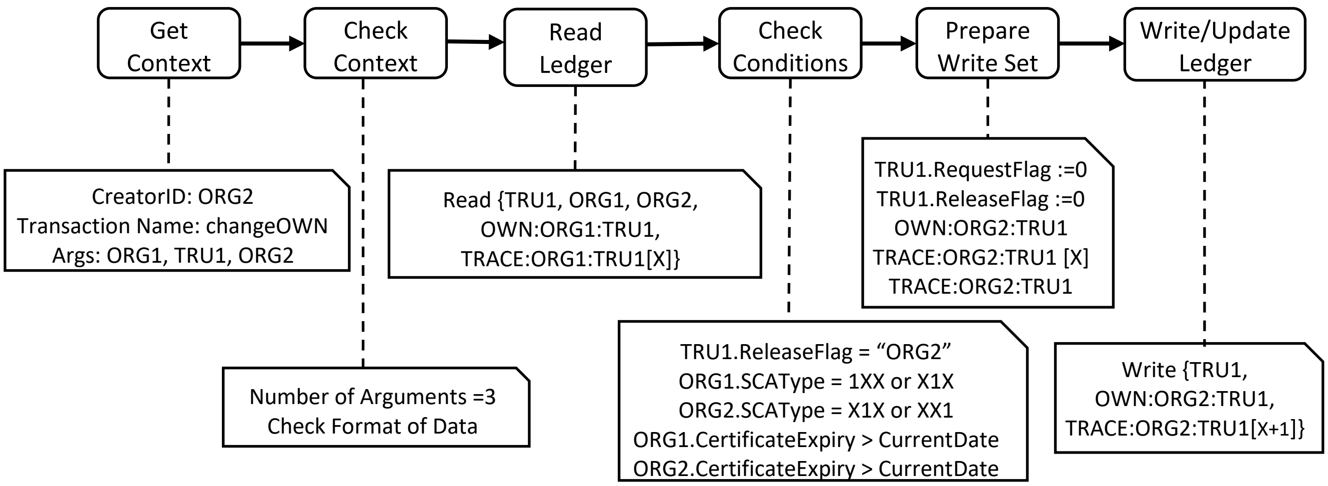


Figure 6. Transaction Flow for *changeOWN* Transaction

Every organization in the prototype blockchain participates as a peer. This means that they can enroll users, participate in the endorsement process and update their own ledger. It is assumed that the smart contract is communicated to peers and validated beforehand.

3.5 GUI and User Controls

The system has two main interfaces supporting the use cases. The first interface is the *part list interface* (see Figure 7). Through this interface the organization can see the list of parts, create a new part and select a part to trace.

Part List:
Using the part list interface (see Figure 7), the user sees the list of parts and their attributes it has access to. By clicking on a part, the trace of the part is requested from the blockchain and trace GUI is displayed. For the owned parts the user can update the information of the part.

The part list includes a button for manufacturers to register new parts to the system. The manufacturer enters the TRU information and CoC and registers the part from the opened menu.

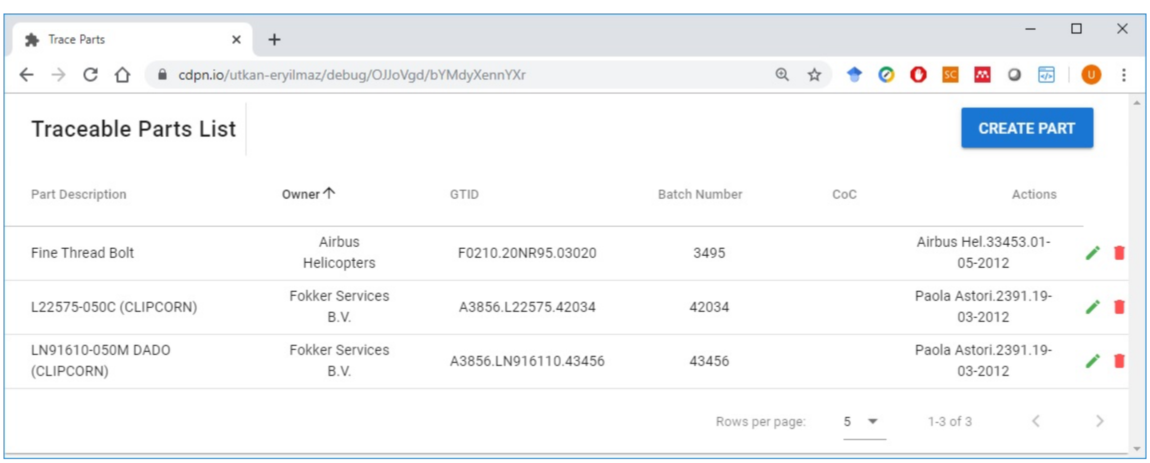


Figure 7. The Part List GUI

Trace Interface:

The trace interface (see Figure 8) displays the BTB trace of the part. In the first part of the trace summary, TRU information is displayed which follows the BTB trace from the most recent to oldest data. The trace can be accessed by the owner or the released party. The information displayed on the interface is marked with special cues to indicate that the validity information about the part.

i. If the data is consistent, previously viewed and handovers have occurred without any dispute and updates, the data is shown as green.
ii. If it is the first time that data is viewed by an actor other than the creator, it is orange.
iii. If data is inconsistent or there is a dispute exists about the data, it is displayed as red.

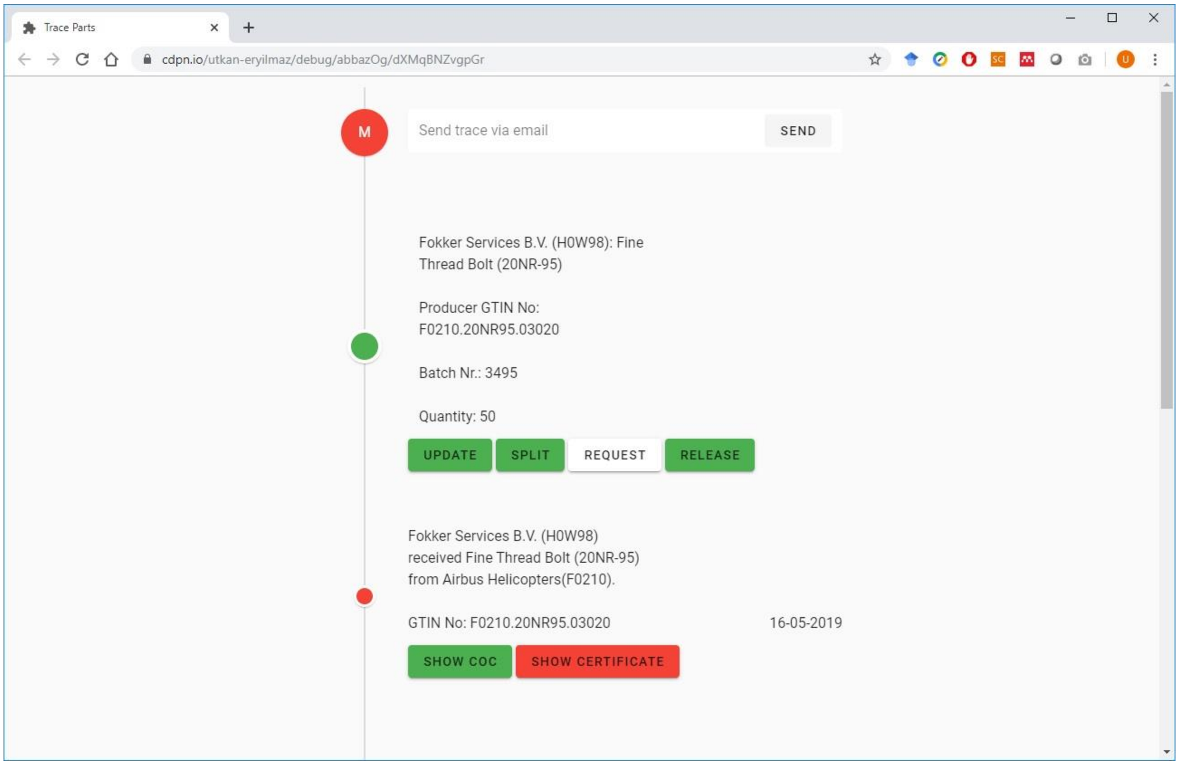


Figure 8. Trace GUI

The trace interface provides a set of options for calling the transactions. If the owner of the part is viewing the trace, TRU can be split or released to an ordering organization. If the TRU is released for the actor *changeOWN* transaction can be called to get the ownership. If the trace of a TRU that is not owned is displayed, the *Request* button is enabled. These functions can be called or triggered using the GUI or by an organizational application (ERP etc.).

The part list and trace interface together realizes the first use case. Through the DLT each company has access to coherent world state and immutable ledger, which together with GUI realizes the second use case. Detailed visual cues coupled with access controlled and immutable DLT realizes the third use case.

4. CONCLUSIONS

In this work, we purposed a prototype for traceability for regulated industries. By the detailed analysis of the traceability process, we showed that the blockchain can significantly transform the process into a more efficient one by eliminating some steps and updating the others.

The blockchain platform realized three uses cases by providing one-click trace, consistent among actors. The validity information is reused providing simpler and more efficient traceability for downstream actors.

We have done a preliminary estimation of the time efficiency blockchain brings by going through each step of the process. The efficiency gains are obtained through the elimination of *check data (*defined as *step 2* in section 2*)* and *prepare data (step 3)* and improvements of other steps. Only the recent invalidated data will be controlled from the trace interface, getting and controlling the trace (*step 5*) will be performed more efficiently. The verification of traceability for a TRU that have changed ownership numerous times is more efficiently performed by using the previous validations and visual cues. The ERP data is easily obtained (*step 1*) and updated (*step 6*) by one-click using TRUID. Trace is no more physically or digitally sent (*step 4*) but TRUID is appended to the package and trace is made available through blockchain. As a result, these operations are now one-click transactions. Our initial prediction is that the new system will perform getting and controlling the trace five times faster by using previously validated information (*step 5*, average duration 15 minutes traditionally, 3 minutes with blockchain) and the streamlined operations will be done less than a minute (*steps 1,4,6*). As a result, all the operation will take *6 minutes* (1, 1, 3, 1 minute(s) for *steps 1,4,5,6*) compared to *60 minutes* (5, 15, 10, 5, 15, 10 minutes for *steps 1 to 6*) for the traditional approach. Therefore a 10-fold increase in time performance is foreseen for each part (TRU) order.

The additional advantages occur as the dispute resolution is streamlined, as the parties of a dispute will access to the unique consistent trace. Moreover, the task of going over a bunch of documents and/or files is eliminated. The trace data is validated by upstream actors or the actors having the same batch which is not possible in the traditional approach. We predict that using blockchain will bring emergent opportunities such as these.

We are working further to define additional use cases and transactions to include reuse lifecycle, complex governance and support tracking (forward traceability). As the process of traceability and intercompany relations are effected from blockchain introduction, there will be emergent opportunities and challenges. We will further utilize our prototype to define, prioritize, exploit and deal with these issues with a wider user group as the following step.

5. ACKNOWLEDGMENTS

This work is done as part of ITOPP project which is sponsored by Dutch Institute of Advanced Logistics TKI Dinalog programme.

6. REFERENCES

[1] S. Nakamoto. Bitcoin: A peer-to-peer electronic cash system, 2008.

[2] Ethereum blockchain app platform. https://www.ethereum.org/.

[3] Jansen-Vullers, M.H. et al. 2003. Managing traceability information in manufacture. *International Journal of Information Management*. 23, 5 (2003), 395–413. DOI: https://doi.org/10.1016/S0268-4012(03)00066-5.

[4] Tian, F. 2016. An agri-food supply chain traceability system for China based on RFID blockchain technology. In 2016 13th International Conference on Service Systems and Service Management (ICSSSM). 1—6.

[5] Stanley, A. 2018. Ready to Rumble: IBM Launches Food Trust Blockchain for Commercial Use. Forbes October (2018).

[6] Mezquita, Y., González-Briones, A., Casado-Vara, R., Chamoso, P., Prieto, J., & Corchado, J. M. (2019, June). Blockchain-Based Architecture: A MAS Proposal for Efficient Agri-Food Supply Chains. In *International Symposium on Ambient Intelligence* (pp. 89-96). Springer, Cham.

[7] Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Enyeart, D., Ferris, C., Laventman, G., Manevich, Y. and Muralidharan, S. 2018, April. Hyperledger fabric: a distributed operating system for permissioned blockchains. In *Proceedings of the Thirteenth EuroSys Conference* (p. 30). ACM.

[8] Wang, Y. et al. 2019. Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. *Supply Chain Management*. 24, 1 (2019), 62–84. DOI: https://doi.org/10.1108/SCM-03-2018-0148.

[9] Kshetri, N. 2018. 1 Blockchain's roles in meeting key supply chain management objectives. International Journal of Information Management. 39, June 2017 (2018), 80–89. DOI: https://doi.org/10.1016/j.ijinfomgt.2017.12.005.

[10] Behnke, K. and Janssen, M.F.W.H.A. 2019. Boundary conditions for traceability in food supply chains using blockchain technology. *International Journal of Information Management*. May (2019), 1–10. DOI: https://doi.org/10.1016/j.ijinfomgt.2019.05.025.

[11] Galvez, J.F. et al. 2018. Future challenges on the use of blockchain for food traceability analysis. *TrAC - Trends in Analytical Chemistry*. 107, (2018), 222–232. DOI: https://doi.org/10.1016/j.trac.2018.08.011.

[12] Morris, N. 2019. Honeywell uses blockchain and startup approach to digitize aircraft parts. https://www.ledgerinsights.com/honeywell-blockchain-aircraft-parts/

[13] Kite, J. 2012. GS1 Standards Document for Full Supply Chain Traceability, GS1 Global Traceability Standard. 1 (2012), 1–67.

[14] Ivan, K. and Lucia, N. 2013. Selected aspects of the supply chain management in the aerospace industry. *Incas Bulletin*. 5, 1 (2013), 135–149. DOI: https://doi.org/10.13111/2066-8201.2013.5.1.13.

[15] Thakkar, P. et al. 2018. Performance benchmarking and optimizing hyperledger fabric blockchain platform. *Proceedings - 26th IEEE International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems, MASCOTS 2018*. (2018), 264–276. DOI: https://doi.org/10.1109/MASCOTS.2018.00034.

[16] Lo, S.K. et al. 2018. Evaluating Suitability of Applying Blockchain. *Proceedings of the IEEE International Conference on Engineering of Complex Computer Systems, ICECCS*. 2017-Novem, (2018), 158–161. DOI: https://doi.org/10.1109/ICECCS.2017.26.

[17] Belotti, M. et al. 2019. A Vademecum on Blockchain Technologies: When, Which and How. *IEEE Communications Surveys & Tutorials*. c (2019), 1–1. DOI: https://doi.org/10.1109/comst.2019.2928178.