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BLOCKCHAIN NAVIGATOR

COLLABORATIVE DEVELOPMENT OF OPEN-SOURCE COMPONENTS FOR DANGEROUS GOODS ROAD TRANSPORTATION

BLOCKCHAIN NAVIGATOR

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The Blockchain Navigator publication series provides insights into current research results of the Blockchain Europe project. It presents scientifically sound insights as well as practical guidelines and methods as a toolbox to enable the effective and targeted use of Blockchain technology in the business processes of different industries - from the initial consideration to the actual implementation. In the spirit of an open community and the open-knowledge approach, we make our results freely available via this format and invite for discussion.

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ABSTRACT

The commitment to open source enterprise projects and usage of resulting components promises diverse potentials for various industries. Nonetheless, collaborative development can be challenging for participating organizations, especially in an inter-organizational context. This research paper shares experiences from an open source development project focusing on blockchain components for dangerous goods road transportation. By means of design principles derived from the gained experiences the paper illustrates circumstances for successful collaboration in open source development projects and how the applicability and added value of respective results can be ensured.

22. March 2023

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The white paper is also available on the Internet at www.blockchain-europe.nrw/blockchain-navigator.

DOI

10.24406/publica-923

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Introduction

The following paper deals with the challenges of digitization in logistics and supply chain management concerning certain road transport documents, such as CMR, customs papers, documents for dangerous goods transportation or the bill of lading. All these documents and the related, to date still highly paper-based, processes have some characteristics in common. One major characteristic is that during the lifecycle of these documents many parties are involved. Further, these documents represent kind of a security paper, as the holder can be entitled with certain rights: upon representation of a respective proof of delivery, banks may execute payments, for instance. Because of this situation, companies struggle with the idea of having these documents digitized by a trusted third party. Instead, a solution is favored which allows for self-sovereign management of digital documents. Due to its immanent features, distributed ledger technology (DLT) is considered a promising solution. Referring to a joint research effort of a Germany-based research institute and an industry partner dealing with dangerous goods transportation as one of their practical use cases, the paper aims to answer the following first research question:

1) HOW CAN DLT SUPPORT DIGITIZATION OF DANGEROUS GOODS ROAD TRANSPORTATION?

The aim of this research question is the development of software and hardware components for dangerous goods road transportation. Regarding the development of software and hardware an increasing number of inter-organizational and collaborative approaches can be observed, often based on the principle of coopetition. Initiatives such as FEDeRATED, GAIA-X, Silicon Economy, Blockchain Europe or the Open Logistics Foundation aim at decrease inefficiencies and to increase synergy effects in joint efforts. Most of these initiatives aim for the collaborative development of open source components, just like it is done in the joint research of this paper.

For reasons of transferability to other fields of interest (e.g. agreements for international road transport (CMR), bill of lading, etc.) and as a theoretical contribution (theory for design & action), the second research question is as follows:

2) WHICH DESIGN PRINCIPLES CAN BE DERIVED FOR THE COLLABORATIVE DEVELOPMENT OF OPEN SOURCE-COMPONENTS?

This paper starts with a background chapter dealing with data processing in practice, its obstacles and possible solutions concerning blockchain and open-source development.

Within chapter 3, the chosen methodology for artifact and design principle development is described. The main chapter is dealing with artifact and design principle development. The paper concludes with a section on discussion, theoretical and managerial contributions, as well as limitations and future research needs.

Background

Nowadays, a significant growth of data can be observed. Six years ago, this fact was already supported by a survey mentioning that 54% of experts participating in the research expect a significant extension of data in the future [1]. Complex and comprehensive IT-systems are examples for reasons for this fast-growing amount of data. Processing these data has a high potential for companies [2]. Regardless of the degree of automatization the data processing itself can be defined as all operations from the collection of data to the sorting, storing, or sharing of data to the destruction in the end [3]. It can be seen as a general description of using data in any kind. By processing data on an extended level, improvements regarding products and services, business processes or models can be achieved [4]. Further, on the supply chain level, the increasing availability of data can create a high level of transparency [1]. Nevertheless, there is a big difference between the potential of processing data in any way like sharing with supply chain partners and the actual processing of data in practice. According to a survey by Nikelowski et al. [5], 50% of small- and medium sized companies answered that no data at all are shared with suppliers. Only 15% of the participating companies mentioned that the own digitization is on a high level, which is a fundamental requirement regarding data processing. 46% of the companies agreed to the statement, that the gap between potential and actual usage of data is high to very high [5]. The aversion of data processing and especially data exchange with supply chain partners can be caused by several reasons. Obstacles for data sharing can be on a technological level, e.g. insufficient standards, heterogeneous systems, infrastructural barriers, lack of data security or documentation [6], [7], [8], [9]. Missing digitization and data exchange on the one hand and increasing requirements for example regarding compliance for specific processes on the other hand, lead to a huge amount of paperwork in processes between companies and external parties. Examples in the supply chain environment can be documents required for dangerous goods transportation, customs clearance, or further documents about agreements for international transport. Especially regarding the complex logistics processes in dangerous goods transportation, it is important to ensure efficient and sufficient compliance with laws, administrative regulations, policies and ISO standards [10].

To reduce the obstacles for data processing, which, apart from technological obstacles, may also consist of a lack of resources or missing know how, applying open source (OS) approaches can be a supporting strategy. In general, OS refers, for example, to software components for which the source code is publicly available [11], [12]. Hence, the source code can be directly used or adapted by other community members. Since open source code can also be reviewed by several different developers in the community with high standards, the potential for good quality results is high. Compared to developments in-house, the chance exists to implement this quality with less extended in-house expertise and in a more time- and costs-saving manner [13], [14], [15]. A further advantage is the independence from a specific software provider (vendor lock-in).

Summarizing, OS can enable companies to overcome organizational boundaries, share development costs, improve services as well as products and leverage the knowledge of a broad community [16]. All these impacts can help companies to increase the level of digitization and improve data processing. The Open Logistics Foundation is one example for a recently initiated foundation with the aim of building a European open source community to advance digitization in the field of logistics and supply chain.

Nevertheless, open source alone is not able to reduce all the existing obstacles regarding data processing. A lack of trust plays an essential role when it comes to data sharing with supply chain partners or external parties.

For the research project concerning the collaborative open source development for dangerous goods transportation, blockchain technology is a promising technology to overcome these obstacles. In addition to other advantages of this technology it is possible to verify interactions between business partners without a trusted third party. Further it is one opportunity to ensure traceability of transaction data and providing a solution for the indicated trust issues between supply chain parties when it comes to data sharing. Blockchain technology uses a network of participating instances, in which data are stored in a decentralized way in distributed ledgers. New transactions need to be verified by validators before being stored with a time stamp on the blockchain [17]. The immanent features of blockchain technology promise increasing trust, transparency as well as more accurate planning and therefore support self-sovereign data sharing and digitization in supply chains.

In practice, the number of node operators is very important for this technology since without an extensive network of verifying participants, blockchain technology cannot guarantee protection from manipulation. This is one reason why it fits well for dangerous goods transportation which requires collaboration of multiple parties along its supply chain. Further challenges in dangerous goods transportation are the processing of sensitive data and that this require a high level of trust between interacting partners. Especially in use cases like this, blockchain can be considered as an appropriate technology to increase the potential for process optimization and reducing paperwork [18], [19].

In summary, development of open source software and usage of blockchain technology seem to have a positive impact on digitization and included data processing. The next section describes the applied methodology for artifact and design principle development.

Methodology

The above-mentioned research questions and goals aim to generate two different types of results: on the one hand, a practice-inspired problem will be solved by developing respective open source soft- and hardware components (artifact development). On the other hand, design principles will be derived as a main theoretical contribution. These research outputs are typical for Information Systems Research (ISR) [20], [21]. To generate this type of knowledge, previous literature distinguished between two different ISR paradigms: design science and natural science [22] (also known as: design science and behavioral science [21]). As the presented research is primarily concerned with solving a practice-inspired problem rather than developing and justifying theories, it can be allocated to the design science paradigm [21]. For such research projects, different design science research (DSR) methods were proposed, for instance by Peffers et al. [23] or Hevner et al. [21]. Apart from DSR, action research (AR) is also a frequently used approach to generate corresponding knowledge [24], [25]. However, a clear distinction between DSR and AR seems difficult due to many overlaps [26]. Nonetheless, there are certain differences which were elaborated, for instance, by Collatto et al. [27] within a systematic literature review. According to their results, AR is characterized by a cooperative understanding of a phenomenon, whereas DSR focuses on artifact development [27]. Furthermore, main differences between DSR and AR are located in the following areas: »objectives, evaluation of results, role of the researcher and need for empirical basis« [27]. The attempt to identify the suitable method for this research project according to their systematization, led to the finding that elements from both approaches (AR and DSR) would be necessary to answer the research questions: for instance, collaborative development between researchers and practitioners (typical for AR) was planned right from the beginning to ensure goal- and practice-oriented artifact development. Equally, a plan was formulated to evaluate the artifact by using it in a real-world setting (typical for DSR). An example for overlapping elements are the research results aimed for, which address a specific situation (typical for AR), while also being generalizable (typical for DSR) by formulating design principles [27]. Therefore, we draw on an approach which combines elements from both worlds: Action design research (ADR). We followed the approach by Sein et al. [20] which incorporates AR into DSR and simultaneously addresses the problem of separating artifact development from artifact evaluation. The method is composed of four different stages and seven principles, which will be described in detail within the next section [20]. The method distinguishes between a continuum of schema for iterative artifact development: IT-dominant and organization dominant [20]. Within this continuum the decision was made to approach the joint development effort with a customized IT-dominant schema (see Figure 1) due to the fact that both industry practitioners involved were able to provide sufficient feedback for early iterations (particularly due to previous professional activities, i.e. one practitioner is the former representative for dangerous goods transportation of the involved industry partner). The process started at the end of 2020 and will be continued for artifact enhancement with regard to other process steps (e.g. main carriage and post carriage). Three researchers from the Fraunhofer Institute of Material flow and Logistics and two practitioners from Dachser SE (> 30.000 employees) represent the action design research team. Together 19 iterations were passed for ß-version development of the artifacts (soft- and hardware components) and design principles. Logistics operatives, truck drivers and commercial employees represent the end users involved in ß -version evaluation of the artifact. ß-version evaluation took place in a branch of the industry partner within a two-day test.

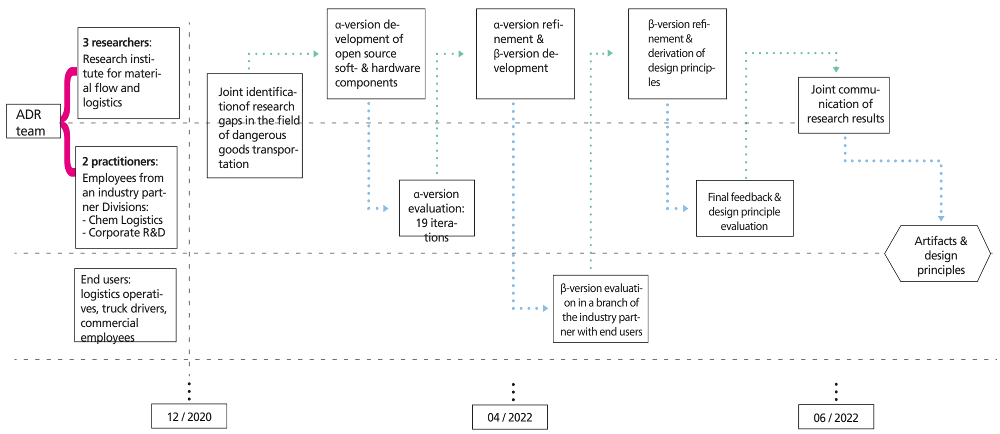

Figure 1:
Customized ADR approach based on Sein et al. [20]

For design principle (DP) development and evaluation, Möller et al. [28] propose two different ways: supportive and reflective (see Figure 2). The reflective approach was chosen as DP development took place during the (multiple) design iterations of the artifacts, not ex-ante. ADR was the framing research design and DPs were extracted from the on-going process. Meta requirements were not formulated, which is common for ADR processes [28]. Evaluation took place by feedback from industry experts and formulation was based on a template developed by Gregor et al. [29]. The process of design principle development is summarized in Table 1, where chosen options are highlighted. The third column indicates exclusiveness (EX) of the different characteristics. It is differentiated between non-exclusive (NE) and mutual exclusive (ME) characteristics.

Dimension	**Characteristics**					**EX**
Perspective	Supportive	Reflective				NE
Research design	DSR	A(D)R	Qualitative	Case study		NE
MR source	Literature	Theory	Interviews	Workshops / focus groups	None	NE
DP design	Derived	Extracted	Responsive			NE
Iterations	Single	Multiple				ME
Evaluation	Expert / user feedback	Instantiation / field testing	Argumentation			NE
Formulation	Free	Based on template				ME

Table 1: Process of design principle (DP) development based on Möller et al. [28]

The presented methodology for artifact and design principle development will be described in detail within the next section by referring to the use case in the field of dangerous goods transportation.

Artifact and design principle development

The research followed the approach suggested by Sein et al. [20]. The different steps and included principles of the ADR method will be explained below by referring to the use case of dangerous goods transportation:

Stage 1: Problem formulation

Principle 1: Practice-inspired research

At the beginning of the research initiative, the current status quo regarding to (inter-) national carriage of dangerous goods by road was analyzed. The status quo revealed three major problems with several subsequent consequences:

1. PAPER-BASED PROCESS

The current process of the involved industry partner and representative for other logistics service providers requires a minimum of nine different papers to be printed during the different process stages: pre-carriage, main-carriage, and on-carriage (three for each). Multiplied with a six-digit number of transports (between 250.000 – 350.000 per year), this leads to a tremendous consumption of resources. Apart from the waste of resources, a paper-based process is not flexible and only allows for manual updates of the consignment notes in case of staggered delivery. Not only the actors involve do not have real-time access to the status of a delivery. For worst case scenarios this also represents a challenge for parties such as police or fire brigade which are not provided with current information. In case of an accident, for instance, these parties must always act on the assumption that none of the hazardous material has been unloaded yet, even though this may be the case. Valuable resources are unnecessarily tied up by this approach that might be required elsewhere to save humans and the environment.

2. MULTIPLE INVOLVED PARTIES

Multiple parties and actors are involved in the process of dangerous goods transportation which may have different knowledge about the status of a transport due to the analog process. Carrying the (analog) documents themselves enables them to handle the papers in a self-sovereign manner but this process is not only prone to errors, there is also risk of losing documents. This poses another problem to any of the involved parties as there is a burden of proof (legal accountability) regarding to these documents.

3. NO COMPREHENSIVE DIGITIZATION

So far, existing digital solutions focus on B2A (business-to-authority / business-to-government) communication, but these solutions do not provide suitable approaches for B2B (business-to-business) processes. Apart from that, existing solutions are highly fragmented with regard to acceptance, i.e. they are only accepted by a few companies. Additionally, there is no solution covering a minimum of relevant (digital) documents, e.g. CMR, customs and dangerous goods documents. Apart from that, existing solutions represent centralized solutions offered by single vendors, which constitutes discomfort to some companies as they do not favor dependency regarding certain (critical) processes and related documents.

These major challenges and the mentioned consequences the existing solutions implicate, led to the research questions stated in the introduction. Blockchain technology promises a single source of truth while simultaneously enabling data management in a self-sovereign manner. It additionally allows for the inclusion of smart contracts (e.g. for the execution of certain alerts or payment processes) and leads to system harmonization [17]. An open source approach should simplify the on-boarding of possible new participants and has proven fruitful for industry standardization in the past. The initial focus of the joint research effort as presented in the paper was on pre-carriage including following actors: consignor, truck driver, and logistics service provider. Long-term organizational commitment was ensured right from the beginning and respective roles and responsibilities were defined accordingly.

Sein et al. [20] also suggest to cast the problem as an instance of a class of problems to ensure generalizable research results. Therefore, the use case is defined with regards to dangerous goods transportation as an instance of blockchain-based digitization of paper-based consignment notes and processes. Both researchers and practitioners are involved in respective other research projects with similar fields of application, i.e. eCMR or digital customs documents. Furthermore, all mentioned fields of application follow an open source approach. Hence, also the derived design principles for collaborative development of open source components constitute a generalized research output.

Principle 2: Theory-ingrained artifact

The development of respective soft-and hardware was based on existing design knowledge. It was particularly driven by design principles for the design of solutions »that mitigate the transactional risk and uncertainty in decentralized, inter-organizational environments« [30]. According to these design principles, respective blockchain solutions should aim for digital, tamper-proof and easily accessible solutions while simultaneously authenticating a systems' users [30].

Stage 2: Building, intervention and evaluation (BIE)

Principle 3: Reciprocal shaping | Principle 4: Mutually influential roles | Principle 5: Authentic and concurrent evaluation

Based on the theoretical foundations, an initial solution design was developed. Respective soft- and hardware components included a so called blockchain device, which has several potential functions: It constitutes an input device for the registration of transports, it can be used as a QR-code scanning device for the registration of incoming / outgoing goods or can be used as an illustrating device showing relevant information (e.g. transportation data). The second component is a sensor-based device, called Dragon Puck, which is able to capture relevant data during the process of transportation, i.e. temperature and humidity, and process them to the underlying blockchain infrastructure. The software is based on the 'Tendermint' framework and both hardware components represent light-node clients. All components were refined within 19 iterations (as shown in Figure 1) by following the principles of reciprocal shaping, mutually influential roles and authentic and concurrent evaluation. Alpha version evaluation took place together with the industry practitioners and was formative. Beta version evaluation took place by applying the artifacts in a real-world setting: to this end, a transport between two branches of the logistics service provider was tracked using both, the device and the Dragon Puck. This set of soft- and hardware components represent an answer to research question one. The previously mentioned design principles developed by Nærland et al. [30] were incorporated to achieve theory-ingrained artifacts. Within the next sections respective design knowledge gained during this process will be described.

Stage 3: Reflection and learning | Stage 4: Formalization of learning

Principle 6: Guided emergence | Principle 7: Generalized outcomes

The developed open source software and hardware components will be available via the Open Logistics Foundation. The following design principles were derived from reflecting the development process and generalizing its outcomes before publication as open source components. Overall, 14 individual design principles were identified. Seven of the derived design principles relate to providing 'circumstances for successful collaboration', while the other seven principles are about the 'successful development of open source components' (see Table 2). The derived design principles provide an answer to research question two.

Table 2: Derived design principles (overview)

	Circumstances for successful collaboration	Successful development of open source components
Principle of ...	Collaboration environment	Interdisciplinary and experienced teams
	Use case specification and scaling	Agility
	Initial participant limitation	Practical evaluation
	Responsibility	Documentation
	Benevolent dictatorship	Common licenses
	Open source mindset	Existing standards
	Long-term commitment	Legacy compatibility

Following, all derived design principles are formalized by applying the design principle schema proposed by Gregor et al. [29]. This schema suggests to structure design principles as shown in Table 3.

Table 3: Design principle schema according to Gregor et al. [29, p. 23 ff.]

Design Principle Title	Principle of ...
Aim, Implementer, and Users	For ... (implementers) to … (aim) for use by … (users)
Context	in …
Mechanism	...
Rationale	because …

While the context is the same for all 14 derived design principles (focus on an inter-organizational setting with multiple companies involved), the common aim is different for each of the two groups illustrated in Table 1. Apart from the aim, also the implementers and users differ for each of the two categories.

For those design principles in the left column of Table 1, implementers are initiators of open source development projects like the founders of the Open Logistics Foundation who aim to provide circumstances for successful collaboration of all involved parties, e. g. the participating logistics service providers, development teams, research partners and other companies. To establish a successful collaboration environment, the recommendation is to apply the seven following design principles that were identified during

Table 4: Design principles regarding circumstances for successful collaboration

Implementer, Aim & Users		For initiators of open source development projects »to provide circumstances for successful collaboration« of all involved parties …
Context		… in an inter-organizational setting, …
Principle of …	Collaboration environment	… define and set up a legal, economical, technical, and organizational room for enterprise open source because this ensures a compliant way for inter-organizational collaboration (legal), funding and handling of financial means (economical), collaboration tools (technical) and project management and staffing (organizational).
	Use case specification and scaling	… start with a specified and scalable use case because a specified use case ensures a purposeful use of development efforts and a scalable use case ensures a broader interest and application range.
	Initial participant limitation	start with a limited number of organizations and expand later in the process because this reduces time-consuming communication and coordination.
	Responsibility	ensure that responsibilities are assigned clearly because this facilitates development progress when a multitude of parties is involved.
	Benevolent dictatorship	assign the coordination to a party that doesn't pursue own interests regarding the developed artifact(s) because this avoids conflicts of interest.
	Open-source mindset	be transparent about the economical, legal, and technical implications of open-source development and establish an open source mindset because experiences from traditional software development or missing experiences in general might lead to false expectations, approaches, and strategies in an open-source context.
	Long-term commitment	ensure long-term commitment by means of contracts or other binding agreements because a reliable and stable environment is mandatory for efficient development processes.

this research (see Table 4).

The first design principle relates to collaboration environment and states that a legal, economical, technical, and organizational room must be defined and installed to collaborate in an enterprise open source project. The Open Logistics Foundation for example consists of a foundation and an association that provides contracts for potential members to gain legal clarity, a defined membership model with transparent cost structures, a common GitLab repository to store the open source components, and is organized in various steering committees, development projects, etc.

The second design principle suggests to focus on a specified, but scalable use case at the start of an open source development project. In the research project for example, focus was set on the handling of dangerous goods transportation rather than trying to develop components for all different types of transportation documents (e.g. CMR, bill of lading, etc.). This allowed to find solutions for one specific paper-based logistics process and provided the opportunity to transfer development results to other fields of use later.

Design principle three proposes to begin with a limited number of organizations and involve more parties in a later stage of the process instead of starting with a multitude of stakeholders right away. The research project started with two parties initially involved and is now planned to be extended with other organizations to consider feedback from other perspectives as well. This ensures that the targeted open source components are not developed according to the requirements of one single organization and thus enables a broader field of application.

Two of the biggest challenges for inter-organizational collaborations faced in this research are alignment of conflicting interests and clear allocation of responsibilities. Design principles derived from facing these challenges are principles of 'responsibility' and 'benevolent dictatorship'. The first one recommends to establish a common understanding of who is responsible for which tasks early on. Additionally, it is important to define rights of every participant, e. g. who determines the next development goals, who executes the development and who provides use case requirements. This constant interaction between various partners with individual goals may reveal conflicting interests that have to be aligned to ensure the efficiency of the joint efforts. Alignment of conflicting interests is the primary goal of the design principle 'benevolent dictatorship'. This suggests to leave planning and prioritization of development to an organization that doesn't intend to deploy the developed open source components itself. This can be a research partner or a development company for example. This is of course no guarantee for proper interest alignment as different organizations can still pursue their own interests, but the involvement of a rather neutral partner as a type of 'benevolent dictator' proved to be valuable for the research project.

Last two design principles aiming to provide circumstances for successful collaboration by contributing to its stability are those of establishing an 'open-source mindset' and ensuring 'long-term commitment'. As the collaborative development of open-source components has its own economical, legal, and technical implications compared to traditional software or hardware development (e. g. variety and multitude of potential users), it is mandatory to be transparent about the consequences early on to not jeopardize the stability of the development environment by false expectations or approaches. Another factor in providing a stable environment is to ensure the long-term commitment of involved organizations. This can be done by binding agreements like the membership contracts provided by the Open Logistics Foundation.

In addition to providing circumstances for successful inter-organizational collaboration, the success of open source components is dependent on other factors as well. These factors can be influenced by responsibles of respective development projects by following seven design principles that were derived from the dangerous goods research project (see Table 5).

Table 5:
Design principles regarding applicability and added value of development results

	Implementer, Aim & Users	**For responsibles of open source development projects »to enable successful development of open source components« for use by companies in relevant sectors**
	Context	… in an inter-organizational setting, …
Principle of …	Interdisciplinary and experienced teams	ensure that the project team is interdisciplinary and has relevant practical experiences because a development project with several different stakeholders and fields of expertise requires a multitude of skills and experiences.
	Agility	implement an agile project management and development approach because this allows to consider feedback and newly gained experiences throughout the development process as well as reactions to changing circumstances.
	Practical evaluation	evaluate the development results practically as early as possible because this ensures goal-orientation and desired performance of developed artifacts.
	Documentation	document the development results extensively and easily understandable because this eases the technical implementation and on-boarding of future users.
	Common licenses	apply common open source licenses because it enhances legal clarity and acceptance.
	Existing standards	explore and draw on existing industry and technology standards because it will extend and accelerate the applicability and acceptance of the developed solutions.
	Legacy compatibility	develop generic interfaces that allow for enterprise legacy system integration because it reduces the individual development effort of organizationsw when drawing on open source components.

First, the principle of ‘interdisciplinary and experienced teams’ concerns the set-up of the development project team itself. It recommends to assemble a team that combines a multitude of skills and practical experiences with regard to a certain use case. For example, the research team of the dangerous goods development project consisted of researchers with a background in dangerous goods and logistics, software and hardware developers, a logistic service provider’s technology consultant and a chemical logistics practitioner.

The second design principle 'agility' suggests to bring these various expertise and experience together by implementing an agile development and project management approach. This allows the continuous consideration of feedback from practical partners and reaction to changing circumstances like newly published legal requirements regarding the electronic dangerous goods transport document.

A design principle that is supported by agility is that of 'practical evaluation' as it allows to consider experiences gained from tests in a practical environment and thus influence the further development. The practical evaluation of the research project artifact took place in a branch of a partnered logistic service provider in April 2022 after approximately one year of development due to COVID-19 restrictions and because initial feedback of involved practitioners was sufficient as shown in Figure 1. The evaluation consisted of testing the prototype in a real-world scenario and together with real end-users.

The design principle 'documentation' enhances the ability of future users to use the artifact as initially intended by proposing to document the development results extensively and easily understandable. In the research project, documentation followed the Arc42 documentation standard that consists of various chapters with different focal points and thus addresses a wide range of potential users.

In addition to a potential barrier of understanding, a multitude of technical challenges can limit the adaptability and application range of development results and thus undermine the success of corresponding projects. The last three design principles contribute to minimizing these risks. First, the principle 'common licenses' suggests to apply common open source licenses like Apache. Another principle is that of 'existing standards' that recommends to explore and draw on existing industry and technology standards. In dangerous goods transportation for example, a reference system architecture was developed and introduced as a legal requirement for the handling of electronic dangerous goods transport documents. Data models in the research project take this reference architecture into account and are designed accordingly. Lastly, the principle of 'legacy compatibility' proposes to consider the existing system landscape of organizations by developing open source components in a way that allows them to be adapted to existing legacy systems with minimum effort.

Discussion and theoretical and managerial contribution

The presented project gives an answer to the first research question by showing that DLT can support digitization of dangerous goods transportation in several ways: first of all, and in combination with the above mentioned Devices, it allows the replacement of paper-based processes in a setup with multiple different parties involved without having to trust a third party. Interoperability to different legacy systems can be ensured with respective interfaces. Second, and especially relevant for fields of application with sensitive data, blockchain technology allows for self-sovereign data sharing, i.e. node operation is theoretically possible for each participant and read and write sets can be chosen respectively. This in turn increases trust in an inter-organizational setting, while simultaneously increasing transparency for parties involved in certain transactions.

With regard to the second research question, 14 design principles separated in two groups of seven principles are derived based on the practical experience gathered in the research project. The design principles of group one are related to providing circumstances for successful collaboration like an open source mindset, long-term commitment or clear responsibilities within the collaboration. The second group of design principles concerns the successful development of open source components and include principles like working in interdisciplinary and experienced teams, using existing standards or ensuring the documentation of developed artifacts. Each principle aims to ensure a successful collaborative development of open source-components.

Regarding the theoretical contribution of the research, developed design principles are the main outcomes (theory for design and action). These design principles are »design decisions and design knowledge that are intended to be manifested or encapsulated in an artifact, method, process or system« [29]. Further, the principles can be even separated in design principles for initiators of a research project and the working groups executing.

For the management level, the developed soft- and hardware components of the project can be used as examples for following the design principles derived. Next to this, since the components are open-source they also can directly be used in the field of dangerous goods transportation. Additionally, a transfer of the developed design principles and artefacts is possible for the digitization of further transport documents like CMR or documents for customs clearance.

Limitations and future research

Nevertheless, there are some open questions left which have not been answered by the presented research and can therefore be part of future research. These questions are related to different fields: within an inter-organizational setting it is of interest for all involved parties how a governance model can be developed. An example for a governance trade-off could be allowing for decentralized decision making, being open and incentivizing participation of new members (inclusiveness), while also not slowing down decision making processes at the same time. Additionally, and closely related to governance questions, the suitability of different technical blockchain infrastructures can be researched from different point of views, e.g. legal certainty of public permissioned vs. public permissionless blockchains. With regard to the derived open-source software and hardware components, future research could focus on aspects of IT security, integration of other devices or in general on their applicability to other fields of use (e.g. eCMR or customs).

On the other hand, the research project revealed some research gaps related to the process of dangerous goods transportation itself. It is of interest how further participants can be included, as well as which impact the inclusion of main and on carriage have on the initial research results, which focused on pre carriage. Furthermore, future research could focus on enhancements of the derived design principles, e.g. by testing them in other open-source related fields of logistics and supply chain management. This could also shed light on the question how enterprise open-source projects in similar contexts can successfully be setup and scaled.

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