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Digging for Quality Management in Production Systems: A Solution Space for Blockchain Collaborations

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Abstract

Quality management (QM) and efficient information sharing among value chain partners have been important IS research topics for decades. Today, IS researchers and practitioners hope to overcome various information inefficiencies in complex supply chains using blockchain approaches. Additionally, future traceability regulations increase companies' interest in innovative blockchain-based enterprise solutions. We identified several factors that could hinder BC adoption, due to a lack of standards. This paper sheds profound light on organizational and technical aspects of blockchain enterprise applications to support future collaboration initiatives. Furthermore, it develops a terminology that researchers and practitioners can reuse. A case study describes several quality-related objects and events that characterize multiple dimensions and traceability types. Based on these findings, we provide a set of design principles to assist future design features. Finally, this paper provides a holistic orientation and implications for researchers and practitioners moving forwards.

Keywords: Quality Management, Blockchain, Supply Chain Traceability, Enterprise Systems, Case Study

Introduction

Traceability of supply chain components, events, and quality certificates plays an essential role in numerous industrial companies to fulfill legal and business requirements, both future and current (Hastig and Sodhi 2020; Zamfir 2020). Furthermore, today's highly regulated manufacturers are interested in selecting trading partners and establishing long-term strategic cooperations to source parts from quality-certified production environments. In this context, companies of various sizes may see blockchain (BC) technology as a tool for new strategic supply chain collaborations and innovative Quality Management (QM) information sharing use cases (Rejeb et al. 2021). Motivations for applying this technology include preventing counterfeiting of safety-relevant parts, coordinating quality-dependent recalls more efficiently, or initiating horizontal integrations for enhanced QM practices to establish a Zero-Defect Production Environment (Caccamo et al. 2021; Miehle et al. 2019; Powell et al. 2021). However, large companies often have vast business and technology integration requirements driven by a combination of objectives, historically grown mindsets,

and complex finished products. This complexity challenges upstream trading partners to create new, standardized forms of inter-organizational collaboration practice and clear nomenclature for communication. Furthermore, there is an urgent need for an integrative perspective to reduce and manage the complexity drivers of quality processes, products, state-of-the-art enterprise systems, and upcoming transparency concerns (Kuhn et al. 2018; Pytel et al. 2020).

The promise of transparency and increased supply-chain quality through horizontal BC integration is still present, but beset by a range of technical and organizational challenges. On the one hand, traditional information systems (IS), such as enterprise resource planning (ERP) or manufacturing execution systems (MES), offer a reasonable basis for horizontal supply-chain integration, but are mainly designed for vertical integration (Sunyaev et al. 2021). Furthermore, research scientific literature on enterprise BC integration is scarce, so a balanced examination of the topic is only possible to a limited extent (Haddara et al. 2021). On the other hand, examining organizational traceability guidelines, we notice that global standardization organizations such as GS1 propose standards for the definition of 'Track' and 'Trace' systems but mention that both of these terms are used indistinguishably for ensuring the traceability of objects in supply chains[1]. This inconsistent usage is also recognized by Olsen and Borit (2013), who, while trying to standardize established organizational traceability terms, described the widespread confusion among practitioners and researchers. Technical discussions are still more intense, regarding the technical aspects of BC traceability terms and the use of digital assets such as hybrid UTXO or ERC-1155 tokens to trace complex product structures (Kuhn et al. 2021; Madhwal et al. 2021; Pytel et al. 2020). In the future, these terms may become more distinct and standardized by ISO/TC 307 guidelines of objects for designing and integrating innovative BC systems[2]. However, as mentioned above, the current literature mainly concerns the transparency and standardization challenges of process and IS integration in supply chains (Heines et al. 2021; Sedlmeir et al. 2022; Sunyaev et al. 2021). Our contribution in this paper focuses on the above challenges of nomenclature and horizontal integration, and explores the following research questions:

RQ1: How can blockchain technology tackle QM data transparency concerns and create trusted industrial traceability solutions?

RQ2: Which design principles enable blockchain adoption to address standardization challenges in supply-chain collaborations?

We begin with an overview of relevant theoretical and practical work to answer these research questions. We then define the methodology we follow within this paper. Subsequently, we dive into QM standards, the integration of BC production environments, and three QM case studies as a foundation for our work. Afterward, we derive meta-requirements and transform them into prescriptive and abstract principles for designing future QM IS artefacts. This is followed by a glimpse into a severe QM transparency dilemma that we identified. We conclude by considering current limitations and future research directions.

Related Work and Findings

This paper focuses on necessary objects influencing design decisions and the quality of secure collaboration in supply networks. We start with an overview of theoretical and practical perspectives, addressing the problematic in the best interest of researchers and practitioners. We begin with supply chain traceability obstacles on the organizational level before zeroing in to a more detailed, object-based level and the solution space required by the methodology followed in this work (Möller et al. 2020; Vom Brocke et al. 2020).

Obstacles to blockchain adoption in supply chain management. BC technology contributes to meeting supply chain objectives by increasing transparency and audibility of transactions and monitoring various conditions. Adopting BC, or any emerging technology, is fraught with obstacles. Among these, there are technical concerns about throughput, latency, size, and scaleability (Hofmann 2020; Lu and Xu 2017; Peck 2017). Furthermore, organizational concerns deal with high coordination efforts within BC consortia (Sunyaev et al. 2021), privacy and security issues, regulatory uncertainty, multiple parties that have to join forces, resistance to change, lack of acceptance in the industry, and, finally, the absence of clear benefits that

[1]https://www.gs1.org/standards/gs1-global-traceability-standard/current-standard#6-Glossary
[2]https://www.iso.org/standard/81978.html?browse=tc

BC technology may bring (Hackius and Petersen 2017). The high mortality rate of BC projects, driven by various complexity drivers of finished products or traditional enterprise systems, may also increase resistance (Dietrich et al. 2021a; Pytel et al. 2020; Sedlmeir et al. 2022). As a result, discussions about the complexity and transparency of BC also are on the rise within supply chains (Dasaklis et al. 2022). Sedlmeir et al. (2022), therefore, suggest starting these discussions at an organizational level, to consider how visibility and workflow processes of sensitive objects could be organized.

Obstacles concerning inconsistent terminology. Terms are used inconsistently on the business side, between published GS1 guidelines and current BC traceability solutions that leading software providers promote as 'Material Traceability' (SAP 2021). Such solutions offer objects like materials and batches, and furthermore include virtualized technical objects like a unique identification of an ERP, a plant, and (predefined) supply chain events. GS1, in contrast, defines those as the tracing of objects (materials), location (plant), a system, and (predefined) visibility events. According to the GS1 definition, tracing all these objects would then result in a 'traceability system'[3], that enables 'mechanisms for the identification of objects' (GS1 2017b). Moreover, we recognize a lack of separation from the technical BC traceability properties of tokens or block hashes in both cases. Overall, the term 'traceability' is poorly defined, hindering BC adoption in supply-chain collaborations and resulting in unstructured transparency discussions (Mendling et al. 2018).

Enablement to support QM with blockchain in multiple production environments. Research has begun to discuss BCs for production under the context of ISO 9001:2015 and IATF 16949 (Kuhn et al. 2021; Westerkamp et al. 2020). These organizational and process quality standards play a significant role in production environments of various sizes. They are widely adopted, but Laskurain-Iturbe et al. (2021) state that ISO 9001:2015 is too generic from the perspective of large companies, as large companies have to fulfill their own extended quality requirements, and also bear an increased need to keep the processes of their trading partners stable. Therefore, it is a reasonable starting point to consider BC adoption in highly regulated environments that have to audit several (5M) objects like humans (man), machine, material, method, or measurements. Another application is the capability of measurement or test equipment for a specific measuring task, to ensure product quality (Doshi and Desai 2019; Saad et al. 2020). The challenge for research and practice is to find a balance between formulated traceability business requirements (Hastig and Sodhi 2020), existing complexity drivers in quality processes (Kuhn et al. 2018), and the potential added value from horizontal integration and the use of BC technology. An example can be seen in large automotive companies that have started developing solutions to trace the object histories of assembly parts (Miehle et al. 2019). Finally, while there are some existing considerations of BC quality frameworks in the literature (Chen et al. 2017; Zhang et al. 2020), they lack discussion of traditional quality management standards, clear traceability definitions, and upcoming transparency concerns on objects.

Research Method

In this section, we adopt the recommendation of Treiblmaier (2020) for rigorous BC research. We first introduce the seven-step methodology that we applied to derive design principles for BC applications in production environments, answering our research questions (see Figure 1). The knowledge generated should be transferable from a single application into more scenarios (Möller et al. 2020).

To show the need for our research, we highlight the industry's objectives and the need for QM and standardization in step 1 (cf. *Introduction*). The QM research includes qualitative study in step 2 in order to derive knowledge with an ex-ante approach (cf. *Participants and procedure*). For the derivation of design decisions, Möller et al. (2020) recommend a supportive approach to assist in the design process of future artefacts. To collect sufficient information in step 4 (cf. *Identify Knowledge Base*), we follow the case-study procedure of Yin (2009), connecting empirical data to a study's initial research questions. We choose a multiple-case research design to ensure the derived design principles' high degree of reusability. To this end, following a semi-structured interview approach, we interview small and medium-sized companies that manufacture safety-related products. In addition, we describe sources to generate a sufficient knowledge base through inductive research design. In step 5 (cf. *Elicit Meta-Requirements*), the collected data sources are converted into a standardized form for systematic transfer to design principles in step 6 (cf. *Formulate*

[3]https://www.gs1.org/standards/gs1-global-traceability-standard/current-standard#6-Glossary

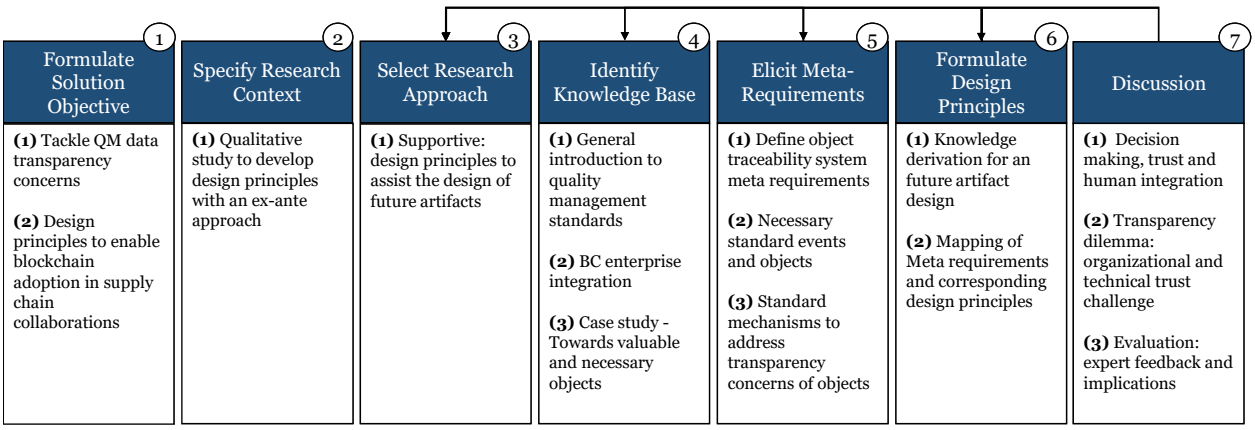

Figure 1. Research methodology in accordance with Möller et al. (2020).

Design Principles). Finally, the method is finalized in step 7 (cf. *Discussion*), discussing the implications and several issues identified throughout our work.

Identify Knowledge Base

This section introduces the sources of our knowledge base for the standardization of traceability dimensions and terms used throughout this paper. Here, we focus first on organizational perspectives of traceability in regulated environments, before comparing different enterprise-BC and quality object-integration approaches. After introducing our knowledge base, we conduct expert interviews to identify necessary traceability dimensions and to classify necessary and valuable objects.

Quality Management Standards

ISO 9001:2015. This ISO standard is intended to ensure that a company strives to produce good products or provide a good service (Bravi et al. 2019). The standard does not standardize individual quality management systems, but instead defines a catalogue of requirements for measuring and comparing quality-management systems through a process perspective. ISO 9001:2015 does not enforce essential traceability, but suggests that it should be guaranteed if required by a customer. In this case, products should be labelled to enable distinction between tested and untested products (Brugger-Gebhardt 2016).

IATF 16949. The IATF 16949 standard is often a mandatory prerequisite for being nominated as a trading partner for large companies. It specifies requirements for quality management systems for production in the automotive industry and, at the same time, complies with the structure and requirements of ISO 9001:2015 (Beckert and Paim 2017; Laskurain-Iturbe et al. 2021). It also prescribes the measurement system assessment and the method of recording the calibration and verification of test equipment. At a finer level of detail, the required measuring instruments must be adequate and suitable for a specific inspection task in the manufacturing process. This requirement, therefore, implies that it must be possible to trace back the test equipment object used for manufacturing safety-relevant products.

Inconsistent terminology and the need to define objects. The above-presented perspectives differ in their process and product dimensions. In general, the term 'Traceability' occurs in various statements, which can be classified into specific objects or without relation to a specific object. This includes different terms used by Olsen and Borit (2013) like 'origin of products' (location object), 'the ability to trace the history' (no specific object), or tracing of documents (several unique document objects). Moreover, large companies also utilize the formulation, 'event history of a part' (Miehle et al. 2019), which is a combination of 'Tracing and Tracking' and includes objects like a timestamp and a part's location. Finally, researchers generalize the term into phrases like 'to trace an entire supply chain' (Pytel et al. 2020), or transform terms like 'backward' and 'forward tracking' from the original literature by Olsen and Borit (2013) into their own quality frameworks as 'backward' and 'forward traceability' (Zhang et al. 2020). These adaptations greatly

complicate the discussion of these terms. In the following sections, we switch to an object-oriented perspective in accordance to Kuhn et al. (2021), and define organizational and technical objects inductively from BC applications.

Blockchain Enterprise Integration

Many organizations have implemented complex enterprise systems (e.g., ERP or MES) to run their day-to-day production environments. This situation puts enterprise software providers into a strategic position where they can create proprietary BC ecosystems. Leading, competing, and sometimes collaborating providers such as IBM, SAP, Oracle, or Microsoft pursue different BC application strategies (Sedlmeir et al. 2022; Wang et al. 2018). Official statements mention that BC enterprise integration, in general, is a considerable challenge (Schuster 2018). Even if large software providers are 'not trying to establish a new BC standard that only works' (Schuster 2018) in their enterprise world, to the best of our knowledge, no available research, BC documentation, or literature (Leske et al. 2019) suggests a collaboration framework for IS of different software providers. Instead, enterprise BC applications are conducted as behind-the-scenes projects without globally defined data fields or interoperability standards for horizontal integration. Furthermore, research has outlined the need for interoperability frameworks and potential ERP integration (Dasaklis et al. 2022). A collaboration of large software providers would allow the integration of simple use cases to trace different objects through production environments. Hereafter, we compare three organizational and technological approaches that include the integration of objects into Hyperledger Fabric, Ethereum, and traditional enterprise systems (Kuhn et al. 2018; Leske et al. 2019; Pytel et al. 2020). We consider two prototypes from research, and one BC solution from practice. Each prototype illustrates integration in production environments, ERP and MES, and considers a complex **product structure (PS)**. A short explanation, provided by Van Dorp (2003), is that a **PS** contains objects like a material description/productID, a batch/**UBID**, a serial number/**UIID**, an input/output relationship, and the consumption of material quantity/amount. As the BC application from practice, we choose SAP's enterprise BC solution[4] as it is currently the only transparently documented traceability solution. Table 1 provides a high-level overview of the comparison, to define different objects from an organizational and technical perspective. Terms are shown in **bold**, along with the **(abbreviations)** used, in the interests of standardization, throughout this paper.

	Organizational Perspective					Technical Perspective						
	Objects				Events	Objects					Events	
	UBID **vPS**	UIID **vPS**	**pOS**	**H**	**Quality Event**	MES **vOS**	ERP **vOS**	ERP **USID**	**UTID**	Hybrid Token	**Token Events**	**SCOR Types**
SAP (2021)	x	x					x	x				x
Kuhn et al. (2021)		x	x	x	x	x			x	x	x	
Pytel et al. (2020)	x		x	x			x		x	x		

Table 1. Traceability objects and events in existing approaches.

The enterprise BC solution contains predefined supply-chain events (e.g., Receive-, Produce-, and DeliverEvent), which indicates a well-known process perspective following the SCOR Reference Model (Zhou et al. 2011). In addition, it considers production events, which enables linking complex and **virtual PS (vPS)**. The tracing over multiple enterprise systems is reached through prerequisites in the backend system and by linking ERP **SCOR Event Types** (e.g., ReceiveEvent and DeliverEvent) (SAP 2021). In contrast, hybrid token approaches used by Kuhn et al. (2021) and Pytel et al. (2020) come from an engineering perspective that originates from conceptualizing the **physical organizational structures (pOS)** objects within a production environment. They primarily digitize physical objects, and focus on linking **vPS** that have a relation to **virtual OS (vOS)** or **humans (H)** assigned to the shopfloor environment (e.g., controller entities or storage locations). Therefore, a BC integration design is driven by multiple dimensions of the physical and virtual world. Information requirements for tracing objects can differ strongly, since relations to location objects (vOS), and the representation of a product structure (vPS), are possible as design features.

[4]https://api.sap.com/api/EventReceiver_Provider/schema

From a technical perspective, legacy or information systems offer different customizable objects (e.g., plant) or more abstract objects like a **Unique System Identifier (USID)** which for example, identifies an enterprise system through a system ID (Leske et al. 2019; Pytel et al. 2020). Moreover, it shows challenging syntactical and semantic ambiguities in the terms for data qualities. For instance, the enterprise BC solution uses 'status' (Recalled or Released) for properties of a batch object **(UBID)**, whereas Kuhn et al. (2021) define status as a hybrid of supply chain events and token technical properties (craft, transfer of a token and 'quality check passed') for serialized objects **(UIID)**. In contrast, Pytel et al. (2020) uses a different syntax for 'batch' and 'serial number', which would correspond to a UBID or UIID object as used by Kuhn et al. (2021).

However, both hybrid token approaches additionally provide a **Unique Technical Identifier (UTID)** as an object (e.g., Token ID / Transaction ID). They have the potential to avoid pushing GS1 identification standards (e.g., GLN) and a further 53 mandatory requirements (Klaeser et al. 2021) into lean production environments that already have strategic cooperations in supply networks but have not yet adopted the standards. Additionally, token properties (e.g., UTIDs and Ownership) challenge central strategic standardization authorities such as GS1, as they provide a technical alternative for the organizational supply of global specific identifiers (e.g., CPID[5]) and generic global identifiers of products (GTIN), or at least an option to improve object identification in supply networks. Furthermore, UTIDs can be transferred into the physical world and attached to products as markers to help companies or end consumers to verify the authenticity and safety of a product before they assemble or use it. In summary, hybrid tokens create a potential symbiosis of traditional IS and BC as a leading supply-chain system for certain objects instead of mapping SCOR event types into the ledger from a traditional enterprise system. Nevertheless, tokens also have downsides, as they need additional objects that result from BC immutability (e.g., markers for cancelation events) or additional business requirements, including information about quality events (Kuhn et al. 2021; Pytel et al. 2020). These tensions illustrate why BC applications and objects are not easy to compare from an organizational and technical perspective. Finally, it should be noted that all three applications deal with complex **vPS**, but only Kuhn et al. (2021) have described a **Quality or Token Event** (e.g., 'Quality Check passed' and 'Transfer') for a UIID Object. Therefore, the analyzed enterprise BC solution instead focuses on UBID and UIID objects of **SCOR Event Types**, which requires more precise differentiation of these traceability objects and events.

Case Study—Towards Valuable and Necessary Objects and Events

Participants & procedure. We conducted six interviews in three different production environments, of which three (I1–I3) turned out to be relevant for this work. We overview the implemented quality management standards to categorize relevant quality standards for the organizations described at the beginning of this study (see Table 2). The interview questions were open-ended, discussing GS1 standards, and implemented information systems for insight into the current supply network situation[6]. The recorded and transcribed interviews were sent to the companies for validation. We furthermore interviewed consultants C1 and C2 for more information on current information systems (SAP S/4 Hana and Navision 365 Business Central) and industry standards. Thus, we integrate GS1 EPCIS standards (GS1 2017a) and take state-of-the-art functionalities in the QM area into account to avoid redundancy in our IS concept basis. To do this, we first classify different products (objects) of the interviewee's manufacturing process into complexity stages, following an established framework (Dietrich et al. 2021a). Then, after data collection and transcription, a methodical data analysis and preparation was conducted with MAXQDA, following the guidelines of Kuckartz and Rädiker (2014), allowing us to identify the most valuable objects that could have a business impact. The findings are presented in Figure 2.

Object classification. We conducted the study with experts experienced in organizing the traceability of complex products and information systems in production environments. We extracted the necessary objects for traceability and processes that result from industry standards or customer-specific needs from the interview transcripts. For this purpose, pre-selected, safety-relevant products were chosen and categorized into a classification and terminology of different product complexities in accordance with (Dietrich et al.

[5]https://www.gs1.org/standards/id-keys/component-part-identifier-cpid
[6]Interview Questionnaire - https://drive.google.com/file/d/1NKl5qZo-KFP7mPYV6h44zVdfbA-egjju/view?usp=sharing

Nº	Business Area	Industry Sector	Profession (work experience in years)	Certification of Organization
I1	Production and quality	Mechanical engineering	SME managing director (30)	ISO 9001:2015
I2	IT ERP/MES/QM	Glass	Developer and consultant with engineer background (35)	ISO 9001:2015
I3	Logistics and quality	Automotive	Logistics and quality control with engineer background (12)	ISO 9001:2015, IATF 16949
C1	Consulting	Pharma	Consultant SAP QM (16)	EPCIS
C2	Consulting	Pharma	Navision consultant (7)	None

Table 2. Overview of interviewed practitioners.

2021a) (see also Table 3). In detail: product complexity comprises three categories (final, single and complex product). We transform the term **Product** into **Object** for our study. **Final Objects** comprise simple products that are not subject to changes (e.g., fruits like a mango). **Single Object** describes subjects with no modular change but are subject to transformation events (e.g., glass with temperature treatments). Lastly, a **Complex Object** can be subjected to modular changes such as assembly or disassembly events (e.g., car or complex test equipment). In addition, the classification is extended with quality objects (documents), which are indirectly related to product objects (e.g., paper-based quality certificates). These quality objects can be issued for any product object that is not directly integrated but has a logical relation caused by a quality event.

Nº	Final Object	Single Object	Complex Object	Indirect Quality Object
I1	-	-	Test equipment for measuring vibrations of safety-relevant assembly objects	QM certifications & test equipment (software)
I2	-	Glass and gel objects with temperature treatments	-	QM certifications for employees, workstations, and test equipment (hardware)
I3	-	Turned objects	Car assembly and sintered objects	QM certifications & equipment (soft- and hardware)

Table 3. Overview of direct and indirect objects modeled after Dietrich et al. (2021a).

Table 3 presents different objects in the production facilities to discuss relevant end-to-end supply chain events (goods receipt, production, warehouse, goods delivery, quality across all events) within the interviewees' companies. Furthermore, GS1 dimensions were obtained to reach a standardized understanding of the business context of location, timing, product identification, and business events. I1, I2, and I3 describe the different information systems used in their organizations to meet essential ISO 9001:2015 and IATF 16949 requirements and to satisfy customer-specific needs following the dimensions of 'who, what, when, where, and why' (GS1 2017b). It should be noted that none of the companies have implemented the GS1 Standards yet. In order to identify the QM-relevant objects, they have been marked with keywords derived from the analysis of the BC application comparison. We did not conduct any further interviews as the last interviews achieved saturation (Corbin and Strauss 1990).

Figure 2 summarizes QM-relevant objects, events and upcoming transparency concerns for sharing particular objects on a BC. The categories are indicated by six colours: Dark green (1) describes objects already accessible in the supply network. Light green (2) describes objects currently shared with direct partners us-

ing enterprise systems, but not in the network. The yellow category (3) contains objects in line with existing traceability standards and customer-specific requirements, shared only upon request. According to the interviewees, all objects marked as orange (4) should not be shared on a BC but could traditionally be shared via traditional communication channels (e.g., email). In addition, the red category (5) describes objects that the partners do not want to share in the network, as these would disclose strategic information or intellectual property of events. Finally, white objects (6) were not mentioned in the interview. Furthermore, Figure 2 is divided into SCOR, PS, OS, and quality-related objects and events, following the standardization approach of this paper.

			I1	I2	I3	Description of information and definition of objects
Traceability Objects and Events	PS	Product ID				Alphanumeric product description
		Batch Number (UBID)				Alphanumeric batch number to identify material in a 1:n (or m:n) relationship
		Serial Number (UIID)				Alphanumeric serial number to identify material in a 1:1 relationship
		Material Amount				Quantity of material that was used within an event
		Expiration Date				Minimum shelf life of the product
		Production Date				When the product was produced
	SCOR Event	Customer Number				Identifier for a trading partner entity in the network
		Supplier Number				
		Delivery Number				Delivery number used to ship the goods to the customer
Quality Objects and Events	Quality Object	Quality Order				Identifier of a quality event
		QM-Measurement Result				Result of a quality inspection, binary OK or Not OK
		QM-Document Reference (QMRefID)				Identifier for the finished QM certificate provided to the customer with the material.
		Employee qualification				Qualification of an employee, proof of sufficient knowledge to manufacture the product
		Quality Contact (Q-Contact)				Contact address for recall and complaint processes (e.g. 8D report contact)
		Quality inspection plan number				Identifier of an inspection plan for a product that is used in a quality order number
	Quality Event	Quality steps				Order operations, which are carried out within the procedure of the quality order
		Temperature measurements of manufacturing events				Several measurements taken during a production event
	vOS	Storage location for goods				Location of the product

Objects exchanged today with all partners in the network
Objects recorded and shared with direct partners using enterprise systems
Objects that are recorded internally today, but not shared with partners
Objects exchanged using conventional processes (e.g. email, documents)
Objects which the interviewers would not like to share in a network

Figure 2. Traceability, Quality Objects and Events identified in interviews.

The interviewees provided **PS** and quality objects that they primarily use in complaints or recall events. A QM document is currently directly shared with trading partners but, for traceability purposes, the information scope could be downgraded to a unique reference number (**QMRefID**). In addition, all partners provide a quality contact (**Q-Contact**), which does not specify a particular identifiable person, but is an anonymous point of contact at an organizational level.

Meta-Requirements—Object Traceability System

Meta-requirements can be derived from one or more sources, and should be abstract so they apply to one or more instances. We follow the recommendation of Möller et al. (2020) to derive multiple meta-requirements in a supportive design principles study, to meet the relevant solution objective. The information acquired to this point opens up a wide range of design parameters for a BC-based traceability system, leading to a structured classification of these parameters. For this reason, we use quality methods adopted in industrial production environments to reach a standardized understanding of traceability dimensions. We rely on the 5S quality methodology, which is integrated into ISO 9001:2015, and can be used by researchers and practitioners in a reproducible way. 5S originates from lean manufacturing philosophy and is not a value-adding practice (Randhawa and Ahuja 2017). 5S focuses on increasing employee motivation and simplifying the work environment in the long term, which fits the long-term nature of BC collaboration agreements. This method offers five steps to eliminate unnecessary objects in the workplace (**Seiri**), put them in the correct place (**Seiton**), keep the workplace clean (**Seiso**), consider a standardized work environment (**Seiketsu**), and organize it sustainably and iteratively (**Shitsuke**).

Organizational Perspective		Technical Perspective	
Objects	**Events**	**Objects**	**Events**
Product Structure (PS) Final Object (e.g. Mango), Single Object (e.g. Glas), Complex Object (e.g. Car assembly part), **indirect**	**EPCIS Event Types** Transaction, transformation, aggregate, disaggregate	**Virtual Organizational Structure (vOS) and USID** System ID, **plant, storage location**, smart contract address, client account ID	**Token Events** Mint, create, transfer, burn, redeem
Physical Organizational Structure (pOS) Plant, warehouse, storage location, machine	**Quality Event** Quality check passed	**Hybrid Token** e.g. UTXO or ERC-1155	**SCOR Event Types** Source (Receive), Make (Produce, ProduceComponent), Deliver
Human (H) Quality contact			

Table 4. Necessary traceability objects and events (Dietrich et al. 2021b; GS1 2017a; Kuhn et al. 2021; Pytel et al. 2020). Reduced.

Seiri—eliminate unnecessary and consider necessary objects. It is important to distinguish between necessary and unnecessary objects in this step. This is one of the most difficult questions since various perspectives, experiences, and digitization levels exist in multiple production environments. For this purpose, we divide traceability objects and events into organizational and technological perspectives. The organizational ones include the most superficial dimension traceability of **PS** (Van Dorp 2003). Furthermore, we consider the traceability of **pOS** (e.g., plant or machine) and add a dimension of humans **H**, as is recommended for modern zero-defect manufacturing solutions and mentioned in IATF 16949 literature (Powell et al. 2021; Saad et al. 2020). The last organizational dimension contains **Quality Event** (Kuhn et al. 2021) and GS1 **EPCIS Event Types**[7], published through EPCIS standards that define a generalizable behaviour of objects in business steps (e.g., aggregate, transformation) (GS1 2017a). From a technological perspective, we include **vOS + USID** identifying locations or an enterprise system and the dimension of **SCOR Event Types**, as they are used in current enterprise BC solutions. Additionally, we include **Token Events** (e.g., mint and transfer), discussed above in the previous *BC Enterprise Integration* section of this paper. From the object side, we focus on BC systems that deploy hybrid tokens which allow splitting and combining of objects. All organizational and technical **dimensions (abbreviations)** are summarized in Table 4 and will be filled with objects and events in a more detailed form to set them in order.

Seiton—set objects and events in order. This step classifies all objects and events into necessary dimensions. At first, we insert final, single and complex objects into PS dimension. The pOS dimension contains physical objects that humans experience in production environments, and the **H** dimension offers a 'human' or a non-personalized quality contact object, extracted from our interviews and prior literature. The **Event types** are filled according to analyzed literature and existing GS1 EPCIS standards. On the technical side, we consider **USID + vOS** (system ID + plant and storage location). Finally, in this step, we integrate the BC types Hyperledger Fabric and Ethereum. Both allow the use of standard or modified hybrid tokens and network objects such as a **contract address**[8] or **client account IDs** for ERC-1155[9] or UTXO tokens[10]. In our research we also note several non-standardized token events between these BC types (mint, create or craft and burn or redeem) that could hinder standardization efforts. These aspects should be discussed for BC terminologies using the UTXO or account-based models to uniformly define object events between BCs and IS (e.g., ERP or MES) (Gramoli and Staples 2018).

Seiso—reduce object complexity. This step describes how to clean up the objects, leading to the realiza-

[7]We point out that the analyzed SCOR and GS1 Event Types are used syntactically in the same way but convey different semantic content.
[8]https://eips.ethereum.org/EIPS/eip-1155
[9]https://github.com/hyperledger/fabric-samples/blob/main/token-erc-1155/README.md
[10]https://github.com/hyperledger/fabric-samples/blob/main/token-utxo/README.md

tion of a possible target state. Thus, unnecessary coordination effort should be eliminated at the beginning to achieve a suitable standard. We take into account the requirements of ISO 9001:2015 in distinguishing between measured and non-measured objects (components) by adding the object **indirect** (Brugger-Gebhardt 2016). The object 'indirect' suggests a logical but not physical connection of tested objects. We furthermore excluded all location objects from the **pOS** and **vOS** objects, as they lead to increased coordination efforts and limit us to the **USID** object as it provides the highest level of abstraction in an information system. For our study, we include the generic **Event Types** offered by the EPCIS standard, because Interviewee C1 requested it. Finally, the BC objects and quality contact of dimension **H** remain, which can lead to discussions about GDPR aspects. Therefore, we limit the contact details to recommendations for data minimization (European Parliamentary Research Service 2019), already transparently published, of production environments in the supply network and organized on a non-personalized organizational level. In aggregate, all reduced dimensions in Table 4 were highlighted in gray. The reduction of objects is marked in red.

Seiketsu—mapping the standard. The arrangement of work equipment or the use of a uniform color code to represent the state of a digital asset is essential to achieving a standardized language throughout complex supply networks. To develop a common and familiar representation of different traceability dimensions, we use gozinto graphs. A gozinto graph is a directed graph with weighted arrows for edges. The nodes represent different kinds of objects (e.g., raw materials, intermediates, or final products), while the arrows represent how many units of an individual part are required for a higher-level assembly (Van Dorp 2003). Consequently, the arrows indicate input–output relationships, which show a high similarity to the input–output token representations used by various researchers (Kuhn et al. 2021; Madhwal et al. 2021; Pytel et al. 2020; Westerkamp et al. 2020). Before discussing these representations and objects' behaviour, we first describe the interaction with IS and event types for various traceability objects.

Necessary events: Figure 3 presents a set of standard events following the product classification of Dietrich et al. (2021b) and existing industry standards of GS1 (2017a), which we extend for IS and BC interactions. The Object Event **OE** describes the virtual transfer of objects stored in traditional IS and loaded into the BC. We also included the transfer of **UTIDs** to the physical world, in case these are used for marking physical products. As a wide range of events can occur to (product-) objects, we defined basic Event Types **DE, DAE, TE** in accordance with GS1 (2017a). We further add an event that links direct objects and indirect QM objects leading into an Indirect Aggregation Event, **IAE**. The IS Transaction Event **ISTE** represents the virtual transfer of a digital asset between two IS. Depending on the BC type used, these objects could map **USID** (e.g., system ID A to system ID B) from different production environments in a standardized integration.

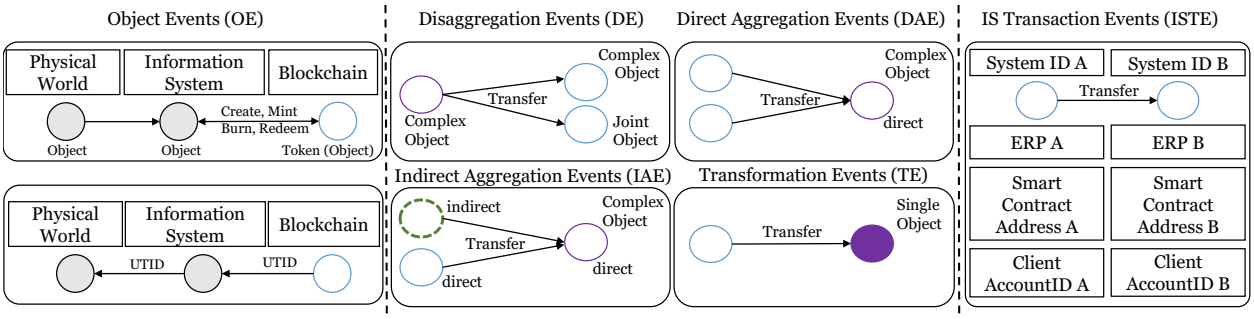

Figure 3. Traceability classification of object attributes in accordance with Dietrich et al. (2021b), GS1 (2017a), and Kuhn et al. (2021).

Necessary objects: The previously defined objects and events will now be used to define the objects and complexity levels of a traceability system. Figure 4 shows an overview of different complexity stages visualized using gozinto graphs. The simplest traceability level is **product traceability**, that includes a material description/productID, a batch/**UBID**, a serial number/**UIID**, an input/output relationship, and the consumption of a material quantity/amount. For this purpose, a **DAE** transfer event should be executed to link different identifiable objects. An enhanced complexity is built if the use case integrates quality objects, which leads to a **quality traceability**. For example, a final and quality object could be created through **OE**

and linked together in an **IAE**. However, every event is executed by an enterprise system that extends the dimension to a **system traceability**. The traceability of a system describes which enterprise system currently holds a digital asset. The owner of an asset is not a physical human **H**, but rather a virtual enterprise system **USID**. The transition from one IS to the other takes place through an **ISTE**. The last complexity dimension concerns **SCOR Events Types**, which we excluded in the previous step. Here, we mark this level with red arrows for comparison and completeness. Depending on the perspective, the graph shows different types of traceability. If the starting point is a SCOR perspective, a predefined process focused event standard is needed, and the outcome is a data integration that will inevitably increase trading-partner transparency through vendor location objects (vendor's country and postcode) to link **SCOR Events Types** across systems (SAP 2021). This apporach, furthermore, conflicts with our product-focused events (e.g., DE, DAE, and IAE) defined in this paper, which tend to provide a more detailed perspective on the product structure and quality objects. According to the traceability dimensions presented, the enterprise BC solution analyzed would be defined not as a 'Material Traceability' but rather a non-token-based 'SCOR Event Traceability Network' system, corresponding to an academic, and less promotional, marketing perspective.

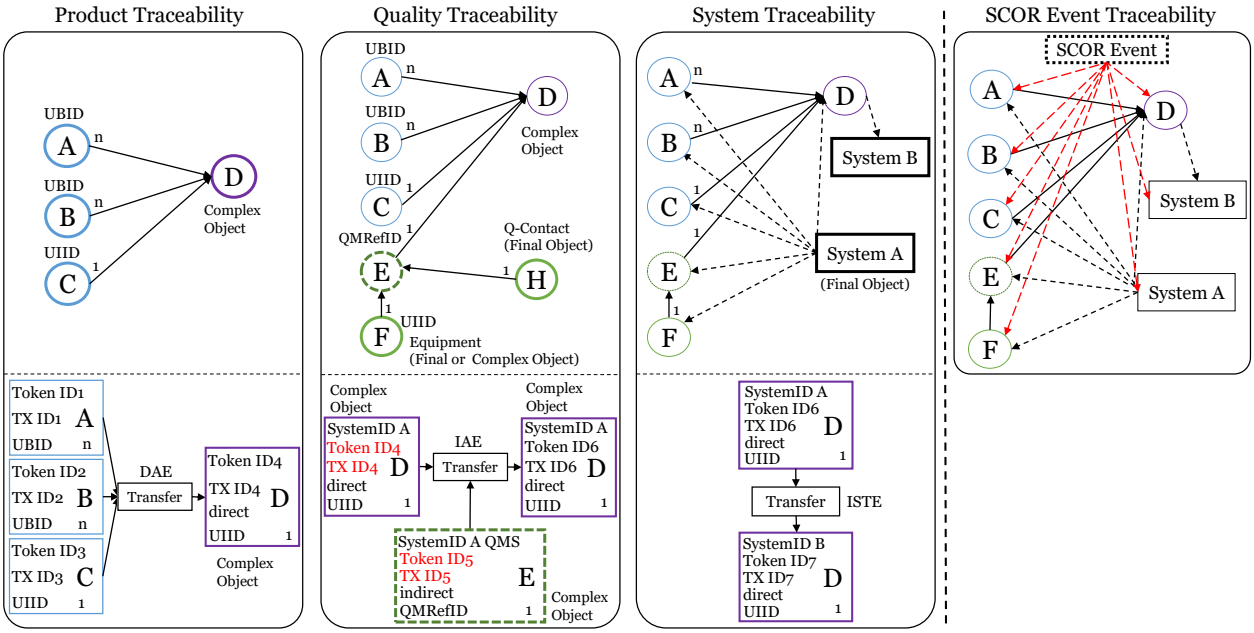

Figure 4. Complexity stages of a hybrid, token-based traceability system.

For the use case presented, we consider a **product quality system traceability** as the basis for production environments with mandatory **USID** in place. At this point, it should be noted that the integration of indirect quality objects would lead to a different sequence of **OE** events in order to achieve the correct tracing of objects (see Token ID4/ID5 or Transaction ID4/ID5). Up to this point, the paper has focused on the organizational dimensions, the design of objects, and transparency concerns. In the following, we extend this perspective and address technical mechanisms for managing the confidentiality of objects.

Technical mechanisms to address confidentiality concerns for objects: From a technical perspective, the goal is to ensure data security under the given requirements. Since BC data is generally immutable, one must decide in advance which data elements are to be stored on- or off-chain. To this end, Xu et al. (2021) propose a decision model to determine when to store data as tokens, on-chain or off-chain. Given the need to represent ownership of objects, the objects are represented by Tokens, as shown in Figure 4. In addition to the token representation, varying amounts of data must be stored depending on the specific object. Figure 2 highlights our interviewees' traceability and quality objects. We use these objects to propose adequate sharing means in Table 5. Hereafter, we describe the three sharing types in detail.

A1—Contract asset. When structured data can be stored directly on-chain, the individual quality objects are encoded in a smart contract. They are mapped to variables in the contract, and relationships can be

established through objects' IDs, similar to a traditional database. In this way, the metadata about objects and their relationships can be encoded on-chain.

A2—On-chain hash and off-chain data. When data exceed the maximum transaction size, or if on-chain storage is too costly, only a hash is stored on the BC. The actual data or document is stored off-chain (e.g., on a cloud server), and only accessible to authorized participants through access control.

A3–Zero-knowledge proof. For cases where specific facts need to be proven to a verifier, an approach based on zero-knowledge proofs (ZKPs) is more suitable. The prover sends only the required fact and an associated cryptographic proof. The proof enables the verifier to assert the authenticity of the claim. Similar to A2, this approach ensures privacy by hiding the actual data and providing only the required facts. As a simple example, ZKPs are ideal for proving that a number is within a certain range.

Based on our interviews, Table 5 maps quality objects to sharing types. While the sharing types are a suitable design for our cases, in practice, different types may be used according to the participants' preferences. For product traceability, objects can be stored directly on-chain **(A1)**, as they do not reveal sensitive information, and can alternatively be obtained by disassembling a physical **PS**. Product ID or Material Amount may be shared through a zero-knowledge proof to keep the specific objects involved in product assembly private, while sharing only necessary facts **(A3)**. Alternatively, a boolean representation to mark a material amount as 'consumed' (spent) may suffice, depending on the use case **(A1)**. Quality objects involve documents that cannot be stored on-chain; in this case, a hash reference is a suitable choice **(A2)**. For system traceability, the USID contains sensitive information. Thus, a hash reference is needed to conceal the system's identity.

Traceability	Object Description	Sharing type	Object type
Product	Product ID UBID UIID Material Amount	A1/A3 A1 A1 A1/A3	Depends on PS: Final, Single, or Complex
Quality	QMRefID / QM document Q-Contact	A1/A2 A1	Complex Final
System	USID	A2	Final

Table 5. Object and Sharing types for the defined Objects.

Shitsuke—maintain established procedures. Our traceability system classification provides a visual and technical orientation. However, the defined objects conflict with object identification standards such as DIN IEC 62507[11], which excludes humans in its definition of objects. Nevertheless, the procedure offers a reduced and standardization overview to formulate meta-requirements from multiple data sources (enterprise solution, prototypes, and interviews) to extract valuable design knowledge. Below, we merge these with design principles (DPs) to present the overall context throughout the DP development process.

Design Principles—Deriving Knowledge for Future Artifact Design

This section describes our mapping of design requirements (DR) and DP's. The requirements should address the objective solution, which, in this study, is the enhancement of supply-chain quality practices that consider consistent traceability objects and address transparency concerns (Möller et al. 2020). Additionally, DP's are part of the solution space connected to a particular problem space (Vom Brocke et al. 2020). Furthermore, they provide knowledge to design a prototype artifact. Therefore, our DPs include prescriptive and abstract knowledge to make them reusable for future researchers and practitioners in Figure 5 (Möller et al. 2020).

[11]https://www.beuth.de/en/standard/din-en-62507-1/148501913

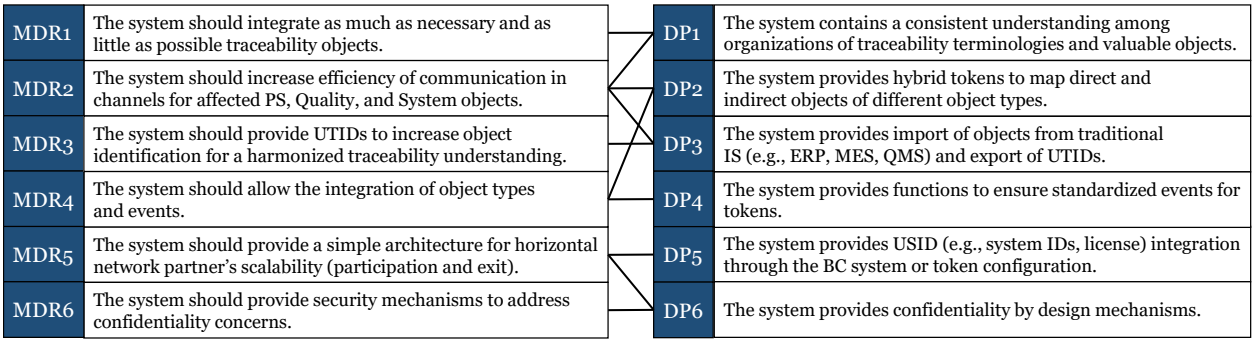

Figure 5. Mapping of meta-design requirements and corresponding design principles.

The first and second DPs focus on a standardized representation of traceability objects through a hybrid, token-based traceability system. Organizations should collaboratively determine necessary dimensions before beginning to develop concrete design features. Additionally, information about direct and indirect objects provides extended quality control over communication processes, the objects affected, and the quality trading partners involved. DP3 describes the ability of the system to import objects from traditional information systems. Furthermore, the export of **UTIDs** is to be enabled, to fully utilize the capability of BC as a leading information system for these identifiers in supply networks. For this purpose, the system allows the definition of standardized events to achieve a syntactic and semantic standard for token events (DP4). Based on this standard, an **USID** application can be used to easily integrate with a network or token standard without having to modify one's enterprise system at great expense (DP5). However, the available information must address confidentiality concerns to protect identity recognition through external parties (DP6).

Discussion: Improving Decision-Making, Trust and QM Transparency

At the beginning of this work, we stated that the traceability of objects and supply chain events is a vital aspect of modern quality management for production environments of various sizes. This has economic reasons, but is also enforced by non-standardized factors such as inconsistent traceability terms, misleading industry standards, and information system event terminologies. The mixing of processes and events is also possible due to the emergence of tokens, which requires more-granular thinking about traceability dimensions.

Trust and transparency can have various associations from a quality perspective in these circumstances. In essence, this paper focuses on transferring all the necessary virtual product data to the customer to confirm the product's authenticity, prevent product counterfeiting offside company borders and avoid isolated information sharing requests in recall situations. Toward this collaboration setting, the technical property of BC immutability is not an economic incentive. It is, rather, an innovative possibility to trace a tamper-resistant product structure's assembly and quality objects with greater integration and efficiency. This is achieved with the help of a multidimensional transaction graph, which serves as a control and visualization medium for several stakeholder organizations. Decision-making for tracing quality-affected objects is reached through direct and indirect objects. In addition, the integration of humans plays a key role, as this dimension mainly involves identifying and eliminating error origins. For example, it concerns incorrectly calibrated equipment (indirect object), which is used for the quality assurance of direct objects. In this case, the transparency increases, indeed improves, for all participants, as the identification of related quality contacts and incorrectly measured direct objects can be done immediately and in a more synchronized way.

Evaluation: Feedback from researchers and practitioners. To evaluate the DP, we interviewed further researchers and practitioners with different perspectives on network technology, blockchains, and the tracing of quality-related objects in traditional enterprise systems. The heterogeneity of the humans indicated that a visual representation of the use case to explain a product structure and events was necessary to discuss the design principles. The experts considered the standardization approach in DP valuable, but identified the main challenges as formulation of terminologies (DP1) and the determination of a system's uniqueness (DP5). Although this paper shows the system ID as a possibility for uniquely identifying an

enterprise system, IS instances are identified in different industries through time-limited licenses.

However, interviewees I1–I3 were particularly reticent about the traceability of their systems, although ideally, they would like to receive this traceability from their trading partners. This is primarily a perceived threat to competitiveness due to a change in transparency and unclearly formulated requirements for necessary objects. Other examples of perceived threats are deriving operational process knowledge or possible integration of organizational structures. At the same time, the need for more effective collaboration between organizations, and for increased product quality, is a driver for adaptation. Therefore, this transparency dilemma can be interpreted as an organizational and technical **trust challenge**. On the one hand, coordination among trading partners is necessary for the organizational level. On the other hand, technology can provide trust and disintermediation at the object level through a leading supply chain system. However, this needs to be coordinated between strategic trading partners for each information system, object, and sharing type. Nevertheless, this study demonstrates the theoretical need for collaborations in which objects can be integrated horizontally and in a standardized way to add value to multiple production environments. Notwithstanding, this must be balanced between effort and benefit, and requires a collaborative rethinking of middle management to disintermediate and reduce the complexity drivers of central authorities.

Implications for research. Current research shows that the important question is no longer whether data should be shared. Instead, it is more attractive to understand which objects and events (informational needs) could create added value for a final (private and industrial) customer (Treiblmaier and Garaus 2022). This paper, therefore, deals with a product structure-focused approach and the integration of multiple blockchain types to meet the differing objectives of researchers and practitioners. Future research and the conceptualization of use cases should consider and reference to what extent existing organizational and technical traceability standards can be reused, reduced or reasonably extended. Furthermore, comparing UTXO (Pytel et al. 2020) and ERC1155 (Kuhn et al. 2021; Madhwal et al. 2021) can be a prospect for determining which advantages and disadvantages arise for both concepts. Specifically, they could be considered to develop an event standard for batch (UBID)- and serial number (UIID)-labeled single and complex product structures.

Implications for practice. Dealing with customer-focused traceability and multiple enterprise systems demands a high degree of open-mindedness towards new technologies. It will change isolated IT landscapes and the current understanding of traceability processes. This analysis may lead to a critical questioning of historically grown traceability definitions, the quantity of traceability requirements (Klaeser et al. 2021), and a rollback of individual system modifications in enterprise systems to adopt a collaborative and standardized metalanguage. In addition, a token-based approach may lead to innovative collaborations between large enterprise software providers to allow an open technology-neutral platform integration for simple use cases (final or single objects). As collaborations among organizations become increasingly blockchain-supported, participants must establish blockchain governance processes to manage conflicting stakeholder needs (ISO 2022). Appropriate decision-making processes can also help establish consensus on token characteristics and incentives for participation. These governance agreements across all operation phases and contexts provide the necessary assurances for partners, going beyond the technical traceability of BC technology.

Conclusion

This paper derives a solution space for production environments to enhance the quality of supply chain collaborations. We provide design knowledge from the literature, enterprise BC applications, scientific prototypes, and expert interviews. The MDR and DP can be reused or extended in other research projects as well as in practice. The illustrated DPs describe the standardization of complex objects and events to coordinate efficiently in supply network initiatives. It is important to note that these DPs allow researchers and practitioners a degree of freedom to design a BC application and integrate it into traditional information systems. However, this design freedom comes with conflicting organizational and technical event configurations. Furthermore, it presents challenges to standardizing objects semantically and syntactically based on industry standards, supply chain frameworks (e.g., GS1, ISO, DIN, and SCOR), the information systems of different software providers, and hybrid tokens. It needs suitable mechanisms to secure objects using BC to achieve an accepted traceability standard. Centralized strategic authorities still publish inconsistent terminology that does not meet modern organizational and technical views of supply chain collaboration ini-

tiatives. This work intends to support researchers and practitioners in a balanced, transparent, and modern information systems research perspective to meet ongoing and mandatory business requirements to design innovative, collaborative use cases for future supply networks.

In a further research question, we investigated how transparency concerns can be addressed and trusted solutions can be designed. This question revealed a trust challenge, already starting at the organizational level (Sedlmeir et al. 2022), before being extended to an object level. Future research in this context first needs to explore the root causes of the transparency dilemma related to the application of enterprise BC solutions. Our study and related work provide the first steps toward a deeper understanding of this problem. Having understood the challenge in depth paves the way for overcoming the issue.

Our research has several limitations. These include the small sample of BC applications used to standardize terms and dimensions. In addition, we interviewed small and medium-sized companies with the guidance of GS1 dimensions (GS1 2017b), different quality dimensions, and traceability requirements. Our study further concentrated on the basic ISO 9001:2015 and extended quality IATF standards of the automotive sector, which need to be extended for ISO 22005:2007. Other sectors, like food production, may entail different problem and solution spaces. Finally, a token-based traceability network design, using several enterprise systems from different software providers, and multiple BC types is still unsolved and needs more research.

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