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Boundary conditions for traceability in food supply chains using blockchain technology

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ABSTRACT

Traceability of ingredients in food supply chains has become paramount in a world in which markets become global, heterogeneous, and complex and in which consumers expect a high level of quality. The food supply chain consists of many organizations having different interests and are often reluctant to share traceability information with each other. Blockchain has been advocated for improving traceability by providing trust. Yet, practice proved to be more stubborn. The goal of this paper is to identify boundary conditions for sharing assurance information to improve traceability. Four cases in the food supply chain have been investigated using a template analysis of 16 interviews. Eighteen boundary conditions categorized in business, regulation, quality and traceability categories have been identified. Some boundary conditions were found in all supply chains, whereas others were found to be supply chain specific. Standardization of traceability processes and interfaces, having a joint platform and independent governance were found to be key boundary conditions before blockchain can be used. Our findings imply that supply chain systems have first to be modified and organizational measures need to be taken to fulfill the boundary conditions, before blockchain can be used successfully.

1. Introduction

Blockchain Technology (BCT) is viewed as one of the most important technology trends influencing businesses. BCT has emerged as a potentially disruptive, general-purpose technology for companies increasing trust when interacting with each other (Yli-Huumo, Ko, Choi, Park, & Smolander, 2016). Potential benefits of blockchain range from technical to social and economic improvements (e.g. Schuetz & Venkatesh, 2019; Ying, Jia, & Du, 2018) and its promises are high (Hughes et al., 2019; Ølnes, Ubacht, & Janssen, 2017). Yet, analysis of Forrester estimated that 90% of the business project based on Distributed Ledger Technology (DLT) are stopped in the period 2015-2017. Blockchain adoption in the logistics and supply chain is country-specific (Queiroz & Fosso Wamba, 2019) and needs to take into account the context. So far, most literature is focusing on the technology level, addressing the technological challenges of using BCT for peer-to-peer (P2P) processes (Yli-Huumo et al., 2016), whereas the halting of projects suggests that the most difficulties can be found at the organizational level.

Recently, BCT has also been introduced as a technology for supporting the enhancement of product data traceability (Mattila, Seppälä, & Holmström, 2016). Gaining more control on the heterogeneous, complex and dynamic food supply chain is strongly required in order to fulfill the increasing demand of consumers on safety and quality of products, triggered by several food scandals (e.g. Bernard et al., 2002; Wales, Harvey, & Warde, 2006; Xiu & Klein, 2010). A very prominent one with disastrous consequences might be the Melamine milk powder scandal in China in 2008 (Xiu & Klein, 2010).

The current constellation in the food supply chain is that actors still use individual quality standards in order to comply with the common nominator as defined by international regulations (Borrell Fontelles & Nicolai, 2004) or national regulations. In order to increase the traceability of food products significantly, companies need to exchange quality assurance information with each other on a detailed level. However, this often encounters a lack of trust between supply chain partners. BCT has been heralded as a technology to create trust. Recent initiatives have been started to address food supply chain challenges by BCT (e.g. Abeyratne & Monfared, 2016; Aitken, 2017; Haswell, 2017; Millward, 2017; Tian, 2016). However, these initiatives are mainly technology-driven, focusing on technical feasibility aspects.

In this paper, a different starting point is used and the focus is put on the investigation of boundary conditions (Behnke, 2018) which need to be satisfied in order to be able to use blockchain and to address the challenges of traceability information exchange in the dairy food supply

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chain by BCT. In this research boundary conditions are defined as "*the social technical constraints in order to realize a global food traceability system*". Boundary conditions show if the necessary constraints are satisfied before blockchain technology can be used.

The following two research questions were defined for this study:

1 What are the boundary conditions for actors in the dairy food supply chain to share quality assurance information for traceability?
2 And, how can BCT fulfill these conditions?

In order to address the first question, a qualitative research method is used to empirically investigate the boundary conditions for sharing quality assurance information between partners in the dairy food supply chain. This part provides insight into the type of information that partners are currently sharing with each other and in the conditions to share *more* information with the goal to increase the level of traceability. The second question focusses on the characteristics of BCT to overcome the boundary conditions. This part has as goal to determine whether BCT can fulfill the conditions of a traceability information system in the dairy food supply chain.

This paper is structured as follows. In the next section the theoretical background is presented followed by the research method description in section 3. The case studies are described in section 4 followed by the findings resulting in a list of 15 boundary conditions in section 5. In the final section, the results are discussed and conclusions drawn.

2. Theoretical background

2.1. The increasing need for traceability of food

The globalization of markets leads to more movements of products, information, and people between nations. Consumers profit from this development by finding food products from other parts of the world in their local markets. In addition, it is nowadays regarded as 'normal' to buy fruit or vegetables independent of the season. Globalization in the food sector has on the other hand also led to the challenge to guarantee the food safety while food supply chains are becoming more and more global and dependent on an increasing number of actors.

Ideally, quality assurance demands full traceability of each individual ingredient of the end product. This requirement results in the need for the exchange of quality information between all actors in order to fulfill the increasing demand of consumers regarding safety, quality, and sustainability. Consumers' sensibility is especially triggered by several food scandals in the 1990s and 2000s (e.g. Bernard et al., 2002; Wales et al., 2006; Xiu & Klein, 2010) which have also resulted in stricter national and international regulations and stricter food safety and quality controls (Borrell Fontelles & Nicolai, 2004).

A very prominent example of a food scandal with disastrous consequences was the Melamine milk powder scandal in China in 2008 (Xiu & Klein, 2010). In this case, at least six babies are confirmed to have passed away because of Melamine contaminated infant milk powder. In addition, it has also led to imprisoning of business managers, market deterioration and bankruptcy of the milk powder supplier who brought the contaminated infant milk powder on the market.

Despite the increasing efforts to stricter regulate the required food control measures, regulatory frameworks between countries and regions diverge still widely and food safety issues and crisis situations still occur frequently on a global level (Chammem, Issaoui, Dâmaso De Almeida, & Delgado, 2018). For example, a search on the key words "food safety" on the website of the New York Times results in thee articles per months about this topic.

The food safety incidents and crisis situations have not only brought the regulators into action, but also created an increased awareness of consumers. Food traceability is nowadays regarded as an important aspect in ensuring the food safety and quality of the products (Liu, Kerr, & Hobbs, 2012; Resende-Filho & Hurley, 2012) and increases the confidence and satisfaction of consumers.

2.2. Concepts and characteristics of traceability and a food traceability system

Several different definitions of the term 'traceability' can be found in the literature (see for an overview Bosona & Gebresenbet, 2013; Karlsen, Dreyer, Olsen, & Elvevoll, 2013; Olsen & Borit, 2013). These different definitions in the literature show that there is not a general understanding about the term 'traceability'. Therefore, we had to define this term as a starting point of this study first to clarify the concepts and ensure the same view on this. The majority of traceability standards (e.g. EU, 2002; ISO, 2007, 2018) focus on describing the capability to follow critical characteristics of a product from origin (including ingredients) to the final process step throughout the supply chain. The analysis of Olsen and Borit (2013) shows that the different definitions of the term 'traceability' cover two or more of the following four concepts: consistency and clarity in used terminology (e.g. 'tracking' vs. 'tracing'), backward follow-up of ingredients (tracing), forward follow-up of products (tracking), and product history information during the supply chain.

As our focus is the activities and using blockchain for traceability, we adopt the definition of (Bosona & Gebresenbet, 2013, p. 35) in which the traceability activities are brought in direct relation to logistics activities:

> "*Food traceability is part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing animal or substance at all stages in the food supply chain so that the product can be checked for safety and quality control, traced upward, and tracked downward at any time required.*" (p. 35)

Defining food traceability as part of logistics management emphasizes the fact that food safety and quality are quality assurance capabilities which efficiency and effectiveness is strongly dependent on logistics operations. Take as an example the case of food recalls which is often used in the literature (Bosona & Gebresenbet, 2013). While a detailed set of traceability information is an important condition for this process, the effectiveness of the recall process is also highly dependent on efficient logistics operations and the level of integration between the different supply chain actors (Bourlakis & Bourlakis, 2006; McCallum, 2012). While other definitions of traceability focus on the main functionality of tracking and tracing, the definition of Bosona and Gebresenbet creates a direct link with the purpose of traceability ("checked for safety and quality control") and the conditions of applicability ("at all stages" and "at any time required").

Dependent on the direction in which information flows, forward traceability ("tracking") is distinguished from backward traceability ("tracing") (Olsen & Borit, 2013). The difference can best be explained in case of a product recall case. The capability of tracking means that products are followed through the supply chain from the beginning till the end and can be identified as based on the recall criteria. On the other hand, the capability of tracing means that origin of a product and with it the relation between objects that the product consists of can be identified.

The difference between *internal and chain* traceability has been introduced by Moe (1998). Chain traceability is the "…ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales", whereas internal traceability is the "…ability to trace…in one of the steps in the chain" (Moe, 1998, p. 211). In general, chain traceability is regarded as the capability of traceability over the whole supply chain between all supply chain actors, while internal traceability is the traceability capability of the internal processes of one supply chain actor. In order to also identify the traceability between two actors in the supply chain, the Global Traceability Standard (GS1,

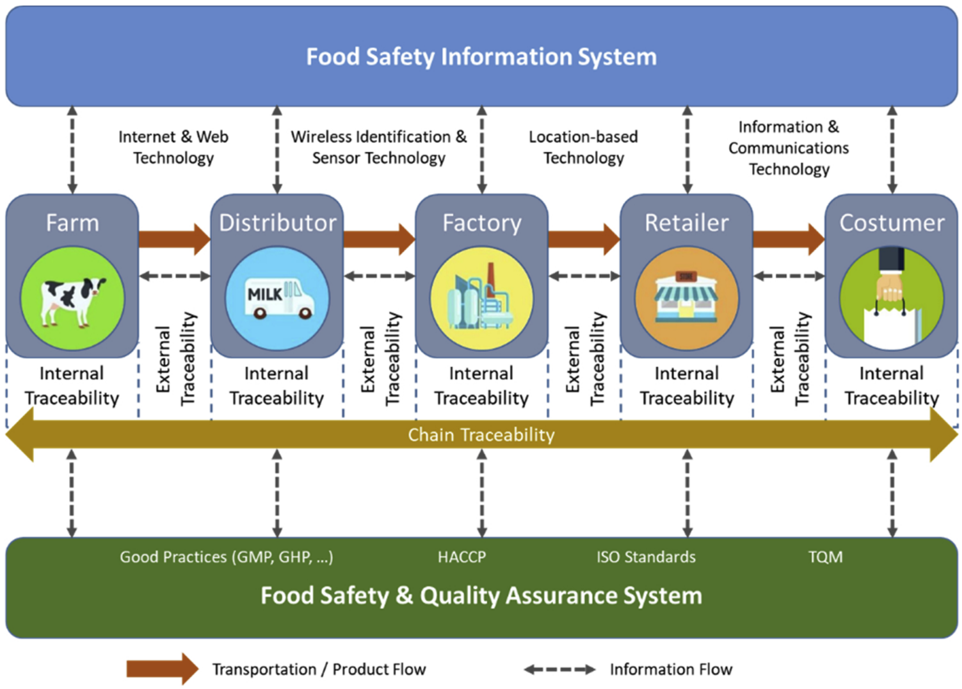

Fig. 1. Conceptual framework of a food traceability system (based on Aung & Chang, 2014, p. 180).

2012) introduces the concept of external traceability (see also Fig. 1).

In order to be able to trace products and its ingredients, unique identifiers (or characteristics) have to be defined for each product or product class and grouped to a so-called traceable resource unit (TRU). Aung and Chang (2014) differentiate between three types of traceable units:

1) Batch unit Products that undergo the same process steps, e.g. cans of milk powder, have the same best before data and the same batch number.
2) Trade unit Products that are sent from one actor to another actor in the supply chain, e.g. a box with cans of milk powder, containing the same batch number.
3) Logistic unit Products that are grouped to logistics objects for transportation or storage, e.g. pallet of cans of milk powder, can contain different batch numbers

Based on these definitions, a batch unit could be the same as a trade unit, and several logistic units could be one batch unit in case the production process was the same and the products have the same batch number. Dependent on the type of data that is stored tractability can be at a batch, trade or logistic unit.

Golan et al. (2004) claim that complete traceability is never possible due to the amount of detailed information and degree of precision that this would require. The characteristics of a traceability system depend on the objectives and can be characterized by the breadth, depth and precision of the traceability system. Breadth is the amount of information that is recorded, depth determines the capability of how far back or forward tracking and tracing is possible, and precision defines the level of certainty to identity a particular TRU. Each factor has a direct influence on the amount of information that the systems must be capable to store and process and should be chosen in direct relation to the objectives of the system.

2.3. A conceptual framework of a food traceability system

For our study, we used the conceptual framework of Aung and Chang (2014) in order to position the different concepts and characteristics of food traceability in relation to the different food supply chain actors (see Fig. 1). In their framework, the supply chain consists of different actors and describes the process from the source (e.g. raw milk from a cow on a farm) till the end product in the store purchased and consumed by a consumer (e.g. baby milk powder). Traceability over the whole chain of actors is achieved via internal traceability within and external traceability between the actors' internal systems.

Central in the framework is that all actors in the food supply chain provide information to and retrieve information from the Food Safety Information System (FSIS) via different types of technology. The FSIS contains different type of data that is essential in order to achieve transparency and assurance of quality among the food supply chain actors. Aung and Chang (2014) do not specify whether the FSIS is a centrally managed or a decentralized information system. Important criteria is that *all* actors have access to the *same* information at the *same* time.

The Food Safety & Quality Assurance System (FSQAS) contains the safety and quality regulations the supply chain actors have to comply with. Traceability information that reflect compliance with these regulations are stored in the FSIS.

In particular, the traceability system contains the following elements which will be used for describing the dairy food supply chains:

1) Business Context The chain from Farm to Consumer and each step in between is dependent on the business context; customer groups, product markets, types of ingredients play a role;
2) Supply Chain Differences in the supply chain determine the complexity of the traceability process; number of suppliers, production process characteristics, packaging and warehouse and distribution process are differentiating factors; this also has an impact in the interaction between the actors, for example in the specification of the traceable resource units which are used for internal and external traceability of products;
3) Regulation Internal quality systems have to adopt applicable food safety and quality regulation which can be country- or product-specific;
4) Quality A food safety and quality assurance system has to record

Table 1
Comparison between different blockchain taxonomies (based on Pahl et al., 2018).

Characteristic	Permissionless	Public Permissioned	Private Permissioned
Consensus model	Each node could take part, no permission required	Validation of block by pre-selected nodes; permission required	Validation of block controlled by central entity; permission required
Transparency of transactions	Visibility to each node	Visible for all users	Dependent on design; mostly restricted
Efficiency	Limited transaction throughput with high latency	Limited scope leads to higher efficiency	Limited scope leads to higher efficiency
Immutability	Due to design, nearly impossible to tamper transactions	Dependent on design; in general transactions are more easily tampered	Dependent on design; in general transactions are more easily tampered
Level of centralization / decentralization	Fully decentralized	Partially centralized	Fully centralized

results of quality tests of product and process properties (also traceability data) – facilitated by applied technologies;

5) Traceability All actors have access to the traceability information system which is used as data sharing platform; for the sake of interoperability, global standards for data sharing technology should be used (e.g. Global Data Synchronization Network – GDSN – and Electronic Product Code Information Services – EPCIS); input and output data to and from the traceability system are mapped to internal processes in order to maintain internal traceability.

2.4. Blockchain technology for traceability

BCT is the underlying technology that is used originally for digital currencies such as Bitcoin (Nakamoto, 2008). Since the discovery of its potential in 2015 for other financial services by several large financial companies (Underwood, 2016), it has gained widespread attention and resulted in an increasing number of use cases in several industries, including insurance, logistics, healthcare and supply chain management. A major promise of BCT for supply chain management is its potential to increase the transparency and traceability of products (Tapscott & Tapscott, 2016) by allowing the exchange of transactional data between two or more supply chain partners, the immutability of stored transactional data, and the maintenance of only one version of the transactional database without a third-party intermediate “accountant”.

The general claim is that BCT will revolutionize business and provide a solution to the current lack of integration of economic and legal processes in the digital world (Swan, 2015). The immense potential is especially seen in the automation of activities which nowadays still require an intermediary of trust like a lawyer, notary or banker. In this sense, BCT “has the potential to create new foundations for our economic and social systems” (Iansiti & Lakhani, 2017, p. 119). However, the “killer application” for BCT still has to be found. Startups have developed several solutions based on BCT, but no application has yet achieved a scale that extends the proof of concept or pilot stage. This is also due to the fact that existing and well-established systems still have economic advantage (Böhme, Christin, Edelman, & Moore, 2015). Therefore, further investigation of pervasive use cases are needed to foster the adoption of BCT and to reveal benefits for its users.

The originally open and decentralized blockchain system that is e.g. used for Bitcoin, is a *permissionless* system in which all users can join and leave the network at any time and have write as well as read rights. In order to be able to control the users and their rights, *permissioned* blockchains have been introduced recently (Wüst & Gervais, 2017). The main difference between these two taxonomies lies in the target group. While the permissionless blockchain is open for everyone, the permissioned blockchain includes control elements which authorize only selected users to join the network and controls their write and read access rights. Popular platforms for the creation of permissioned blockchain systems in business-to-business context are Hyperledger, Ethereum, and Corda (Valenta & Sandner, 2017). Within the taxonomy of permissioned blockchain a difference is made between public and private permissioned blockchain. The difference is whether a central entity has control about the correctness of the state of the system (private permissioned blockchain) or whether all participants should have the same view (public permissioned blockchain). The differences in the taxonomy can best be defined by the characteristics as shown in Table 1.

Blockchain is regarded as a technology that has the potential to impact society while its potential is for a large part still unexplored (Mattila, 2016). Similar to the development of the Internet as a new platform for activities of governances and companies, the expectation is that also BCT will undergo disruptive developments which will lead to fully new, unexplored possibilities. The supply chain process is one of these areas (Fosso Wamba, Kala Kamdjoug, Epie Bawack, & Keogh, 2019; Queiroz, Telles, & Bonilla, 2019; Wang, Hugh Han, & Beynon-Davies, 2019) and in particular the adoption of track & tracing of products (X. Xu et al., 2019), the improvement of efficiency in governmental processes (Weerakkody, El-Haddadeh, Sivarajah, Omar, & Monar, 2018), the distribution and delivery of digital products (Vazquez-Martinez, Gonzalez-Compean, Sosa-Sosa, Morales-Sandoval, & Carretero Perez, 2018), and the assurance of food safety by applying a food supply chain traceability system (Kshetri, 2018; Tian, 2017).

In order to understand the potential of this technology for a food traceability system, it is also important to realize its technical constraints and limitations. The following concepts focus on constraints or limitations that are addressed in current research literature (e.g. Eyal, Gencer, Sirer, & van Renesse, 2016; Tian, 2017; Zheng, Xie, Dai, & Wang, 2018).

First, the transaction rate is limited, as the original blockchain design based on a permissionless system limits the size of a block to max 1MB and the processing rate to seven transactions per second. Real-time processing of hundreds of transactions in a short period of time during the supply chain process is with this design not possible. Alternative implementations of BCT have significantly improved the transaction rate (e.g. Eyal et al., 2016; Kogias et al., 2016). In addition, the usage of a permissioned system with an optimized consensus model will improve the throughput time significantly. Current pilots seem to show that scalability requirements can be fulfilled (e.g. Galvin, 2017).

Second, transactions that are stored in the blockchain are immutable and they cannot be tampered (Zheng, Xie, Dai, Chen, & Wang, 2017). That means that the blockchain is growing with each transaction and can become ‘bulky’. This is in principle an issue in a permissionless system which can be accessed by an uncontrolled number of users and in which each block has to store all previous transactions. This constraint is of less relevance in the context of a food traceability system with a limited number of users.

Third, the commercial adoption of BCT in the supply chain is dependent on the level of protection of sensitive information and in particular cases even dependent on the level of protection of the anonymity of users (Tian, 2017). For example, scenarios can be defined in which not all users of a blockchain should be known to all, but only to a limited number of users. In addition, in order to enable effective traceability particular information in the blockchain might be confidential, which require protection against unauthorized access and leakage. While the original blockchain design included hardly any functionality to protect sensitive information, current commercial platforms have recognized this requirement and enable the possibility to control access to information in the blockchain (Hyperledger, 2018).

Fourth, BCT depends on programming codes and the correct implementation of the technology. Such type of software is vulnerable to poorly developed or maintained code which provides hackers – looking for financial gain – the opportunity of exploitation of such vulnerabilities (Devries, 2016). However, due to the processing of confidential information in the supply chain process, the security of blockchain implementations will also play an important role for a broad adoption of BCT in the supply chain domain (Xu, 2016).

A smart contract is computer code in the blockchain that is executed once conditions are fulfilled (Swan, 2015). The defined progress of action is automated and irrevocable as predefined in the logic of the computer code. For example, a smart contract can lead to the automatic payment of a delivered product to a supplier. Similar to system hacking, also the programming logic directly encoded in the blockchain can lead to uncontrolled, unwanted actions. If a user does not understand the software in all its details, he does not know which contract he "signs". The probably most prominent example is the "hack" of the *Distributed Autonomous Organization* (DAO). Due to a logical error in the "smart contract" code, $50 m virtual currency was stolen by a program developer (Finley, 2016). In the end, human intervention was required to determine how to fix the issue, leading to the not-answered question, whether a self-executing contract is really a smart idea (Stinchcombe, 2018).

Finally, a larger adoption of blockchain requires an architecture that support of more than only one supply chain process and in which actors can fulfill different roles. A supplier does not want to be confronted with different blockchain architectures of different customers. This would lead to fragmentation and a high level of complexity in interfacing with the different blockchains. Standardization towards a blockchain platform is required supporting supply chain processes of different consortia.

Our literature background shows that the usage of BCT requires a good understanding of the business problem and a clear definition of the goals to be achieved. Following a hype uncritically is never a good idea, although it is necessary in current times to start investigating where the potential of this new technology lies in the own business processes. Therefore we will investigate the boundary conditions in this paper.

3. Research approach

There is no general agreed conceptual framework or theory for the realization and use of traceability in the food supply chain. In addition, the existing scientific knowledge base about the application of BCT in the supply chain in general, and in using this technology for supply chain technology in particular, is limited. Therefore we wanted to understand the boundary conditions of BCT in supply chains. These aspects lead to the decision to choose for an exploratory research in form of a holistic multiple-case study (Yin, 2009). The unit of analysis were four different supply chains in the dairy food sector with discriminative characteristics. The role of traceability is investigated for each supply chain process separately.

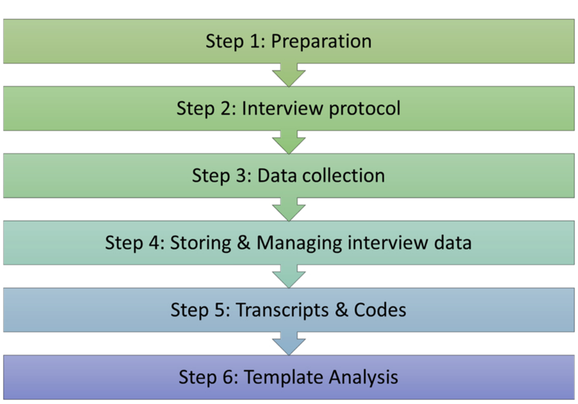

Fig. 2. Data collection process used in this study.

3.1. Data collection

Data has been collected by following the steps as depicted in Fig. 2. In total, we performed 16 interviews for analyzing the 4 case studies. Interviewees from four different companies have been selected based on their ability to provide information about elements as defined in the end of chapter 2.3 – business context, quality, regulation, supply chain, and traceability (step 1). The selection of interviewees (sampling) was performed based on a purposive (nonrandom) sampling technique (Etikan, Abubakar Musa, & Sunusi Alkassim, 2016).

Interviews were held based on a semi-structured interview protocol (step 2).The interview protocol contained a set of questions which are relevant to get an understanding of the business context, the supply chain process, the specifics of quality assurance and the role and relevance of traceability for each of the cases. Interviews have been conducted in Dutch and English and were recorded, transcribed and stored encrypted (step 3 & 4).

Interviews have been analyzed based on a template analysis approach (step 5 & 6). A codebook template has been developed which includes the coding categories identified in an a priori conceptual model (King & Brooks, 2017). The coding categories and subcategories have been selected based on the set of interview questions. After the analysis of three transcribed interviews, the codebook has been reviewed and small adaptations to the codebook has been made in order to make a distinction between generic quality management aspects and specific quality assurance aspects

3.2. Quality of data collection

The quality of a study is controlled by the following factors: correctness of operational set of measures (construct validity or confirmability), validation of the "truth" of the findings (internal validity or credibility), level of generalization of the results (external validity or transferability), and replication of the results in case of replication of the study (reliability or dependability) (Guba, 1981; Yin, 2009). Since our research is an exploratory study no statements are made about causal relationships. Therefore, we have excluded the factor internal validity / credibility from the quality assessment.

For each of these factors we explain in more detail how we employed to meet them.

The *construct validity or confirmability* factor should ensure that the results of the research study are objective and do not reflect biases by the researchers. Translated to our study, the important confirmability factor is that the collected data elements reflect the unbiased traceability and quality assurance aspects of the investigated food supply chain process. By making use of a semi-structure interview protocol for all interviewees and analyzing the interview results according to a code template coding schema, we avoided that unconscious biases of researchers had influence on the interview results.

The case study research investigates the characteristics of the dairy supply chain processes of four different business environments. The results show commonalities between the cases but also differences. The *external validity* was created by performing interviews in different companies with similar business environments. This allows to generalize the findings with respect to boundary conditions.

For the *reliably*, a variety of data sources have been used such as interviews, company quality manuals and production location visits (data triangulation). The validity of the collected data is ensured by using a semi-structured interview protocol in combination with a

Table 2
Overview of the dairy food supply chains.

Element	Dairy Essential	Dairy Consumer	Dairy Special	Dairy Ingredients
Business	● Hard cheese, butter, milk (powder) ● B2B / B2C market ● Main supplier for 'Ingredients'	● Country-specific branded products ● B2C market ● Large variety of products	● Products for special target groups (e.g. baby) ● B2C market	● B2B market, often based on specs of customer ● Large variety of different suppliers ● Specialized production process
Supply chain process	● Raw milk as ingredient ● Small number of ingredients ● Standardized production process ● Hard cheese requires extra step (ripening)	● Raw milk as ingredient ● Large number of different ingredients ● High variance in production processes ● Packaging important at the end of production process	● Short production process ● Packaging important at the end of production process	● Mass production process as well as customer-specific processes ● Technology driven ● Delivery in big bags
Regulation	● Food Safety System Certification (FSSC) 22,000 applicable to all products ● HACCP principles ● Products for particular countries might need to comply to specific regulations ● Generic traceability requirements ('one step back, one step forward' principle)			
Quality assurance	● Compliance with internal quality standard ● No quality sampling by customer ● HACCP implementation	● Compliance with internal quality standard ● No quality sampling by customer ● HACCP implementation	● Compliance with internal quality standard + extra requirements ● No quality sampling by customer ● HACCP implementation	● Compliance with internal quality standard Production process certified by customer ● HACCP implementation
Traceability	● Demand based on regulation from customer	● Increasing demand from consumer; demand based on regulation from customer	● High demand from consumers	● Additional requirements from customer
	● Level of traceability dependent on granularity of production batches and backflush of ingredients			

template coding schema as analysis tool. The interview results can be generalized since interviews were held in different companies with people of equivalent functions. Finally, detailed documentation of the study design, data collection, and data analysis are available which allows to replicate the study in a different environment (Behnke, 2018).

4. Case study descriptions

Subject of investigation for this study were four different dairy food supply chain processes. The selection of the four supply chain processes is based on diversity of products (ranging from standard to customized products), processes (ranging from mass production till small batches), which influence the requirements coming from regulators and is expected to different boundary conditions. In this way boundary conditions representing a variety of different situations will be identified. These cases were analyzed based on the following five elements (see also paragraph 2.2): a) business, b) supply chain process, c) role of regulation, d) quality assurance, and e) role of traceability. Table 2 provides the overview of each of the four supply chains.

In the *Dairy Essential* supply chain large volumes of milk are processed to produce high-quality cheese, butter and milk powder. This is a highly standardized production processes making use of a relative small amount of other ingredients. The ripening of cheese is a complicating factor due to the different periods of ripening, the usage of external ripening locations and the usage of the cheese for different purposes (B2C and B2B). An important by-product is whey, which is the main ingredient for the production of specialized milk powder in *Dairy Ingredients*. Standardized regulation and quality controls apply.

The *Dairy Consumer* supply chain delivers products for the B2C market and contains a high variety of production processes. In general, a large number of different ingredients is used. An essential step in the production process is the packaging of the final product which contains a large variety of packaging processes and an additional number of suppliers (packaging) and customers (end products). Standardized regulation and quality controls apply in general, additional quality and traceability steps apply for specialized products (e.g. biological products which imply additional requirements on the nutrition for the cow and the supply chain process).

The *Dairy Ingredients* supply chain is targeting the B2B market and contains for a large part customer-specific, technological advanced production processes. In addition to standard quality controls, customer-specific quality and traceability controls are in place and locations and customers can require separate certification. Additional regulatory requirements can apply, e.g. in case of ingredients for the medical sector. This includes also requirements with respect to traceability.

The *Dairy Special* supply chain produces products for specific groups of consumers, e.g. infants, athletes or elderly people. The production process consists in general of mixing different ingredients and from a technological point of view simple. However, due to the special customer segments, additional quality controls are required, partly demanded by additional regulatory requirements (e.g. for infant milk powder). Traceability requirements by regulation are not different in comparison to other supply chain processes. However, a trending development is to create more transparency on source and type of ingredients towards to consumers which requires a higher level of traceability.

The understanding of the supply chain using this conceptual framework was used as a starting point for the analysis of the boundary conditions and the applicability of BCT as a food safety information system.

Table 3
Boundary conditions for traceability.

No.	Category	Boundary condition	Case
1	Business	Actors in the supply chain have standardized the traceable resource units which are used for internal and external traceability of products	All
2	Business	Product and process properties (traceability data) are recorded	All
3	Business	Actors in the supply chain are technologically capable to have access to the traceability information system	All
4	Business	Data from the traceability system are mapped to internal processes in order to be able to maintain internal traceability	All
5	Business	Business requirements are consistent and make no difference between internal or external supplier.	All
6	Business	Confidentiality requirements apply with respect to the transparency of actors in the supply chain.	All
7	Supply Chain	Standardization of quality requirements between all actors in the supply chain	All
8	Supply Chain	Same quality standards apply for the internal supply chain process as for the external supply chain process	All
9	Supply Chain	Interfaces with customers and suppliers are generic enough to support customized production processes	Dairy Ingredients
10	Regulation	Compliance of all actors in the supply chain with FSSC 22,000	All
11	Regulation	Compliance with special quality requirements for products	Dairy Special Dairy Ingredients
12	Regulation	Compliance with country-specific / customer-specific requirements	Dairy Consumer Dairy Ingredients
13	Quality	Consistency between the actors in the supply chain on type, format and level of details of quality information (master data)	All
14	Quality	Support for the level of details of quality data and data about origin of ingredient to consumer by all actors in the supply chain	All
15	Traceability	Consensus between the actors in the supply chain on type of traceability data	All
16	Traceability	Standard about the level of detail of traceability information required to store critical traceability points	All
17	Traceability	Granularity of internal traceability is in line with traceability goals across the supply chain and supported by all actors	All
18	Traceability	Standardization of internal processes with respect to critical traceability points and traceability data	All

Table 4
Boundary conditions for technology solution.

No.	Category	Boundary condition	Case
3	Business	Actors in the supply chain are technologically capable to have access to the traceability information system	All
4	Business	Data from the traceability system are mapped to internal processes in order to be able to maintain internal traceability	All
6	Business	List of actors in the supply chain shall not be transparent to all.	All
14	Quality	Support for the level of details of quality data and data about origin of ingredient to consumer by all actors in the supply chain	All
16	Traceability	Standard about the level of detail of traceability information that is required to store at defined critical traceability points	All

5. Findings

5.1. Boundary conditions for blockchain systems

The analysis of the findings in the interviews has led to the identification of boundary conditions for traceability are shown in Table 3, and for blockchain in Table 4. The table below contains the 18 boundary conditions for traceability that have been identified based on the interview findings a description and in which cases they were found. The boundary conditions are allocated into five categories as used for characterizing the cases.

Surprisingly, the majority of the boundary objects are applicable for all four supply chains. This finding was not expected at the beginning of the study since the supply chains differ significantly in business context and supply chain characteristics. This finding can be explained as traceability requirements are defined primarily by regulatory standards which are applicable for all four food supply chains. Differences in the boundary objects are related to customized processes or specialized regulatory requirements for a particular supply chain type. The supply chain boundary object of needing interfaces for customized production processes was found for one supply chain. In contrast, the need for compliance with specific regulation requirements was found in all supply chains. This suggests that blockchain applications in food supply chains should be flexible enough to deal with various types of regulations. Food regulations typically change over time, which requires blockchain applications to be able to adapt to the changing regulations.

The interviews emphasized the dependencies between internal supply chain processes, in which one supply chain process acts as supplier for the other – an aspect that was not described explicitly in the framework of Aung and Chang (2014). One interview partner emphasized that an important part of her work is to coordinate and prepare audits by customers and governmental institutions with the different production locations. She said:' *We audit a lot, that is an important aspect of our work. We cannot control the quality of every single product that we deliver. Therefore we agree on quality requirements which we audit or on which we are audited. This means at the same time how important the internal quality management system is and that it complies with international standards.'* This finding leads to an additional boundary condition which emphasizes the consistency in quality processes between internal and external suppliers (boundary condition 5).

Next to this play information confidentiality play a critical role. Interviewees were very consistent in their answers regarding the confidentiality of information. On the one hand, traceability information of suppliers and quality assurance information during the supply chain process is not regarded as confidential. However, the information that is related to the composition of products and related machine parameters is regarded as confidential for competitive advantage. The following comment was made: '*Quality data is in principle not confidential and can be shared. The advantage is that this creates a lot of transparency and therefore trust to the customer. But you have to define in advance to which detail level you want to go. Quality of products vary and deviations, although within acceptable bandwidths can easily be regarded as 'bad'. In general, the more details you give the more questions you get … so you have to determine case by case how far you want to go in this.'* Also the information to whom the products are sent (customer base) is regarded as confidential and actors in the supply chain shall not be transparent to all players in particular to their competitors. (boundary condition 6). The condition to keep business information confidential is not specific to supply chain processes. For example, Engelenburg, Janssen, and Klievink, (2019) have found three reasons for keeping information in a blockchain confidential: 1) businesses need to be able to keep information confidential to prevent misuse; 2) businesses want to avoid liability and therefore in some cases are not willing to have information and consequently cannot share it; and 3) information sharing should be lawful.

Surprisingly, the *Supply Chain* boundary conditions are similar, although the supply chain processes differ significantly from each other. Standardization of quality standards and requirements between all internal as well as external actors in the supply chain is essential. Due to the customized production process within *Dairy Ingredients*, an additional boundary condition has been identified for this supply chain process regarding the interfaces for customized products between customers and suppliers (boundary condition 9). Not surprisingly trust was not found as a boundary condition. Trust should be provided by the blockchain technology, however, to enable this the boundary conditions should be satisfied.

The *Regulation* boundary objects show that there is no difference between the cases with respect to the regulation in food traceability. There are differences in the regulations with respect to quality assurance and control with respect to products in the medical sector and for infant nutrition for *Dairy Ingredients* and *Dairy Special* (boundary condition 11). In addition to this, country-specific and customer-specific requirements are applicable especially for *Dairy Consumer* and *Dairy Ingredients* (boundary condition 12). Furthermore, the interviewees indicated that regulations has changed over time. Due to incidents the trend is to have more strict regulations.

The *Quality* boundary objects show that the implicit assumption that quality assurance information is an important source for realizing traceability capabilities is only partly confirmed. Traceability activities can be performed in first instance *without* including quality assurance information. Quality information is of importance in order to determine the scope of a quality issue or a recall and therefore the amount of products that are impacted – but not to track and trace ingredients and products. In addition, if quality controls have been chosen right and processes have been designed correctly, then one can also state that quality controls have the primary goal to *avoid* traceability actions. The quality controls should detect food safety issues and avoid that these issues will spread in the supply chain. Quality assurance information is important to create more *transparency* between actors in the supply chain and towards the consumer about the origin and quality of ingredients. This information is – as long as it does not contain product-specific details – not confidential and can be included in a generic food traceability system.

Finally, the *Traceability* boundary objects confirm that supply chain actors need to have clear agreements about granularity and standardization of traceability data. Further improvements in limiting the impact of a recall of a product can be made when traceability capabilities between the players go beyond the one step backward and one step forward regulatory requirement. A complete overview of the supply chain processes are needed, which can be provided by blockchain technology. However, the interviews emphasized the fact that capabilities and standardization of *internal* processes are a boundary condition that has to be fulfilled first (boundary conditions 17 & 18).

5.2. BCT as a traceability information system

The boundary conditions that have to be fulfilled by a technology solution are listed in Table 4. The number of the condition corresponds to the number in Table 3. The boundary conditions in Table 4 have been selected according to the following line or reasoning. The production of dairy products requires access to and storage of traceability information from different events in the internal supply chain process and therefore support for the technological requirements of the traceability information system (*boundary condition 3*). Although this might seem to be an obvious boundary condition and easy to achieve due to the focus on the internal supply chain process, the interviews showed that it is in fact not due to lack of automation in parts of the process. An interview partner described this as follows: '*We simulated a traceability situation in which we found a deviation in a product that was packaged in location A, the basic ingredient for the product was made in location B, and another ingredient part was made in location C. In this case, we had to trace back from location A to location B to location C. During test, we experienced that a lot of manual actions still had to be performed, and that it was quite an effort to deliver the required information within the request period of time of four hours.*' In addition to the technological capability, the data in the traceability information system has to be compatible with the traceability data that is used in order to maintain traceability within the internal processes (*boundary condition 4*).

Quality assurance information as well as detailed traceability information that is linked to traceability control points require support of the traceability system for different data types and different levels of detail (*boundary condition 16*). One interview partner explained it based on the different roles in the organization: '*On process level, the traceability control points can be defined on high level, indicating generic information about date, time and suppliers. However, dependent on the level of detail that is agreed or required, more information related to attributes and characteristics of a specific batch are required in order to specify the unique batch unit*'.

As indicated above, not all information in the traceability framework should be visible to all actors and access controls should be defined by the information owner based on confidentiality requirements (*boundary condition 6*). The traceability system can also be used to store quality assurance information that is presented to the consumers in order to be able to verify this later (*boundary condition 14*). Consumer products are equipped with special QR codes which contains then a link to quality-related information and provides information about the source of specific ingredients.

In order to be able to determine, whether BCT can fulfill the technical boundary conditions, the decision framework of Pahl, El Ioini, and Helmer, (2018) is used, answering the two most important questions: i) does it make sense to use a blockchain, and ii) if yes, which type of blockchain fits best for the application scenario. BCT can fulfill the technical boundary conditions of Table 4 in order to function as a dairy food traceability framework. BCT allows (read & write) access for multiple supply chain actors in order to deliver their part of the quality and traceability information that they own. In addition, a particular level of interaction between the actors when performing a traceability activity is supported. Dependent on the chosen blockchain architecture and the level of confidentiality that is required, information can be easily made visible to other actors while safeguarding the confidentiality and integrity of this information at the same time. A key aspect is to define which information will be shared and which not (boundary condition 4, 5, 15 and 16). Too much information sharing will result in resistance of parties as they are afraid that their competitive power might be undermined, whereas, too little makes the system useless. The type and amount of information is dependent on the already established controls in the process. Table 3 shows the boundary conditions for traceability that the supply chain companies should be able to store and share information using standards. Any blockchain imitative should first analyze which information will be stored and which not. An implementation strategy could be to start with limited information and gradually add more. More research is needed in this direction.

A public permissioned Blockchain type is the most suitable architecture. This type supports control on the group of supply chain actors ('permissioned') who act a same level based on distributed solution without a trust partner as middle man ('public'). Such an architecture can provide transparency for supply chain partners, regulators and customers and create more trust in the food supply chain. A complicating factor in this is that actors have different relationships with each other. While they can be competitors in the same market segment, they can be at the same time in a customer-supplier relationship in a different market segment – with even changing roles dependent on the market segment. Therefore, trust in the confidentiality of information within the blockchain and control of access is an important condition. The question is who should initiate such a blockchain? Initiation by a supply chain partner might cause resistance. Government might require this for its advantages, but do not want to be involved in the realization.

Software companies do not have the necessary food supply chain knowledge to make this a success. More research in this direction is needed.

5.3. Implications

BCT is a possible technology solution for a food traceability framework. However, the boundary constraints show that the implementation of a traceability framework requires a well-organized and standardized supply chain between all (internal and external) actors. An important practical implication of this study is, that governance around the blockchain type and standardization of data have to be defined first before automating of processes can be started.

Not the technology is a critical factor, but the standardization of internal and external traceability processes (requiring organizational changes) and standardizing master data between the supply chain actors are critical constraints in order to achieve a traceability level that makes the whole supply chain transparent for all actors, and in the end also the consumer. Data governance should ensure uniform data definitions and authorities for creating, accessing and changing data. Data governance cannot be defined by partners of one Blockchain initiative alone, but requires agreement on sector if not even on industry level. Otherwise, suppliers will have to comply to different interface standards which makes Blockchain technology from an economical point of view inefficient.

We recommend the development of consortia within business sectors, supported by governmental institutions, in order to define and drive standardization. In order to make the next maturity step from blockchain pilots towards long-term blockchain implementations, interface standardization and data governance are important pre-conditions.

While the process of standardization will probably take several years, this does not mean that BCT cannot be used for food traceability in the meantime. The increasing demand of consumers to get more transparency about the origins of ingredients will lead to different solutions on short term, of which BCT can be one of it. Even if boundary conditions are only fulfilled between a limited number of supply chain actors, it might result to an improvement in transparency for consumers and hopefully to a reduction of food safety incidents.

6. Conclusions and further research

The findings show that BCT can be used in supply chains for traceability of goods and can be used to create transparency in the goods supply. Blockchain is a suitable technology as this can result in the sharing of more data among supply chain partners who compete with each other. Yet, boundary conditions should be met before BCT can be used. This is the first paper investigating BCT boundary conditions and in total eighteen boundary conditions for a food traceability were identified from which 5 directly apply to BCT. A significant number of these are related to regulatory requirements, the internal supply chain and production processes and require significant organizational changes in order to support the full benefits of traceability. This includes the tracing as well as the tracking functionality. What type of data is shared and who has access to which data are key questions. The lack of standardization of master data and interfaces limit the level of automation. The complexity lies in the alignment between interfaces and standards used by the various actors in the supply chain. The findings suggest that first the supply chain needs to be organized before blockchain can be used.

The variety of boundary conditions suggests that organizational changes are needed before BCT can be used successfully in supply chain. This finding can explain why many blockchain projects remain at the piloting level. A well-organized and standardized supply chain between all (internal/external) actors is needed before BCT can be used. The boundary conditions can likely be generalized to other domains, although the idiosyncratic conditions of the domain should be taken into account. For example, in our situation food regulations of different countries involved in the supply chain play a key role, whereas in other supply chains this might not be the case. The list of boundary conditions be used as an instrument to determine which changes are needed in a supply chain before BCT can be adopted.

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