Design and Implementation of a Distributed Ledger Technology Platform to Support Customs Processes within Supply Chains

Full research paper

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Abstract

In international trade, customs clearance fulfills complex and country-specific tasks in the execution of supply chain processes. Importers and exporters have to integrate customs authorities into the information flow, as customs authorities require information, e.g., on the bill of lading and the commercial invoice apart from the customs declaration. In addition, involved sub-service providers increase the problem of information asymmetry and the required coordination effort. Practice and research consider Distributed Ledger Technology (DLT) as a potential solution since this technology maintains a mutually agreed and secure database of value-creation partners. However, research has hardly investigated the design of such DLT systems. Therefore, we present a requirements catalogue, a concept, and a prototype of a DLT platform to address the outlined problem of information asymmetry, especially with a focus on customs processes.

Keywords Distributed Ledger Technology, Supply Chain, Customs Processes, Design Science Research

1 Introduction

Due to globalization and the increasing interconnectedness of the economy through digitalization initiatives, foreign trade has been growing for years and has become a central part of international trade relations (Liotine and Ginocchio 2020). Technologies such as Electronic Data Interchange (EDI) have been a factor in optimizing communication between trading partners in terms of time and cost (Jensen et al. 2019). However, when additional parties, such as customs authorities, are involved, point-to-point data transfer limitations become evident. Furthermore, the highly standardized interface for transmitting data in EDI encounters challenges in the context of customs processes (Jensen et al. 2019). Customs processes, however, require at least the involvement of the importer, exporter, and customs authorities of the transiting and importing countries (Belu 2020). The limited possibilities for sharing necessary documents and customs applications contribute to the problem of information asymmetry. The need for different documents depending on the type of goods imported intensifies the problem. In this case, information asymmetry in custom processes of a supply chain (SC) refers to a situation where different actors within the SC possess varying levels of information, e.g., the customs authority receives inaccurate information on the value, and quantity of the imported goods or the importer does not know the current customs status (Segers et al. 2019). Therefore, the problems arising from information asymmetries do not seem to be fully solved by established communication standards and centralized information systems since, for example, there are deficits in the quality of transmitted data and their storage in data silos within companies (Chang et al. 2020). This concludes with considerable financial damage due to incorrect data and leads to the continuation of paper-based processes, which in turn are also prone to error and manipulation through misrepresentation (Liotine and Ginocchio 2020).

DLT is a promising technology for addressing information asymmetries, as it provides a unified, consistent, tamper-proof database through the cooperative validation of partners (Jensen et al. 2019). Precisely the inherent properties of DLT to replace trust with transparency and immutability are the subject of investigation within the SC science (Jensen et al. 2019). Extending the technology to include smart contracts, a way to automate simple contractual content using if-then logic, and oracles capable of validating real-world information and incorporating it into the DLT database, have opened up additional potential benefits in SC processes for science and practice, which has to be explored (Liotine and Ginocchio 2020). Finke et al. (2022) show that investigations have already been carried out in product tracking, document management, SC financing, compliance checks, and customs processes. However, there are research gaps for the use of DLT in customs processes, specifically in the research area of design science research. DLT could offer an alternative for paper-based processes with a high need for communication and error potential, especially in the area of customs processes.

Therefore, this paper aims to optimize inefficient and paper-based customs processes by allowing information to be shared and mutually validated between the parties involved on a DLT. Hereby we want to propose a level 1 research contribution to design science, according to Gregor and Hevner (2013). We follow their idea by providing requirements, a concept, and a prototype implementation of a DLT platform to support customs processes with SC activities. To achieve this goal, we address two research questions:

RQ1: *Which requirements arise for Distributed Ledger Technologies to support custom processes within supply chains?*

RQ2: *How should a prototypical implementation using Distributed Ledger Technology in custom processes within supply chains be designed?*

To answer these questions, the remainder of this paper is structured as follows: First, for a common understanding within the paper, the concepts of "Foreign Trade" and "Distributed Ledger Technology" are explained. In addition, we outline the related research. Then, we present the underlying methodology of the conducted design science research framework by Peffers et al. (2007). The afterwards presented results comply with the design science research framework. Lastly, we discuss and conclude the research results.

2 Theoretical Background and Related Research

Foreign trade covers the export, import, and transit trade of goods by companies and institutions across national borders. To realize the delivery processes of foreign trade, various parties, such as exporters, importers, container ports, and controlling entities such as customs, work together. For this cooperation and the exchange of information, the participating states provide a framework through foreign trade laws. Particularly relevant for implementing legal correctness within the import processes are customs authorities which control the cross-border movement of goods (Jensen et al. 2019; Juma et al. 2020). In this paper, we consider the import process in more detail. Here, customs offices may only release goods from abroad after importers have declared them in a customs procedure (Juma et al. 2020). Within this process step, the involved parties must provide all necessary documents, e.g., consignment note, customs declaration, certificate of origin, or commercial invoice. The origin of the goods and an accurate description are of major importance for tariff treatment. This affects, on the one hand, possible import restrictions and, on the other hand, the amount of duty (General Customs Authority 2022; Jensen et al. 2019). After the customs declaration, a customs inspection may take place. The customs inspection describes the physical determination of the quantity and nature of the goods specified in the customs declaration. The customs officials record the customs findings on the customs declaration. The authorities then calculate the customs duties the importer must pay to receive the goods (General Customs Authority 2022; Popa et al. 2015).

Distributed Ledger Technology is a technology that potentially addresses the outlined challenge of information asymmetry within customs processes. DLT is an umbrella term for distributed ledger architectures, such as blockchain or a directed acyclic graph, where blocks are not chained (Ballandies et al. 2021). However, the general mode of operation is the same, thus, we will use the following definition in the context of this work. Using a DLT, users can implement a fully distributed database to cryptographically capture and store a consistent, immutable event log of transactions within blocks between networked actors (Ballandies et al. 2021). The involved parties consensually maintain, update, and validate all transactions within the network to enforce transparency and system-wide consensus (Tan and Sundarakani 2021). The chosen architecture of DLT may differ depending on the application purpose in terms of restricted access for authorized parties, e.g., publicly accessible, private, or hybrid. Furthermore, a consensus mechanism allows the DLT to store the data consensually (Ballandies et al. 2021).

However, the functionality and properties presented up to this point are only partly sufficient for implementation in SC processes, because so far only storage and no processing of the data have been discussed. Here, the introduction of smart contracts as a complementary technology has provided a solution (Liotine and Ginocchio 2020). **Smart contracts** map contract contents by applying an if-then logic and automatically executing them according to the defined conditions. Within this understanding, smart contracts represent a computer program whose code is stored in a DLT. The underlying data of the contracts and the data, which are to be processed, are located in the data of the DLT (Liotine and Ginocchio 2020).

Finke et al. (2022) systemized research regarding the use of DLT to support SC processes and identified that the current research on custom processes supported by DLT is barely investigated so far. The research considers the logistic documents relevant for customs authorities, which have to view, evaluate, and confirm these documents. A market-ready application that addresses this area is the TradeLens application, although IBM shut the application down in early 2023 due to missed economic objectives (Kjærgaard-Winther 2022). TradeLens provides SC actors with direct and transparent access to digitized, cross-company processes and documentation workflows for their maritime SCs. From a scientific perspective, Jensen et al. (2019) formulate requirements and a concept for supporting customs processes with DLT. Otherwise, hardly any contributions from research address this complex of topics. For example, the publications by Chang et al. (2020), Li et al. (2020), Liotine and Ginocchio (2020), and Tan and Sundarakani (2021) consider the cross-border movement of goods and enable the derivation of requirements, but do not formulate concrete design recommendations.

3 Research Design

To identify requirements (RQ1) and develop a prototype (RQ2) to support customs processes, we follow a problem-oriented design science research approach adapted from Peffers et al. (2007), shown in Figure 1.

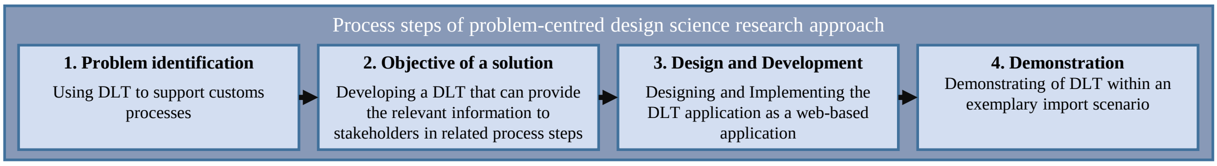


Figure 1: Research design adapted from Peffers et al. (2007)

Using the design science research approach, we aim to address the given problem of information asymmetries within customs processes and their involved parties in international trade. Therefore, we conducted a literature review according to Fettke et al. (2006), vom Brocke et al. (2009), and Webster and Watson (2002) to complete the first step of problem identification. We identified 2482 papers and checked them for duplicates. Furthermore, we checked for relevance, i.e., by checking the titles and abstracts with the help of inclusion and exclusion criterias. An article fulfills the relevance criteria if the use of DLTs in customs processes is examined or if requirements for this area can be derived or transferred from the knowledge presented. Articles that consider the use of DLT outside of SC processes or do not allow the derivation of requirements are not relevant and therefore excluded. A period was set from 2008 onwards, as the research area on DLTs emerged from this point onwards. The literature review covers 23 relevant articles, which build the basis for a holistic overview of current DLT approaches in customs processes. In step two, we established an objective for solving the identified problem within customs processes. This includes defining the objective of the developed DLT application and deriving functional requirements. The reference for our analysis was the German customs process, chosen due to a large number of different customs processes worldwide. We referred to the 23 identified relevant articles to derive the problem statement. Here, articles from practice-related databases, such as WISO-net, were also analyzed in order to supplement the scientific perspective, with a practical one. Figure 2 summarizes the conducted procedure.

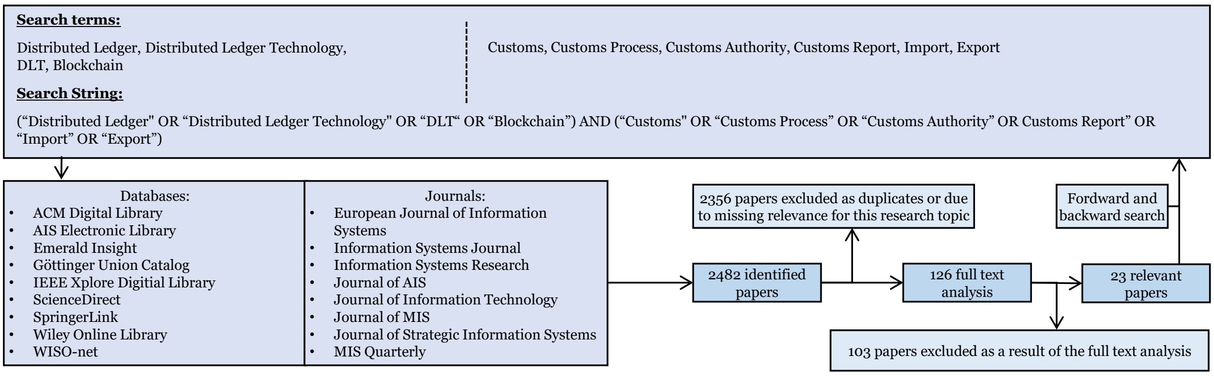


Figure 2: Structured Literature Review Research Framework for Steps 1. and 2.

In the third step of the design science research process, we used the requirements to develop a prototypical DLT artifact called LUCID. In step four, we then internally demonstrated the prototype within the project team using an application scenario by following the methodology of Peffers et al. (2007) to complete the design cycle for prototypical implementation as part of the research project.

4 LUCID Application

In this section, we present the design of LUCID (Lightweight Unified Customs and Invoice Declaration). Here, we aim to address the previously presented research gap by describing the requirements, design, implementation, and demonstration of DLT for customs processes.

4.1 Problem identification

To illustrate the problem, we consider the import process of goods within Germany and the related customs procedural steps. A customs declaration requires a commercial invoice from the exporter and potential additional documents such as an import permit, certificate of origin, packing list, bill of lading, etc. (Belu 2020). Furthermore, the forwarder must place the goods at a customs presentation point at the appropriate border crossing, and the importer must provide correct information on the type, value, quantity, and origin of the placed goods (Segers et al. 2019). If the customs authority accepts the customs declaration, they check the goods to see if a manual customs inspection is required before they can be imported. The customs officer denies the import process if the goods do not meet the stated specifications. Furthermore, the customs authority issues a customs notice if the goods meet the stated specifications or if no customs inspection is required. The customs notice contains the results of the customs inspection and a list of the goods, their value, origin, and customs tariff. Finally, the importer must pay the import duties (General Customs Authority 2022; Popa et al. 2015).

It is clear that a large number of people with different functions from several stakeholder companies or authorities are involved (Belu 2020). For example, a purchasing department places an order which the sales department of the other company then processes. Another example is the payment processing, which is handled by the respective financial accounting department (Jensen et al. 2019). Furthermore, persons responsible for the transport of the goods are involved, as well as officials of the customs authorities (Jensen et al. 2019). To provide more clarity, we distinguish between importer, exporter, and customs authority in the following, although the research presents the different functions of the individual activities. These three stakeholders involved emerge at a higher level from the user groups described as examples.

Within the framework of the customs process explained above, we give special attention to fraud cases by considering them separately since the evasion of customs duties, negligent or intentional misrepresentation, and counterfeiting cause financial damage every year (General Customs Authority 2022). Within these fraud cases, the authorities distinguish between misstatement and smuggling. While smuggling means illegal imports of all kinds and the non-declaration of dutiable goods, false declaration or tax customs fraud aims to manipulate critical customs data in customs procedures to reduce or avoid duties. Customs regulations divide false declarations into false declarations of value, false declarations of origin, and false classifications of goods (Segers et al. 2019). As mentioned above, to prevent customs fraud, customs authorities carry out physical inspections of goods, and customs authorities exchange information about persons, movements of goods, and means of transport. During the checks, the customs official compares the provided information against the actual information (Jensen et al. 2019). For this purpose, we divided the relevant research contributions into the investigated areas of customs process management and risk management by applying the structured literature review (Belu 2020). Table 1 lists the relevant research contributions with the assignment to the corresponding application area.

Sources	Angert (2019)	Ballandies et al. (2021)	Belu (2020)	Botton (2018)	Brookbanks and Parry (2022)	Chang et al. (2020)	Copigneaux et al. (2020)	Di Benedetto (2020)	Dutta et al. (2020)	Green (2017)	Jensen et al. (2019)	Juma et al. (2020)	Kshetri (2018)	Li et al. (2020)	Liotine and Ginocchio (2020)	Mainelli and Smith (2015)	Okazaki (2018)	Segers et al. (2019)	Sturmanis et al. (2019)	Tan and Sundarakani (2021)	Tyagi and Goyal (2021)	van Engelenburg (2019)	Yaren (2020)
Customs Process Management	•	•	•			•		•	•	•	•		•	•	•	•	•	•	•		•	•	•
Customs Risc Management		•	•	•	•	•	•	•				•	•	•	•		•	•		•			

Table 1: Relevant research contributions with the assignment to the corresponding application area

However, the customs process is subject to weaknesses, which we briefly discuss in the following. The first problem that emerges from the scientific and practical literature and is also a problem in SCs outside of customs processes is the required manual comparison of (customs) documents in processes that rely on paper-based documents despite electronic data exchange capabilities (Segers et al. 2019). This leads to information asymmetries among the parties involved and a time-consuming process of validating paper-based documents and the electronically received customs declaration or equivalent documents (Segers et al. 2019). Media discontinuity is another problem that arises from paper-based documents about the import of goods since manual input into the customs authorities' application systems is required for data that is only available in paper form (Jensen et al. 2019; Popa et al. 2015). Lost documents, as well as human input errors, can hinder the process. This can also affect the customs officer's physical inspection of the goods if, e.g., the missing data leads to a follow-up request for the documents at this point (Segers et al. 2019). The resulting necessary and error-prone manual processes due to missing standards and unused automation potentials, e.g., automated verification of missing data in the electronic customs declaration, lead to time and cost inefficiencies (Jensen et al. 2019). These weaknesses cause the central problem of inconsistent data management within customs processes, which also arises in the upstream stages of logistics activities. For example, paper-based processes or EDI interfaces that are only available at certain points do not create a uniform information base, which leads to inefficiencies.

4.2 Objectives of a Solution

To solve the above-mentioned problem, we aim to develop an artifact that partially automates handling the customs declaration and documents relevant to it within a DLT platform. To answer RQ1, we examined existing literature according to the structured literature review for requirements and were able to identify 17 functional- and two non-functional requirements. Appendix 1 lists the requirements and the corresponding sources. Following the description, Figure 3 shows all requirements and their interconnections.

Our work divides the identified functional requirements into five categories: (1) establish a connection with a trading partner, (2) manage orders, (3) manage documents, (4) initiate customs declaration, and (5) overview features. A block of non-functional requirements supplements this list. As a first step to start the customs process, a trade relationship must exist between the importer and exporter. It is also necessary to generate an overview of the existing trade relationships of the involved companies within the customs process to enable the user, e.g., from the purchasing department, to quickly and easily check the trade relationship that is relevant for the user. Implemented filter functions, e.g., enable the specific search for individual products (R1; R2) (Jensen et al. 2019). Once the user calls an existing trade relationship, this trade relationship must be provided with detailed information, e.g., about existing orders (R3) (Segers et al. 2019). To enter into a trade relationship, the system should send an invitation link to the trading partner, or a request is to be made via the Economic Operators´ Registration and Identification (EORI) number (R4) (Kshetri 2018). The EORI number uniquely identifies economic operators within the European Union and LUCID (General Customs Authority 2022). To carry out international trade, the second requirement block shows requirements to manage orders. First, it is necessary to create new orders to handle the import of goods (R5) (Brookbanks and Parry 2022). For this purpose, the user must specify the trading partners since at least one importer and one exporter are required (R6) (Kshetri 2018). Finally, the system must display company or user-relevant orders by status in an overview (R7) (Segers et al. 2019). It is possible, for example, that an importing company purchases the same product from different exporting companies. This results in trade relations for the importer with each of these exporters, which the system must represent by including the order (Segers et al. 2019). Trading partners and customs officials need document management capabilities to complement the successful processing of orders because documents such as customs declarations and certificates of origin are relevant to the process. The entire customs process, from declaration to payment, is processed and tracked using these documents (Li et al. 2020). First, an overview of the documents added to the order is needed, which can be accessed further in a detailed view (R8; R9) (Jensen et al. 2019). In addition, users need the ability to add new documents related to the order and then validate them (R10; R11) (Belu 2020). An example of this is uploading a certificate of origin by an exporting company. The fourth block of requirements refers to the created orders concerning document management to involve the customs authorities. Within this area, smart contracts can realize partial automation by checking inputs and converting them into a customs application (R12) (Juma et al. 2020). If the provided information is correct, the system transfers the customs application to the customs authority (R13) (Chang et al. 2020). Here, smart contracts are suitable for supporting the processes, as they are standardized processes with fixed specifications (Jensen et al. 2019). At this point, customs officials become involved in the import process to verify the application and documents within the system (R14) (Copigneaux et al. 2020). If these are correct and correspond to the goods, a customs official can create a customs report, upload it, and send it to the importer (R15) (Botton 2018). Finally, we can derive functional requirements from the literature in which the aim is to create a general overview to apply usability for the users to the system. Here, a dashboard should integrate the specific information for trade relationships, orders, and documents into a meaningful display of information (R16) (Jensen et al. 2019). In addition, an event-based notification system is needed to speed up the import process by informing the involved parties (R17) (Di Benedetto 2020).

Furthermore, we identified two non-functional requirements. First, to prevent fraud and for data protection reasons, a system environment is required that protects data integrity in terms of changes and access (NF1) (Botton 2018). Furthermore, low-threshold and intuitive access to the platform is relevant to integrating many actors in trading processes (NF2) (Belu 2020).

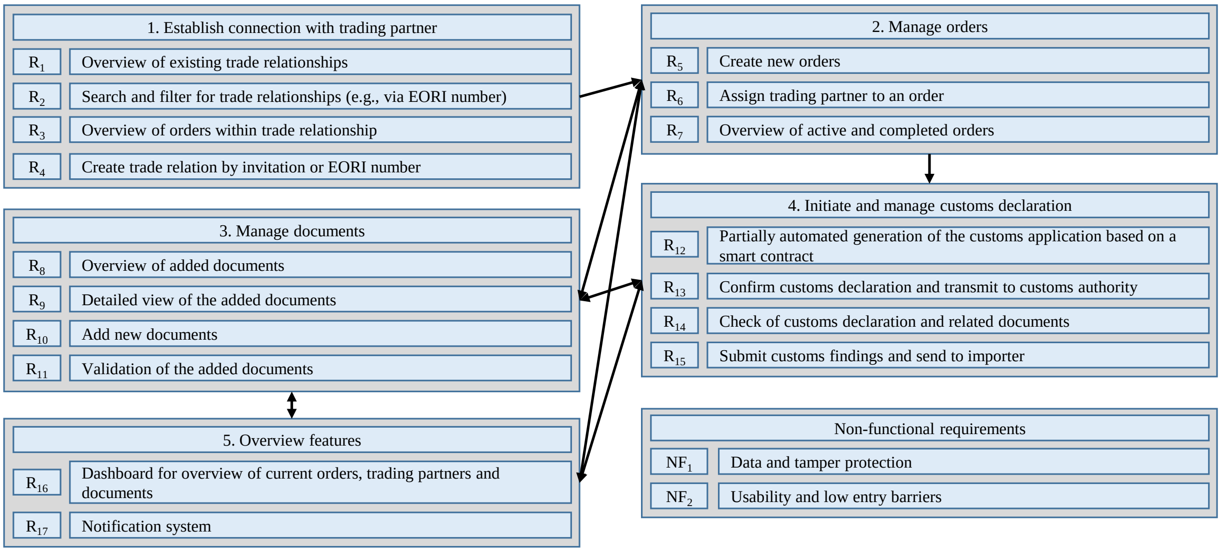


Figure 3: Functional requirements for a DLT platform to support customs processes

4.3 Design and Development

Within To implement the above requirements and thus solve the problem described, we have developed a DLT to support customs processes. Within the DLT platform, the user can submit customs applications and gain access to relevant documents. Furthermore, customs officials can utilize order-relevant information in customs tasks. For this purpose, our application consists of two layers: (1) frontend and (2) backend.

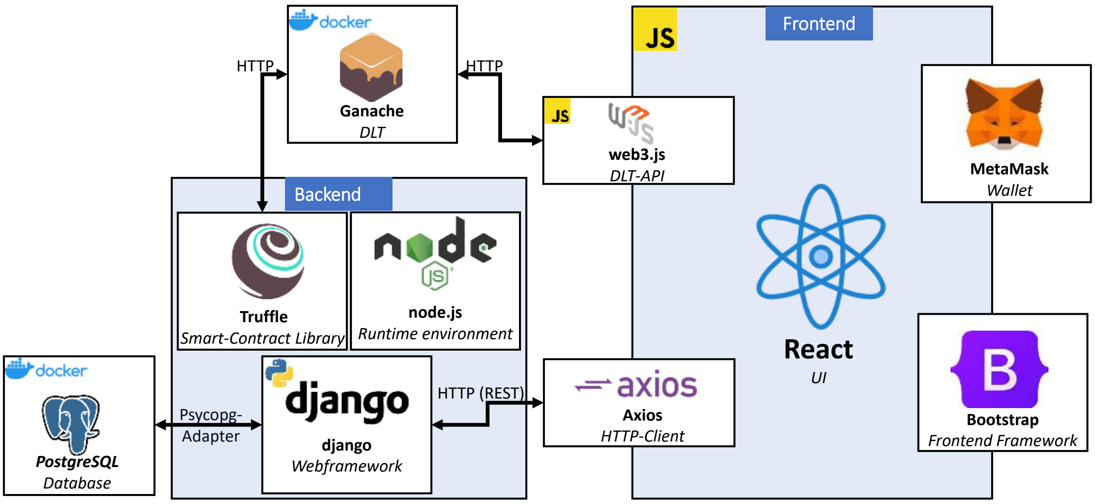


Figure 4: The architecture of the LUCID DLT-Web-Application

Figure 4 depicts the architecture, including the two layers of LUCID. Within the backend, LUCID distincts between DLT and web frameworks for implementing DLT in a web application. Furthermore, the backend uses several frameworks to realize the application logic and data management in LUCID. In this, the Django web framework implements the application logic, and Node.js provides a runtime environment. Data management in LUCID is divided into data storage on the DLT and within a relational database. The Postgres database system establishes the relational database. Furthermore, the DLT layer is based on a Ganache Ethereum blockchain, which is not connected to the Django-based backend part, and can thus serve as the basis for the distributed nodes of the DLT network. The Truffle smart contract library enables the communication and provisioning of the smart contract functions, while the MetaMask browser plugin provides access to the smart contracts. Here, the choice was Truffle Suite, since it offers an established framework for the implementation of DLT applications. Since extensive knowledge of the implementation of DLT applications is currently lacking, the Truffle Suite is also suitable for drawing on existing guidelines and documentation. As a transition to the frontend, LUCID uses the extension module "Django Rest Framework", which contains methods for providing the REST interface that the frontend application accesses by using methods from the Java-Script library Axios. For communication with the DLT and smart contracts, LUCID uses the web3.js library within the frontend application. The presentation layer of the frontend uses the JavaScript-based web framework React and uses Bootstrap to realize design templates.

Within the system landscape of a company, the application could be integrated as follows. The relevant data, e.g., customs notifications, must be transferred from existing company information systems into LUCID. If the stored data corresponds to the data structures of the use case, a corresponding transaction can be stored in the DLT network using a wallet. The data provided in this way is important for the smart contracts, as they work on the data and enable LUCID to function correctly. If the transaction is valid by consensus, the DLT network shares the information. Authorized partners of the value network can retrieve this information via an explorer and use it for further use within their own system landscape.

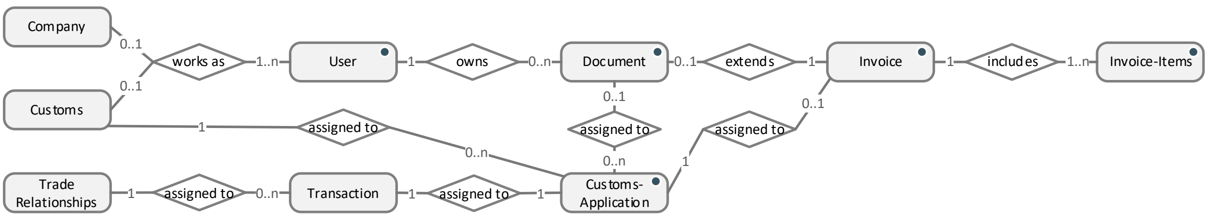


Figure 5: Data Model of LUCID (Software Artifact)

Figure 5 shows the database model of LUCID in reduced form, where a dot in the entity indicates elements that have attributes that are also stored on the DLT. The complete version can be found in Appendix 2 due to its complexity. The database stores the identifier and contact data of process-relevant companies and customs authorities. The EORI-No. and the Public Key are of particular relevance as they serve as unique identifiers in the system. The public key is the unique identifier of the MetaMask wallet to operate within the DLT network. This is stored in the conventional database to perform the matching between the registered users and the wallet deposited with MetaMask. If the data does not match, the transaction is rejected, e.g., when uploading documents or declaring customs. Furthermore, the system stores the initiated trade relations between importers and exporters. The system stores the transactions created between companies in the "transactions" table and establishes a direct link to the corresponding partnership. Uploaded documents are stored with master data and authorized users can access the path to the file. The invoice extends the document object with specific attributes such as invoice amount, description, and invoice item. The document customs declaration takes on a unique role because this is stored in a separate table that maps the attributes of the customs declaration based on the requirements of the German customs declaration.

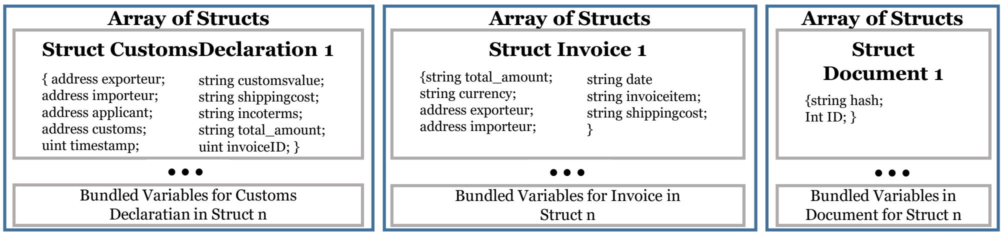


Figure 6: Data management in the DLT

A smart contract holds the data, which is stored on the DLT network. Here, LUCID uses so-called structs to structure data within associations. These structs can then be stored in arrays. When creating the struct, it generates an individual ID, enabling access to individual data within this array. This ID is stored in the relational database to enable this access. The methods required to store it are defined when the smart contract is created. Figure 6 shows the data structure within the smart contract.

Finally, this section presents two views of the prototype implementation. The software artifact is more extensive, but due to the limited scope, it is not possible to demonstrate the complete range of functions. Figure 7 shows the user an overview of the active orders and the processing status. Figure 8 in turn shows the processing view of customs applications from the customs official's perspective.

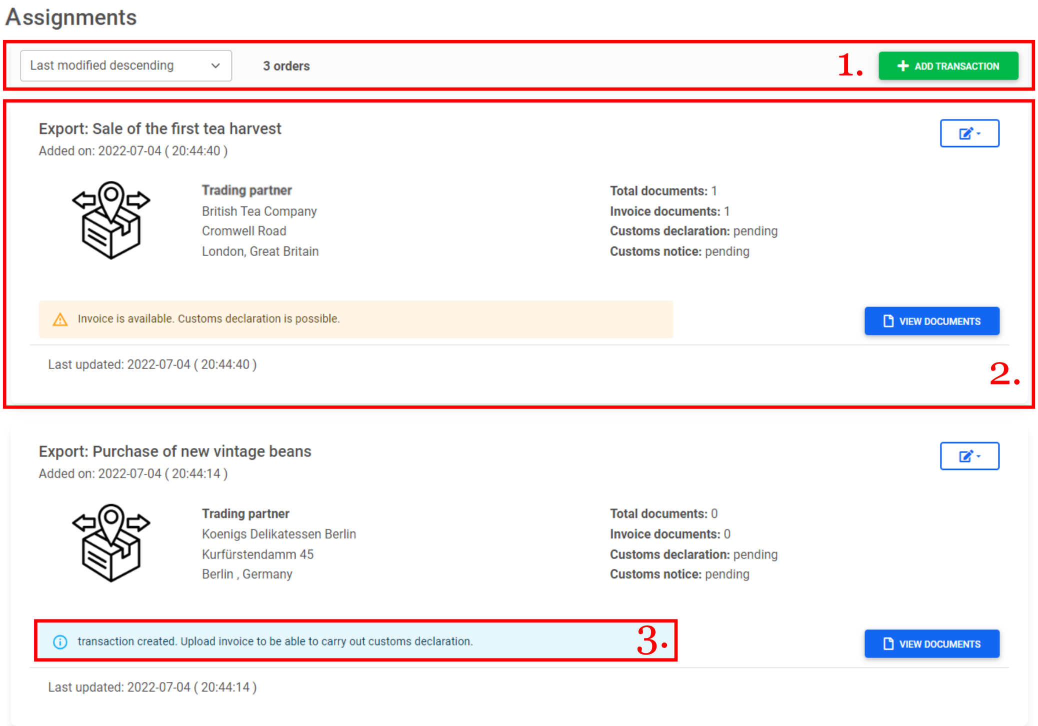


Figure 7: Overview of active orders with current processing status

In the first part of the first view (Figure 7), the system allows the importer or exporter to sort the orders based on description or date. Furthermore, it is possible to add further orders. The view categorizes each order as either an import or an export order and requires the user to assign a corresponding trading partner to each order. Additionally, each order has its description. The second part of the view represents an exemplary order. For each active order, a card is displayed which always follows a consistent structure. The card includes information about the number of attached documents and indicates whether a customs declaration and a customs notice are available. Additionally, users have the option to view the attached documents and add new ones. Appendix 3 provides an example of this view. Furthermore, Appendix 4 provides an overview on the customs declaration process. The displayed information card also shows the status of the order, which provides the user with a recommended course of action. The third part of Figure 7 represents the status of the order and can represent the following statuses in addition to the two, which are shown: "Customs declaration sent. Waiting for customs declaration to be processed," "Customs declaration accepted," or "Customs declaration rejected."

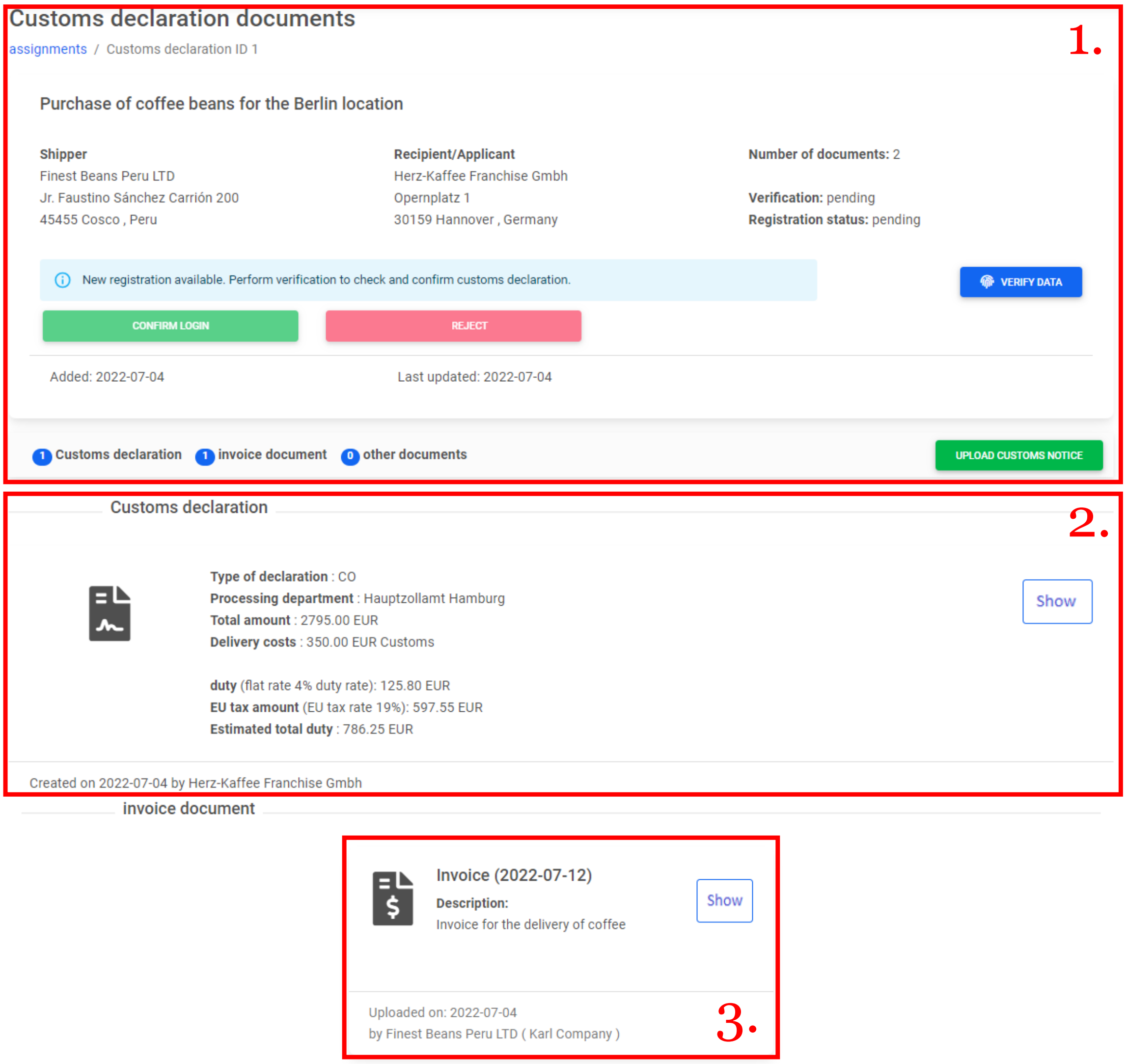


Figure 8: Processing view of the Customs Applications

The second view shows the essential information about the customs application to the customs officer by dividing the provided information into three areas, indicated by red boxes in Figure 8. The first area lists the basic information about the companies involved (importer and exporter) for the customs officer (R7). In addition, the area displays the current processing status and the number of attached documents (R8). This corresponds to the information provided in the customs declaration. The customs officer must now verify the data (blue button) (R11 & R14). This triggers a transaction on the DLT via MetaMask where LUCID compares the stored information of the relational database with the stored information within the struct on the DLT. A subsequent falsification of the information on the actual delivery of goods is thus impossible. Therefore, the information and documents stored in a tamper-proof manner, which is necessary for all parties involved in the customs process are made available for authorized personnel by avoiding the problem of inconsistent data management (NF1). Furthermore, the customs officer must upload a customs notification after checking the goods and documents to accept or reject the customs application. This information is also stored tamper-proof with the hash value of the document on the DLT (R10 & R15). For informational supplementation, to support process execution from the first area, the second and third areas provide additional information and documents. The second area displays the completed customs application in short form, which the customs officer can display and check in its entirety by clicking the "Show" button (R7). The third area displays all attached documents. In any case, the applicant must attach the invoice. The customs officer can call the document for verification via the "Show" button (R9 & R11).

4.4 Demonstration by using an application scenario

After implementing the DLT artifact, we internally validated the functional correctness of the LUCID by applying it to an application scenario. Here, the demonstration focused on the three most important roles and their activities, namely the roles of importer, exporter, and customs authorities. We have examined what measures each party must undertake with regard to the existing problems. An outline of the tested process within the demonstration is available within Appendix 5.

First, exporters and importers can establish a trade relationship within LUCID and on this basis add, display, or manage previous and current orders, which in the end are used for the customs declaration (Requirements categories 1 & 2). In doing so, the DLT platform can be used to reduce the overhead and error-prone communication from paper-based processes or via a multitude of EDI-based point-to-point connections, as only one connection to the DLT network via a wallet is required. The DLT application provides another advantage over EDI or paper-based solutions in terms of document management by addressing the problems of media discontinuity and data inconsistency. Once saved, the customs-relevant documents, as invoice data, proof of origin, or consignment notes, are directly available to all involved and authorized actors of the associated customs order (Requirements category 3). In addition, the immutability of the data of a DLT has a positive effect on the prevention of customs fraud. If the identified problem of missing documents or data occurs, this can be determined by the customs authority and the customs application can be returned to the applicants. The applicants will then receive information from the system regarding the missing documents. Again, all parties involved are included in the information flow so that no information asymmetries arise (Requirements categories 4 & 5). In addition, validation of the documents added to the customs application is possible by comparing the documents of the relational database with the DLT. This can be used to identify inconsistent data to avoid cases of fraud, and to eliminate the need for a manual check of the documents, since a subsequent change in the information, e.g., on the cargo carried, would lead to an error message (Requirements categories 3 & 4). When the customs authority has checked the information and documents against the customs receipt, it can create a customs notice. Finally, the customs officer can attach the customs notice to the document flow of the order, which leads to inform the parties involved about the status of the order (Requirements categories 4 & 5). In addition, LUCID can display former paper-based documents in the digital DLT platform to avoid the resulting media disruptions. This means that, e.g., a customs officer can retrieve the documents stored in LUCID via the mobile web application even during a customs inspection, provided MetaMask is available.

The application scenario shows that the DLT platform can potentially contribute to addressing the overall problem of information asymmetry in the application context of customs. The importer, the exporter, and the customs authority can work with the same information and documents and verify them via the DLT network. Thus, LUCID can address the situation regarding data inconsistencies, lost or modified documents, or media breaks of the paper-based or EDI process.

As a result of our first validation, we could show that the developed prototype could be used to implement our exemplary application scenario. Evaluating the developed prototype in a real-world scenario is subject to a future research study. Within the evaluation in a real-world scenario, the prototype could also be evaluated in a non-functional way, apart from the functionality within the customs processes, to gather insights into the user experience or the integration into the existing system landscape. The integration of the system landscape of companies in SCs in particular involves aspects that research needs to clarify, such as the necessary scalability of a DLT and the long-term handling of the stored data. Furthermore, future research should critically reflect on whether the inherent properties of DLT potentially improve the SC processes. After completing a full evaluation in future research, the generated results could then serve as the basis for an additional iteration of the design science process.

5 Discussion and Conclusion

In this work, we designed and prototypically implemented a DLT platform to support customs processes and created a design science contribution that adapts the problem-centered design science research approach of Peffers et al. (2007). As a first step, we identified theoretical problems of customs processes within SCs. Furthermore, we derived requirements for a DLT which support customs processes to address the identified problems by conducting a structured literature review according to Fettke et al. (2006), vom Brocke et al. (2009), and Webster and Watson (2002) (RQ1). Based on this, we used the derived requirements to implement a prototypical implementation of a DLT platform, which supports customs processes by allowing the involved trading parties and customs authorities to manage their related documents according to the corresponding customs declaration and open trading order (RQ2). Finally, we showed that LUCID is potentially able to solve the previously identified problem of inconsistent data management in value networks with a focus on the import process via the internal demonstration of the prototype based on the application scenario. Although research still needs to confirm this within a practical evaluation.

As with any research, there are limitations to our work according to the conducted literature review, the derived requirements, and the software artifact. First, limitations exist concerning the literature review, as only contributions in English and German were included as the spoken languages of the authors. Second, as identified by Finke et al. (2022) the application area of DLT in customs processes has hardly been considered within research so far, which means that the scope of relevant contributions allowing the derivation of requirements is limited. In this context, future research contributions must include the practical perspective to revise and specify the requirements. Third, the prototypically implemented software artifact uses the framework conditions of German customs procedures. Customs procedures of other countries potentially influence necessary adaptations of the prototype. Last, limitations exist concerning evaluation when considering the problem-centered design science research process we followed, according to Peffers et al. (2007). Since we only conducted an internal demonstration so far, a practice-based evaluation is necessary to validate and revise requirements, concepts, and prototypes. Here, experts from the field should be interviewed in the context of the identified roles of an exporter, importer, and customs authorities concerning the requirements and the prototype to capture a practice-based knowledge base to adapt the research findings.

Despite the limitations, we have implemented a system with a DLT that can potentially address the identified problem areas of inconsistent, enterprise-related data silos between process partners in supply chains. We could derive these problems, among other sources, from the public statements of Customs. Based on this, we derived requirements from the literature and translated them into a feasible concept. Finally, we developed an initial software artifact. Within the import process, LUCID enables all involved actors to verify the attached information and documents at any time through a flexible and uniform database based on DLT. From a scientific perspective, the requirements, concept, and prototype provide an entry point for developing design recommendations. Due to the lack of results within the research gap on DLT deployment in customs processes, this contribution represents a systematized entry point to address the identified problems in a targeted manner. In this context, the lack of DLT experts in particular presents a hurdle to the inclusion of fully comprehensive practical experience on the technology side. Nevertheless, our proposed further research uses the insights gained to pass through the design cycle a second time with the help of the practical perspective, e.g., by conducting expert interviews and developing a level 2 design science contribution. These evaluation results can then help to derive generally applicable design recommendations for the use of DLTs in SCs. This is possible because DLTs, based on their inherent characteristics, are only suitable for use in SC processes with a high degree of information exchange, and customs processes are just one example of this. However, researchers should reflect these results of the practice evaluation critically caused by the current reason of a large number of failed DLT companies. Therefore, particular attention should be paid to the question of how DLT-based systems need to be designed to ensure their economic feasibility, as the shutdown of Tradelens in 2023 is just one example of a large number of failed DLT applications. For practitioners, the requirements and the prototype implementation represent an initial step in addressing the issue of information asymmetries within customs processes.

6 References

Ajienka, N. 2017. "Tax Fraud and Blockchain," available at https://www.fintricity.com/blockchain-tax-fraud/, accessed on Jan 17 2023.

Angert, S. 2019. *Blockchain technology implemenation in the U.S. customs environment*, Monterey.

Ballandies, M. C., Dapp, M. M., and Pournaras, E. 2021. “Decrypting distributed ledger design—taxonomy, classification and blockchain community evaluation,” *Cluster computing* (25:3), pp. 1817-1838.

Belu, M. G. 2020. “Blockchain Technology and Customs Procedures,” *The Romanian Economic Journal* (23:78), pp. 13-26.

Botton, N. 2018. *Blockchain and trade: Not a fix for Brexit, but could revolutionise global value chains (if governments let it)*, Brussels, Belgium: ECIPE European Centre for International Political Economy.

Brookbanks, M., and Parry, G. 2022. “The impact of a blockchain platform on trust in established relationships: a case study of wine supply chains,” *Supply Chain Management: An International Journal* (27:7), pp. 128-146.

Chang, Y., Iakovou, E., and Shi, W. 2020. “Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities,” *International Journal of Production Research* (58:7), pp. 2082-2099.

Copigneaux, B., Vlasov, N., and Bani, E. 2020. *Blockchain for supply chains and international trade: Panel for the Future of Science and Technology*, Brussels, Belgium.

Di Benedetto, M. 2020. *Design of a blockchain-based platform to support the availability of Entry Summary Declarations to European Customs*, Delft.

Dutta, P., Choi, T.-M., Somani, S., and Butala, R. 2020. “Blockchain technology in supply chain operations: Applications, challenges and research opportunities,” *Transportation research / E* (142), pp. 1-33.

Fatz, F., Fettke, P., Hake, P., and Risse, R. 2018. “Potenziale von Blockchain-Anwendungen im Steuerbereich,” *HMD Praxis der Wirtschaftsinformatik* (55:6), pp. 1231-1243.

Fettke, P. 2006. “State-of-the-Art des State-of-the-Art,” *Wirtschaftsinformatik* (48:4), pp. 257-266 (doi: 10.1007/s11576-006-0057-3).

Finke, C., Freier, P., and Schumann, M. 2022. “Using Distributed Ledger Technologies to Support Complex Supply Chains,” in *AMCIS 2022 Proceedings*.

General Customs Authority. 2022. “The ATLAS System,” available at https://www.zoll.de/EN/Businesses/businesses_node.html, accessed on Jan 27 2023.

Green, A. 2017. “Will blockchain accelerate trade flows?: Technology raises hopes for increased efficiency and security at borders,” available at https://www.ft.com/content/a36399fa-a927-11e7-ab66-21cc87a2edde, accessed on Jun 10 2022.

Gregor, S., and Hevner, A. R. 2013. “Positioning and presenting design science research for maximum impact,” *MIS Quaterly*, pp. 337-355.

Jensen, T., Hedman, J., and Henningsson, S. 2019. “How TradeLens Delivers Business Value With Blockchain Technology,” *MIS Quarterly Executive* (18:4), p. 5.

Juma, H., Shaalan, K., and Kamel, I. 2020. “Customs-Based Blockchain Solution for Exportation Protection,” in *PAAP 2019*, H. Shen and Y. Sang (eds.), Guangzhou, China. 2019, Singapore: Springer Singapore, pp. 405-416.

Kjærgaard-Winther, C. 2022. *A.P. Moller - Maersk and IBM to discontinue TradeLens, a blockchain-enabled global trade platform*.

Kshetri, N. 2018. “Blockchain's roles in meeting key supply chain management objectives,” *International Journal of Information Management* (2018:39), pp. 80-89.

Li, S., Li, B., Li, L., and Wang, S. 2020. “Research on the Application of Blockchain Technology in the Field of Cross-border Logistics for Small and Medium-sized Enterprises,” in *The Nineteenth Wuhan International Conference on E-Business*, pp. 503-510.

Liotine, M., and Ginocchio, D. 2020. “Chapter 4 - The supply blockchain: integrating blockchain technology within supply chain operations,” in *Technology in Supply Chain Management and Logistics*, A. M. Pagano and M. Liotine (eds.), Elsevier, pp. 57-89.

Mainelli, M. R., and Smith, M. 2015. "Sharing ledgers for sharing economies: An exploration of mutual distributed ledgers (aka blockchain technology)," *The Journal of financial perspectives* (3:3), pp. 38-58.

Okazaki, Y. 2018. "Unveiling the Potential of Blockchain for Customs," *WCO Research Paper No. 45* (45), pp. 1-24.

Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. 2007. "A Design Science Research Methodology for Information Systems Research," *Journal of Management Information Systems* (24:3), pp. 45-77.

Popa, I., Belu, M. G., Paraschiv, D. M., and Marinoiu, A. M. 2015. "Best practices in customs procedures," *Amfiteatru Economic Journal* (17:40), pp. 1095-1107.

Segers, L., Ubacht, J., Tan, Y.-H., and D. Rukanova, B. 2019. "The use of a blockchain-based smart import declaration to reduce the need for manual cross-validation by customs authorities," in *Chen, Salem et al. (Hg.) 2019*, pp. 196-203.

Sturmanis, A., Hudenko, J., and Juruss, M. 2019. "The Application of Blockchain Technologies for Rail Transit Customs Procedures," in *RelStat 2019*, I. Kabashkin, I. Yatskiv and O. Prentkovskis (eds.), Riga, Latvia. 2019, Cham: Springer International Publishing, pp. 260-267.

Tan, W. K. A., and Sundarakani, B. 2021. "Assessing Blockchain Technology application for freight booking business: a case study from Technology Acceptance Model perspective," *Journal of Global Operations and Strategic Sourcing* (14:1), pp. 202-223.

Tyagi, N. K., and Goyal, M. 2021. "Blockchain-based smart contract for issuance of country of origin certificate for Indian Customs Exports Clearance," *Concurrency and Computation: Practice and Experience* (2021).

van Engelenburg, S. 2019. "Design of a software architecture supporting business-to-government information sharing to improve public safety and security: Combining business rules, Events and blockchain technology," *Journal of intelligent information systems* (52), pp. 1-24.

vom Brocke, J., Simons, A., Niehaves, B., Reimer, K., Plattfaut, R., and Cleven, A. 2009. "Reconstructing the giant: On the importance of rigour in documenting the literature search process," in *Proceedings of the 17th European Conference on Information Systems (ECIS),* Verona, Italy, pp. 2206-2217.

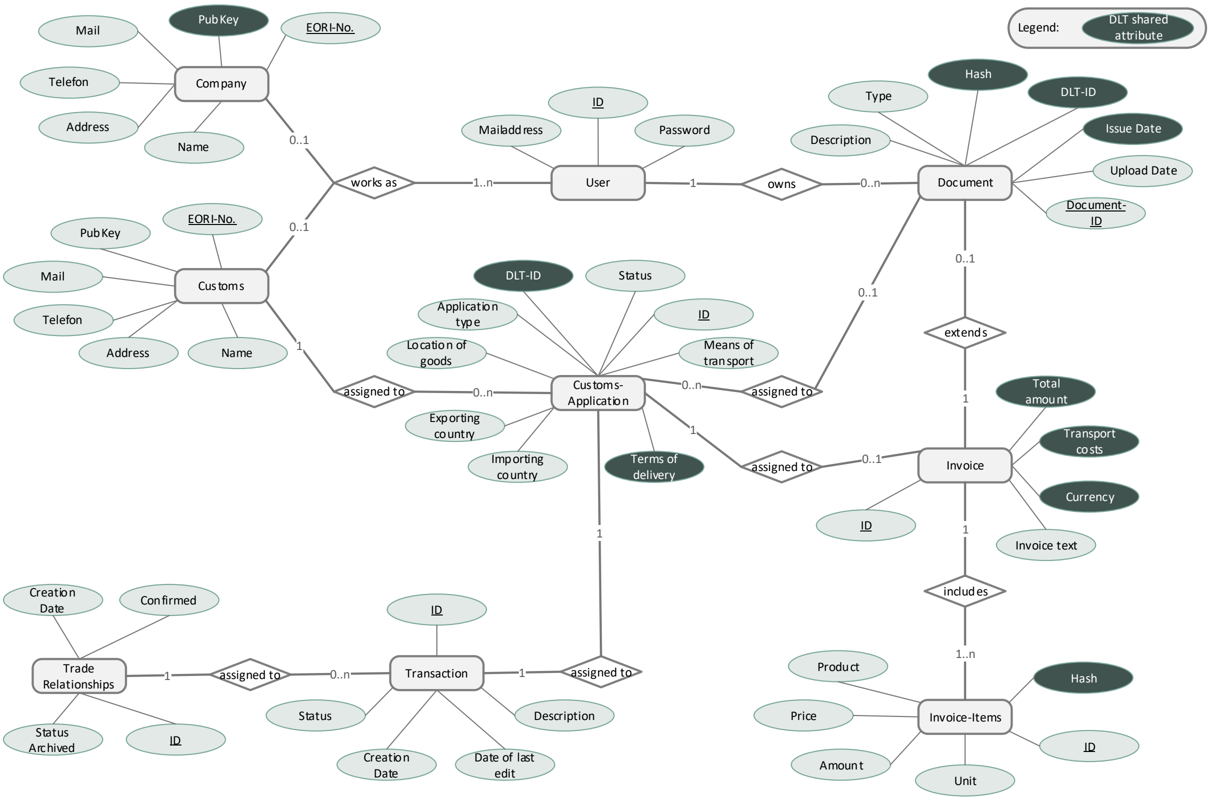
Webster, J., and Watson, R. T. 2002. "Analyzing the Past to Prepare for the Future: Writing a Literature Review," *MIS Quartley* (26:2), pp. xiii-xxiii.

Yaren, H. 2020. "Implementing blockchain technology in the customs environment to support the SAFE Framework of Standards," *World Customs Journal* (2020:14), pp. 127-138.

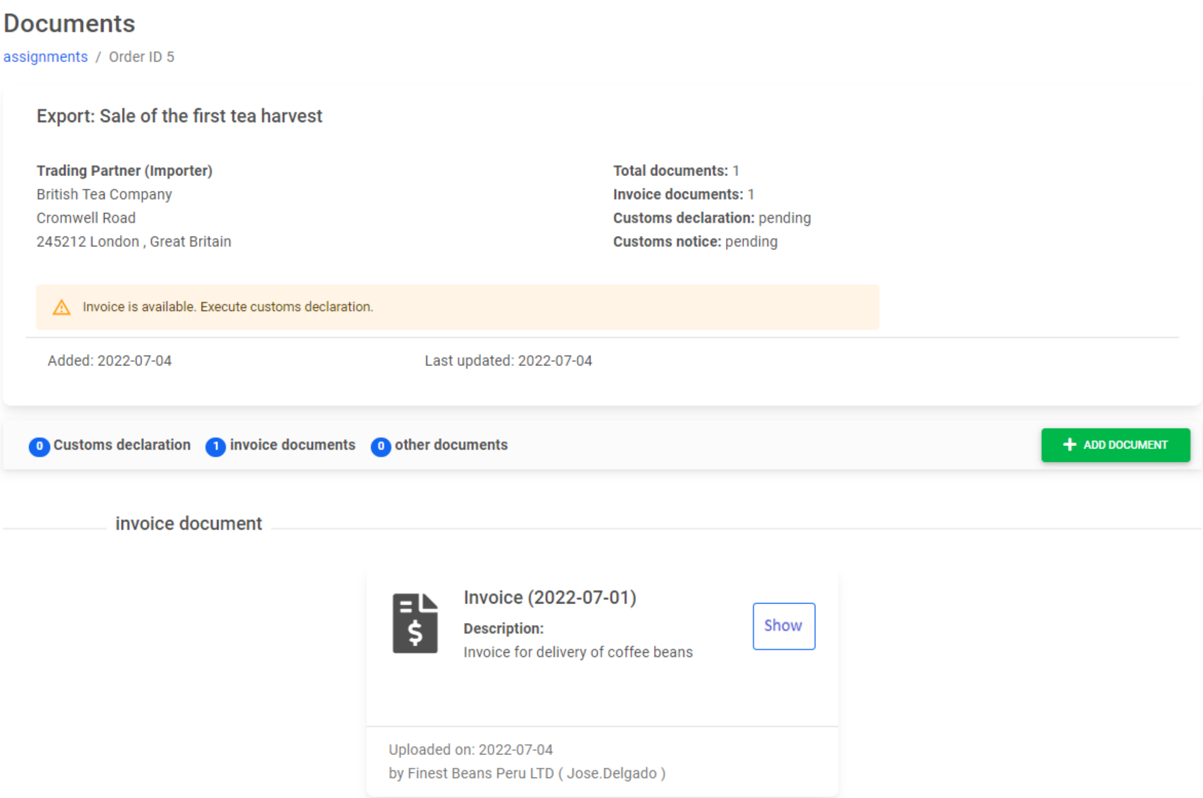
Appendix 1 Relevant literature in assignment to the considered requirement

	Establish connection with trading partner				Manage orders			Manage documents				Initiate and manage customs declaration				Overview features		Non-functional	
Sources	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	NF1	NF2
Angert (2019)								•		•									
Ballandies et al. (2021)																		•	
Belu (2020)	•			•		•		•	•	•	•			•	•			•	•
Botton (2018)								•		•			•	•	•			•	
Brookbanks and Parry (2022)	•		•		•	•	•			•	•		•						
Chang et al. (2020)								•	•	•	•	•	•	•	•				
Copigneaux et al. (2020)	•	•	•	•				•	•	•	•			•	•			•	
Di Benedetto (2020)	•		•									•	•	•	•		•		
Dutta et al. (2020)								•	•	•									
Green (2017)						•	•	•		•	•								
Jensen et al. (2019)	•	•	•	•		•		•	•	•	•	•	•	•	•	•		•	
Juma et al. (2020)									•	•		•	•	•	•			•	
Kshetri (2018)				•		•	•	•	•	•	•			•					
Li et al. (2020)				•			•						•			•			
Liotine and Ginocchio (2020)										•	•		•	•		•		•	
Mainelli and Smith (2015)	•		•					•	•	•									
Okazaki (2018)										•	•			•					
Segers et al. (2019)			•		•	•	•		•	•		•	•	•	•				
Sturmanis et al. (2019)								•	•	•		•		•	•			•	•
Tan and Sundarakani (2021)					•		•	•	•	•		•	•	•	•				
Tyagi and Goyal (2021)	•		•	•	•		•	•		•	•		•	•	•				
van Engelenburg (2019)								•		•							•	•	
Yaren (2020)										•	•			•	•				

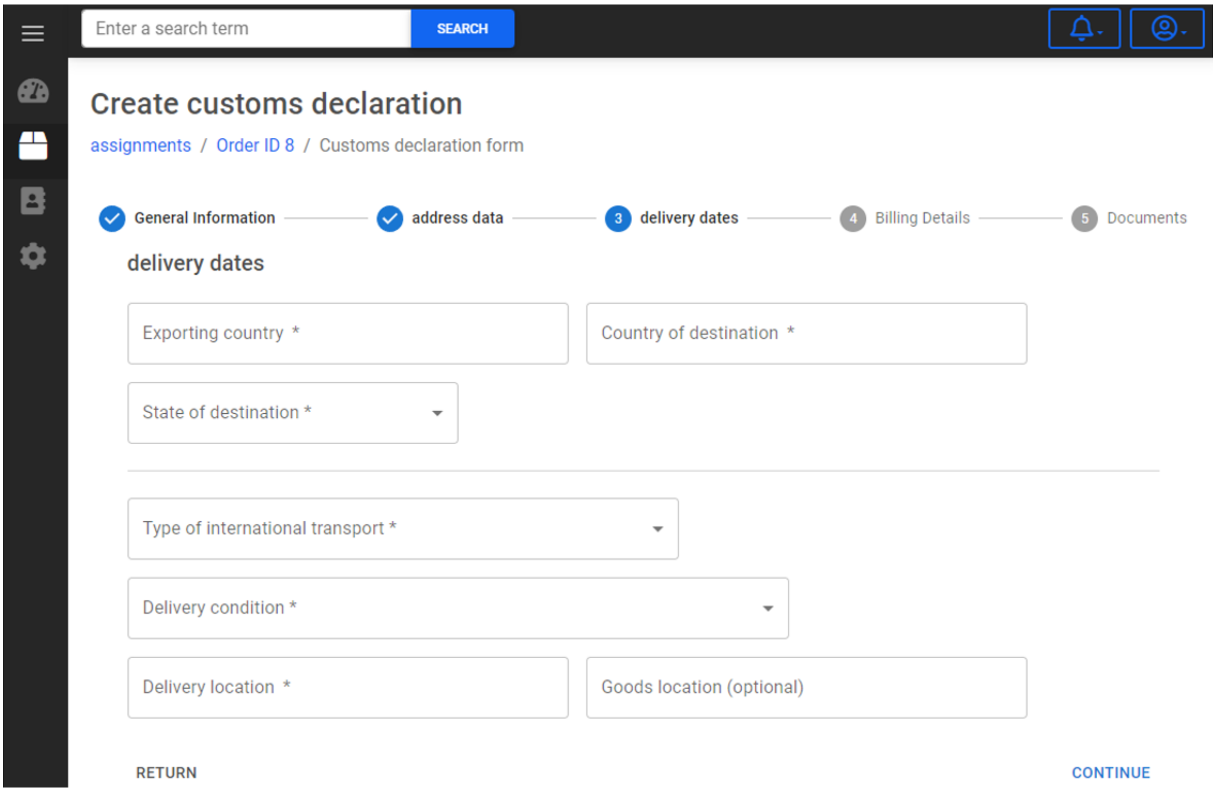
Appendix 2 Full Data Model of LUCID



Appendix 3 Detailed view of an order with attached documents



Appendix 4 Customs declaration process



Appendix 5 Procedure in the LUCID demonstration scenario