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Blockchain for Supply Chain Traceability: Business Requirements and Critical Success Factors

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Abstract: We seek to guide operations management (OM) research on the implementation of supply chain traceability systems by identifying business requirements and the factors critical to successful implementation. We first motivate the need for implementing traceability systems in two very different industries – cobalt mining and pharmaceuticals – and present business requirements and critical success factors for implementation. Next, we describe how we carried out thematic analysis of practitioner and scholarly articles on implementing blockchain for supply chain traceability. Finally, we present our results pertaining to the needs of different stakeholders such as suppliers, consumers, and regulators. The business requirements for traceability systems are curbing illegal practices; improving sustainability performance; increasing operational efficiency; enhancing supply-chain coordination; and sensing market trends. Critical success factors for implementation are companies' capabilities; collaboration; technology maturity; supply chain practices; leadership; and governance of the traceability efforts. These findings provide a nascent measurement model for empirical work and a foundation for descriptive and normative research on blockchain applications for supply chain traceability.

Keywords: supply chain traceability systems; blockchain; thematic analysis; stakeholders; business requirements; critical success factors

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1. Introduction

The lack of supply chain traceability to check whether production is ethical, compliance with sanctions, or product safety is an economic and social challenge (Badzar, 2016). Companies have limited knowledge of the provenance of the components or raw materials for the goods they manufacture or sell (Abeyratne and Monfared, 2016), so they seek visibility into the supply chain. Operations management (OM) and other researchers are turning their attention to the related areas of transparency, visibility, and traceability in the supply chain (Sodhi and Tang, 2019). In this vein, we seek to understand the context of IT-based systems for achieving supply-chain traceability. Although companies and IT vendors have proposed different technologies for traceability, we focus on blockchain technology. The apparel and the electronics sectors have existing or proposed web-based or social media-based solutions to provide transparency to their consumers (Sodhi and Tang, 2019). However, the focal technology for traceability is blockchain. Transparency solutions complement rather than supplant blockchain-based traceability systems. In this paper, we seek to provide the business context for the implementation of (blockchain-based) traceability systems by *identifying business requirements from the viewpoint of the focal companies in the supply chain and the factors critical to the successful implementation of such systems*.

We start with motivating the need to implement traceability systems with two very different industries as examples: cobalt mining and pharmaceuticals. For both, we provide business requirements and critical success factors. Next, we present the findings from a thematic analysis of academic and practitioner articles on blockchain and supply chain traceability. These findings include the identification of various stakeholders, including suppliers, customers, and regulators, as well as their needs. Other business requirements for traceability include curbing unlawful practices; achieving sustainability; improving operational efficiency; increasing supply-chain coordination; and sensing market trends. Finally, the factors critical to the successful implementation of blockchain- or some other technology-based solutions are capabilities; collaboration; technology maturity; supply chain practices; leadership; and governance of the traceability efforts.

This paper lies at the intersection of three streams of literature. One is the relatively new stream on supply chain traceability (e.g., Sodhi and Tang, 2019). We contribute to this stream by detailing the business requirements for traceability systems from the viewpoint of the supply chain's focal companies. Factors critical to the success of any implementation are also detailed.

The second stream is the nascent literature on blockchain applications in OM (e.g., Alexander, 2018; Babich and Hilary, 2018). We contribute to this stream by providing information on blockchain applications for supply-chain traceability.

The third is the well-established operations-and-IT literature on critical success factors for implementing enterprise-wide or supply-chain-wide systems, and more broadly, on system implementation in general. For instance, Nah et al. (2001) discuss success factors for the implementation of enterprise resource planning (ERP) systems. Power (2005) and Ngai et al. (2004) do the same for supply chain integration and Khan et al. (2018) for a *halal* traceability system. Iansiti and Lakhani (2017) offer a framework for blockchain implementation. We contribute to this stream by providing the business requirements and critical success factors for implementing a supply-chain-wide system with many more stakeholders than ERP or integrated supply chain systems. Within this literature, our work is positioned on *chartering*, the first phase of any enterprise system's lifecycle (Markus and Tannis, 2000: p.18).

In all three cases, we further empirical research by providing an initial measurement model for business requirements as well as for critical success factors. This model can be useful for developing questionnaires or other ways to collect information for theory building or testing.

In the rest of the paper, Section 2 presents cobalt mining and pharmaceuticals as examples to motivate the implementation of traceability systems. Section 3 provides the materials and methods we used, followed by our findings in Section 4. We conclude in Section 5 with implications for researchers and managers.

2. Background and Motivation

We focus on systems that propose to use blockchain technology, which is a 'peer-to-peer network that sits on top of the Internet' (Iansiti and Lakhani, 2017). Blockchain technology has two notable aspects. One is the ‘distributed ledger' or database to record transactions physically residing in multiple copies in different locations. The other is a system of ‘trust' across different users by enabling and requiring them to consensually and digitally agree to any change in the database (Cordon and Bris, 2019). ‘Blockchain' refers to a chain of ‘blocks' in a distributed database, a block being a set of records that has a pointer to data in another block, creating a link in a chain of such relations. The database is distributed across a peer-to-peer network, relying on ‘consensus' algorithms across the network to validate the addition of any new block with security and consistency, in other words, with "tamper-proof transaction cryptography" (Bahga and Madisetti, 2016). Every node in the distributed database keeps an upgraded copy of a database with all the ‘ownership' information and transaction history.

While blockchain is best known for the crypto-currency Bitcoin, the technology can also be applied to supply chains for transactional data as goods change ownership along the supply chain. Transactions entered on a blockchain-based supply-chain solution would be validated by the consensus of all supply chain partners and others – all parties are accountable for the information on the chain (Antonopoulos, 2014). The consensus enables tracing the ownership of a diamond from the mine with the diamond's digital thumbprint to the retail shop via logistics companies. As of this writing, blockchain technology has limitations (Zheng et al., 2017), but there are few other mature solutions available for supply chain traceability.

Many different sectors have proposed or, as of this writing, begun to develop blockchain-based traceability systems. We describe the business context in two such industries – cobalt mining and the pharmaceuticals – by way of the business requirements and factors critical to the success of the implementation of traceability systems.

2.1 Cobalt Mining and Pharmaceuticals

Businesses use cobalt for lithium-ion batteries used in electronic devices and electric vehicles. Mining practices associated with cobalt have gained notoriety with a significant quantity of the global production mined by child and slave labor in the Democratic Republic of the Congo (DRC) (Amnesty International, 2016; UNICEF, 2012). Workers labor under ill-regulated conditions in artisanal mines without protective equipment, often manually (Naylor, 2018). Traders buy the metal from such mines as well as from more regulated mines, but they mix the mineral. Mixing results in such buyers as Apple, Renault, and Volkswagen not being able to establish the mining source (Bonanni, 2018).

In response to Amnesty's report, some companies said they would take 'appropriate' action. Others said they trust their (trader) suppliers to abide by legal and responsible sourcing practices (Sanderson and Cornish, 2017). However, merely believing suppliers can be risky. Tesla's battery manufacturer Panasonic was forced to suspend a cobalt supplier that was unable to ensure compliance with U.S. sanctions on Cuba. As a result, Tesla risked component shortage and reputational damage while potentially facing a U.S. Treasury investigation (Desai and Yamazaki, 2018). The London Metals Exchange (LME), the world's largest metal exchange, requires companies obtaining 25 percent or more of their metal from small-scale (artisanal) mines in the DRC to undergo a professional audit (Financial Times, July 2, 2018). With only 20% of the cobalt from DRC coming from artisanal mines, this is not a particularly challenging requirement to meet. However, the LME is sending a strong signal by threatening to delist failing companies from the exchange. Still, with traders mixing minerals from different sources, buyers may not be able to ascertain the proportion of the cobalt they are purchasing from artisanal mines.

In contrast to cobalt, the **pharmaceuticals** sector is well organized across the globe but still requires traceability. The industry has to deal with counterfeit drugs reaching end-consumers and patients throughout the world (Aves, 2017; Petersen et al., 2017). The World Health Organization (WHO) estimates that 10% of medicines sold in low- to middle-income countries are substandard or counterfeit (Reuters, 2017). In the US, the Food & Drug Administration discovered fake pills of a well-known cancer medicine made from wheat and a chemical component used in nail-varnish remover (DeCovny, 2017). These counterfeit drugs came from Africa, moved into lawful supply chains in Europe, and eventually reached patients in the US (Berkrot, 2012). Companies in pharma and other industries increasingly see blockchain as a solution that provides secure, confirmable documentation of every transaction (Badzar, 2016; Crosby et al., 2016).

The growing counterfeit-drug problem is not just a threat to profits but also to pharma's reputation as an industry because of life-and-death implications for patients. The WHO attributes tens of thousands of deaths every year to the billion-dollar trade of illegal drugs, including antibiotics

(Reuters, 2017). Pharma's complex supply chain operations – with a large number of handovers to different supply chain partners before the drugs reach hospitals and pharmacies – likely contribute to lack of traceability (Gilbert and Dasgupta, 2017). Manufacturing is vulnerable to counterfeit raw material or ingredients from unknown sources. Moreover, illicit producers can relabel a fake product to infiltrate legitimate distribution (Bernstein, 2013). There is also the question of whether the focal company is tracking the drug or its package (or container). A bottle containing pills is traceable but not necessarily the individual pills inside it, potentially allowing counterfeits to enter the supply chain despite traceability.

2.2 Businesses Requirements for Traceability Systems

Many stakeholders perceive blockchain to be crucial for eradicating forced child labor from the **cobalt** supply chain (iAfrikan News, 2018). Managers have a responsibility to investigate the technology's potential for verifying that they are not making money off the suffering of miners' (Merchant, 2018). A blockchain-based system tracking cobalt would flag metal from questionable mines. It would point out if otherwise acceptable mines are producing larger than expected quantities, suggesting mineral mixing. The system could show if the metal has moved through sanctioned rebel zones (Bonanni, 2018). Tracing the chain of companies holding custody can help confirm ethical procurement and production practices (Chow, 2018).

Proposed solutions use ideas from the diamond blockchain (du Venage, 2018; Churchill, 2018), but tracking individual diamonds as discrete products is different from monitoring cobalt as a commodity (Chow, 2018). For diamonds, there is a digital 40-point record for tracking known as a thumbprint that is unique to each diamond (du Venage, 2018). However, cobalt transforms differently than diamonds as it goes from the mine through a 12-step production process before ending up in a battery for a vehicle or a phone (Lewis, 2017).

Even if the chain of custody were flawlessly traceable along the supply chain, records for the original mine could be manipulated at the time of entry, defeating the purpose of traceability. Managers need to ensure that users enter the correct data into the blockchain at the outset as well as that the product is indeed not coming from mines using forced or child labor (Sulkowski, 2018).

Moreover, the means to capture data need to be standardized – both upstream and downstream players have to decide on a set of input data for identification and align registration points (Chow, 2018; Lewis, 2017). Lastly, the problem of being able to dilute provably sustainable cobalt with ethically-questionable cobalt remains to be tackled (Chohan, 2018; Sulkowski, 2018). Industry buyers and executives could solve this problem by collaborating on common standards for product stewardship and purchase terms to endorse best practice (Chow, 2018). Alternatively, companies could add blockchain to IT systems already in use by smelters (Chohan, 2018). Another alternative is a mass-balanced approach in use by the FairTrade certification of cocoa (Lewis, 2017).

Traceability solutions for cobalt mining are emerging based on blockchain. Responsible Cobalt Initiative and the Better Cobalt pilot are two of several ongoing sustainable cobalt initiatives (Pilling, 2018; Buck, 2018). However, there is opaqueness in that the participants are not fully disclosed (iAfrikan News, 2018). Stakeholders are concerned that these programs do not demand accountability from their participants and may give buyers false assurance (Pilling, 2018).

For the **pharmaceuticals** sector, the European Union (EU) has passed the Falsified Medicines Directive. The directive stipulates pharmaceutical firms and other actors in their supply chains to implement full traceability by 2019 to curb these unlawful practices. Similarly, the Drug Supply Chain Security Act (DSCSA) in the US provides a deadline for 2023 for the industry to implement a traceability system (Lo, 2018; Patrick, 2018). As such, the industry has to define the business requirements for traceability.

Pharma companies use legacy IT computer systems that are often incompatible with those of supply chain partners. As a result, these companies have to rely mostly on paperwork for interacting with their partners (Hackius and Petersen, 2017; Rabah, 2017). Negative consequences can include lost ingredients, incorrectly prescribed drugs, crashing IT systems, and misplaced paper trails (Bhardwaj, 2018). Using blockchain (or other technologies) in the supply chain to digitize and automate transactions could improve pharma's responsiveness and operational efficiency (Rabah, 2017). Such technology could also be cost-effective for meeting regulatory requirements (PRNewswire, 2017).

Using blockchain or other technology for traceability can bring about operational efficiency in different ways. Currently, companies expend extensive resources, paperwork, and time to fulfill the EU's new regulation requiring pharma companies to report on changes in temperature to downstream partners. Companies use refrigerated transportation for all drugs, but 60% of drug deliveries are not sensitive to temperature, which results in a waste of resources and money (Campbell et al., 2018; Hulea et al., 2018). Blockchain could help reduce these expenditures by tracing and screening only the medical deliveries that require cooling for temperature changes in their supply chain journey in near-real-time (PwC, 2017; Pharmaceutical Commerce, 2018). Smart Internet-of-Things (IoT) technology, including RFID tags and sensors, would help.

Securing the integrity of the supply chain and facilitate fraud-detection to protect patients globally is also possible with a blockchain-based traceability system (Bocek et al., 2017; Bhardwaj, 2018; Mackey and Nayyar, 2017). The online medicines market remains highly unregulated, but blockchain could help prevent the illegal product from entering into companies' supply chains (Hackius and Petersen, 2017). Blockchain-based traceability systems can help companies to comply with legislation and to record ownership transfer (Patrick, 2018). As such, pharma managers need to investigate (1) blockchain's technical aspects in terms of scalability and immature infrastructure, (2) regulatory compliance for patient security and privacy, and (3) implementation of standardized and confidential data collection practices across the value chain (Glover and Hermans, 2017; Wentworth, 2018).

2.3 Critical Success Factors

Although business requirements are generally well understood, many factors affect the implementation of blockchain-based traceability systems in cobalt mining and pharmaceuticals. The political climate in the DRC regarding **cobalt** poses a challenge for executives wanting to adopt blockchain or any other technology solution for traceability. DRC ranks near the bottom of the countries on the Worldwide Governance Indicators ranking for corruption control, government effectiveness, and the rule of law (Bazilian, 2018). Without appropriate institutions and a supporting regulatory system in place, companies are left fending for themselves with a disjointed and opaque monitoring system (Naylor, 2018). Moreover, the government in DRC has recently increased its stake in cobalt and imposed higher royalties (EMJ, 2018). Blockchain could help trace the flow of money to intermediaries and pinpoint suspicious activity, which could make it unattractive to some stakeholders. Additionally, since blockchain is decentralized, it would prevent the ledger from being controlled by the DRC government (Buck, 2018) or indeed any other entity.

Another market uncertainty for blockchain's successful adoption in cobalt mining is disinterest from Chinese buyers. The lack of interest is despite the largest sustainability project, RCI, having been initiated by the China Chamber of Commerce of Metals, Minerals and Chemicals Importers. The world's largest cobalt refinery, China-based Huayou Cobalt, does not believe blockchain to be the solution to the supply chain challenges (Buck, 2018). One solution may be to approach miners directly, something Apple is investigating (Imahshi and Sun, 2018). For some companies, blockchain could be used to even out the competitive playing field (Campbell et al., 2018; Imahshi and Sun, 2018).

As for the **pharmaceutical** industry, some regulations could hamper implementation indirectly despite potential operational cost savings and other benefits that companies could realize with traceability. Indeed, regulation is one reason why the sector pharma still uses legacy IT systems (Wentworth, 2018). Indeed, the industry is slow-moving in part because it is highly regulated. Executives seeking operational efficiency need to figure out how to bridge rapid technological development with the pharmaceutical supply chain (Patrick, 2018; Hoy, 2017) that needs to comply with regulation and to demonstrate this compliance. Indeed, regulations and governance influence the extent to which any traceability solution could fulfill business requirements in the pharmaceutical industry. Companies also need guidelines to curb illegal practices globally, especially when motivated users can manipulate data between the material and digital stage. Such manipulation is possible because data collection practices and traceability methods do not follow the same standards across the supply chain.

3. Materials and Methods

Having looked at the business requirements and critical success factors in two sectors, we seek to get more information on these from the literature on blockchain implementation of supply-chain traceability. We aim to compile the literature to develop early-stage measurement models for business requirements and critical success factors. Such measurement models would provide researchers and practitioners with a starting point not only for instruments for empirical research but also for further descriptive and normative research.

We carried out a thematic analysis of the available research and practitioner literature on traceability systems using blockchain. Thematic analysis is a qualitative research method for finding, investigating, organizing, defining, and producing themes found within a corpus of data (Nowell et al., 2017). It is a flexible approach to analyzing a comprehensive account of data while requiring the researcher to be well-organized (Braun and Clarke, 2006; King, 2004). In our context, the data is a sample of 'relevant' articles, so identifying which of the articles are relevant is an essential step for this analysis. Sodhi and Tang (2014) present four stages in any research stream maturity: (I) awareness, (II) framing, (III) modeling, and (IV) validation. Thematic analysis, as employed here, can be useful for building awareness amongst researchers and initial framing.

Following Sodhi and Tang (2018), we carried out thematic analysis (Braun and Clarke 2006, Table 1) in six steps. We (1) familiarized ourselves with the corpus of 'data'; (2) generated initial codes; (3) searched for themes; (4) reviewed these themes; (5) defined and named these themes; and (6) produced the report. The initial challenge was how to select the data corpus; in this case, a sample of the relevant literature. Steps 2, 3, and 4 were iterative across codes, themes, and data reduction, with a critical decision being on the 'level' of any theme or sub-theme. We extracted themes that are general enough to apply to any industry and with the use of any technology. In doing so, we used a three-level hierarchy: theme, sub-theme, and codes, with the naming of themes and sub-themes in Step 5 as the initial development of a measurement model with concepts and constructs.

Our data corpus needs to be a broad sample of the research and practitioner literature on *blockchain for traceability in the supply chain*. Research on this topic is still nascent in operations management (OM) journals; therefore, many of the sources for the corpus could not be from OM journals. This shortage of OM articles at the time of this writing rules out a systematic review of OM journals as an alternative to how we selected the literature. We used Google Scholar with the words ‘blockchain’ and ‘supply chain traceability’ together and obtained only 840 sources at the time of the search in July 2018). The search engine ranked these articles in decreasing importance with its proprietary algorithm. Going through the list using this rank order, we either included or dropped the article based on its relevance to us. We established pertinence by reading the text of its abstract or sometimes the whole text. Once we found ten items in a row to be off-topic, we ended the search under the assumption that there would be few pertinent articles further down the list. We thus identified a total of 75 sources from technical and information systems journals as well as conference proceedings (**Table 1**). These sources covered a wide variety of industries.

Insert Table 1 somewhere here

This approach may seem to have limitations in that relevant sources may have been excluded from the search, resulting in some themes not being identified. We did not use close synonyms, like ‘supply chain provenance’ or ‘supply chain visibility’ or ‘distributed ledger’ to search for articles. Moreover, our selection of articles depends on Google Scholar’s proprietary ranking because we went through the articles in rank order. So, there may be relevant articles further down the list beyond where we stopped looking. The search engine would not have included sources not available to it at the time of the search (King, 2004), especially as information on blockchain and traceability was mostly new in 2018.

Despite these limitations, we believe we achieved saturation in uncovering themes – more articles would not necessarily have yielded more themes. We are not trying to find ‘gaps’ in the literature. Instead, we are identifying themes on business requirements and critical success factors. Our corpus was broad with articles from a wide variety of sources, allowing us to argue that the list of themes and codes is likely exhaustive. Google Scholar’s proprietary algorithm ranks each source based on the full text. The algorithm also uses the source's author; the publication in which the source appeared; and the frequency of its citations in the scholarly literature (Google Scholar, 2018). Therefore, the sources ranked higher by Google Scholar are also desirable for our purpose. Again, note that we are not looking for ‘gaps’ in the literature. The search engine analyses and extracts citations even if the documents appear only in books or other offline publications (UMN, 2017). Finally, recent articles would not have been cited much and would, therefore, be ranked too low to show up in our search. However, we note that most of the literature in the sample we collected, dated 2017 and 2018, was quite recent at the time of this writing.

4. Findings

The thematic analysis allowed us to develop themes and sub-themes for business requirements and critical success factors.

4.1 Business Requirements

Focal companies driving implementation have diverse business requirements that we discuss in turn (**Figure 2**) using the themes and sub-themes. The hierarchical structure of themes, sub-themes, and the codes under each sub-theme provide an initial measurement model. If we consider the themes as concepts and the sub-themes as possible constructs, then we can use a subset of the codes for developing indicators for research instruments such as questionnaires. However, this is only an initial attempt: empirical work would be needed to validate constructs. We discuss each theme or concept in turn below.

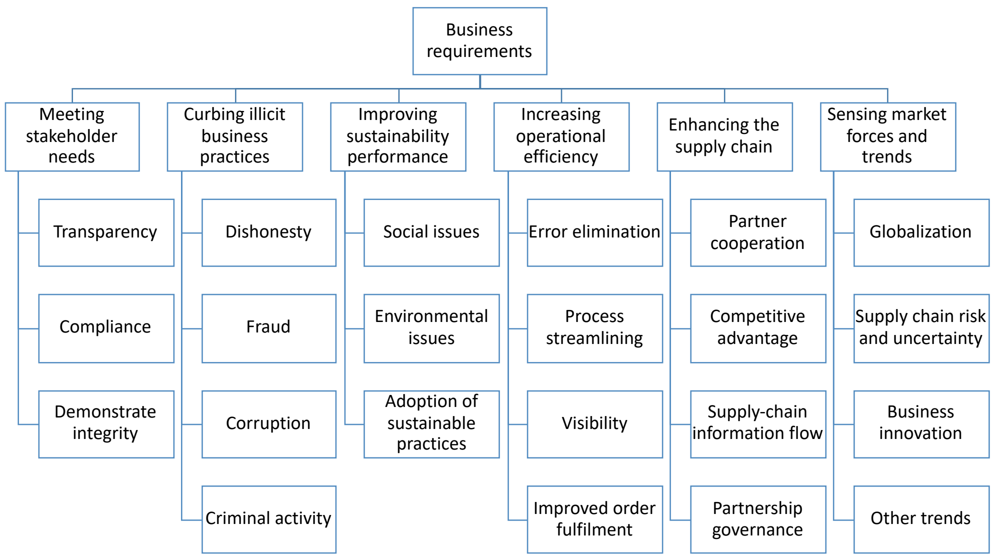

Figure 1: Business requirements themes and sub-themes

4.1.1 Meeting stakeholders' needs

Firms have stakeholders who should be engaged with and managed (Donaldson and Preston, 1995; Sodhi, 2015), and these firms need to provide transparency or traceability to some of these stakeholders (Sodhi and Tang, 2019). Thematic analysis indicated that stakeholders for supply chain traceability include suppliers and other upstream partners; customers; the community and environment; governments; NGOs; and trade associations (**Figure 2**; **Table 2**).

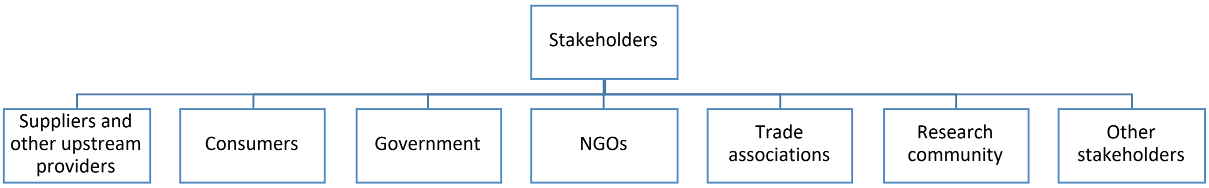

Figure 2: Stakeholders for traceability systems, as identified through thematic analysis

Insert Table 2 somewhere here

These firms need to meet stakeholders' needs for legitimacy in society (**Table 3**). Tian (2017) describes a blockchain-based system for a food supply chain in China motivated by consumer concerns over the safety and quality of food. Customers have little knowledge of what information companies collect on them and where this information might resurface in case of an IT security breach (Tapscott and Tapscott, 2016). Therefore, customers not only demand information disclosure on product provenance but also on information collected on themselves by companies (Kim and Kang, 2017).

Insert Table 3 somewhere here

Legislation and increasingly strict food traceability laws may be behind the considerable interest in blockchain within the food and agricultural industry (Tse et al., 2017; Visser and Hanich, 2017). Within the EU, each supply chain party is accountable for tracing food one stage upstream and one step downstream through production, handling, and delivery. This requirement ensures a full retrievable record in the event of food contamination (European Commission, 2002).

The need for control is not solely driven by the company internally, but also by trade associations, NGOs and government, and regulators to protect the society and environment in which the supply chain operates (Chow, 2018). Governments try to combat illegal practices by increasing regulation or imposing trade barriers. At the same time, NGOs and international trade organizations attempt to raise awareness about the link between smuggling illicit commodities and the backing of organized crime (Van Bockstael, 2018; Sharma, 2017). Note that regulations may be *country*-specific, thus creating contingencies – corpus items 1, 7, 8, 11, 12, 16, 26, 36, 37, 38, 39, 41, 45, 47, 63 (**Table 1**) refer to individual countries. These include China, Germany, Pacific Islands, UK, France, India, Vietnam, Democratic Republic of the Congo, Sweden, Ghana, Australia, and the USA.

Blockchain provides the opportunity for companies to offer customers increased transparency, and its encryption function provides security and safe data-management practices (Aves, 2018). Jeppsson and Olsson (2017) note that firms are investing in traceability systems in logistics to counter political and public pressure. They also find that many firms implement blockchain to satisfy regulation to continue operating in the market. As a result, the sub-themes of (a) *transparency*, (b) *compliance*, and (c) *demonstrating integrity* are requirements that are narrow enough to be treated as constructs. An empirical researcher could seek to build and validate an initial set of constructs using the codes to motivate indicators (**Table 4-1**).

Insert Table 4-1 somewhere here

4.1.2. Curbing illicit business practices

Sub-themes of illegal business practices that emerge from the analysis include (a) *dishonesty*, (b) *fraud*, (c) *corruption*, and (d) *criminal activity* (**Table 4-2**). In general, blockchain technology can be useful for curbing illegal business practices such as fraud, product tampering, illegal trade and criminal activity (Chapron, 2017; Lee and Pilkington, 2017; Kim and Laskowski, 2017). Unlawful business practices are widespread in many sectors. For instance, there is illegal mining for sand extraction (Pour et al., 2018), black-market trading in aircraft spare parts (Madhwal and Panfilov, 2017), and adulteration in wine production (Biswas et al., 2017). There is even a risk of plagiarism associated with 3-D printing (Holland et al., 2017).

Insert Table 4-2 somewhere here

Preventing upstream data corruption is a requirement for the blockchain (or other) technology-based traceability system (Chapron, 2017). For instance, blockchain can be used to prevent the miscount of quantity in the supply chain (Kim and Kang, 2017).

4.1.3 Improving sustainability performance

To improve their sustainability performance, companies require the traceability system to tackle (a) *social issues*, (b) *environmental issues*, and (c) *adoption of sustainability practices* (**Table 4-3**). Companies wish to be accountable for the provenance of their goods and the environmental-and-social sustainability of the supply chain in which they operate (Tse et al., 2017). So, another business requirement is to ensure adherence to legal and ethical procurement and production practices (Sharma, 2017). Also, many organizations focus on implementing blockchain to facilitate product lifecycle transparency, circular economies, and supply chains, and to better control their environmental footprint (Abeyratne and Monfared, 2016; Davcev et al., 2018; Chow, 2018; Agrawal et al., 2018; Chapron, 2017).

Insert Table 4-3 somewhere here

Blockchain technology is particularly relevant for companies buying such commodities as cobalt and timber. The origins of such products are necessary for ascertaining sustainability but cannot be easily verified. Human rights violations occur in other industries, such as the Pacific Islands tuna trade. Indeed, human slavery and trafficking often go hand-in-hand with unregulated fishing (Visser and Hanich, 2017). Not only do these problems cause the depletion of vital resources for developing countries and hamper their economic growth, but also damage the public's belief in institutional structures (Düdder and Ross, 2017; Kim and Kang, 2017). Opacity in supply chains enables the exploitation of natural resources as well as of human beings (Badzar, 2016). Indeed, illegal trade is worth billions of dollars per year. Responsible companies would like to have traceability systems that can assure social sustainability in their supply chains on pressing social problems.

4.1.4 Increasing operational efficiency

Businesses require the system to help them improve operational efficiency in a variety of ways. These include: (a) *error elimination*, (b) *process streamlining*, (c) *visibility* into the supply chain, and (d) *improved order fulfillment* (**Table 4-4**). Traceability can help realize supply chain efficiency (Bateman, 2015) by way of information sharing. Aside from human error, forecast error and slow processing times, companies also need to tackle fragmented production data and system breakdowns (Edwards, 2017; Kumar and Iyengar, 2017; Mattila et al., 2016).

Insert Table 4-4 somewhere here

Companies may require the use of blockchain-based traceability systems for performance measurement (de Vos, 2017), with improvement in operational efficiency starting with various measures. Using blockchain for traceability with automated transactions can improve inventory management and speed up data reconciliation (Rabah, 2017). Blockchain-based traceability can also enhance quality management and decrease production costs due to increased forecast accuracy (Madhwal and Panfilov, 2017).

4.1.5 Enhancing supply chain management

Businesses require traceability systems to help them enhance their supply chain management by working with supply-chain partners. The requirements for these systems are (a) *partner coordination*, (b) *competitive advantage*, (c) *supply-chain information flow*, and (d) *partnership governance* (**Table 4-5**). Many partners operate in near-isolation in the supply chain, making coordination challenging (Abeyratne and Monfared, 2016; Badzar, 2016). Although dependent on each other, partners individually seek to maximize objectives that conflict with those of others' (Xu et al., 2017). Despite communications technology, many companies do not share demand information upstream, causing inventory and order levels to fluctuate widely across the supply chain (Kim and Laskowski, 2018).

<u>Insert Table 4-5 somewhere here</u>

In this context, a blockchain-based traceability system may be attractive for achieving supply chain coordination (Lefroy, 2018). As information is distributed peer-to-peer in real-time using a consensus mechanism, reduced information asymmetry could reduce the rent-seeking behavior of any of the supply chain players. With this increased flow of information, suppliers would get a better insight into demand data allowing them to estimate lead times better (Kim and Kang, 2017; Tian, 2016; Tse et al., 2017). Moreover, transfer and clarification of ownership, become much easier to manage and trace with blockchain-based traceability as goods and raw materials change hands.

4.1.6 Sensing market forces and trends

Market forces and trends include (a) *globalization*, (b) *supply chain risk and uncertainty*, or disruptions, (c) *business innovation*, and (d) *other trends* (**Table 4-6**). Globalization of trade has led to increased competition among incumbents, new business models, and markets (Debabrata and Albert, 2018). Political instability, natural disasters, global population growth, and rapid technological advancement add to the challenging business climate for international companies (Armbruster and MacDonell, 2017; Calatayud, 2017). Companies manage risk by continuously innovating and improving their business to ensure customer responsiveness and loyalty to safeguard their market share (Seebacher and Maleshkova, 2018).

<u>Insert Table 4-6 somewhere here</u>

Blockchain technology has the potential to make supply chains more responsive to movements or trends and more resilient against market disruptions (Calatayud, 2017). As blockchain connects the partners, the company can access intelligence – whether through picking up patterns on sales on new products or disruptions to supplies upstream – quickly. Moreover, the system can be designed to be autonomous to continue working even in the case a blockchain node breaks down (Bahga and Madisetti, 2016).

It is not only the possibility of gaining long-term value that attracts supply chain practitioners but also the competitive advantage from being ‘in-the-know’ (Edwards, 2017; Uslay and Yeniyurt, 2018). Companies seek to learn about fluctuations or trends in demand in the short term, and increased market competitiveness, use of renewables, innovation, rapid new product development (NPD), new business models/markets, rapid technological development, and political instability, in the longer term. In that sense, blockchain-based traceability is disruptive (Van Bockstael, 2018). Players that act sooner than their competitors to set standards for operational information sharing in the business can gain a competitive advantage (Edwards, 2017). De Beers Group's 'Tracr' initiative seeks to trace diamonds on the blockchain using ID inscriptions (Van Bockstael, 2018). The initiative proposes an open platform for all industry players in the diamond value chain (Tracr, 2018). Opening up the system to all players would allow De Beers to learn more about diamond movements and sales throughout the world.

4.2 Critical Success Factors

Next, we identify themes that focal companies in the supply chain need to be aware of as they set about implementing traceability systems using blockchain (**Figure 3**).

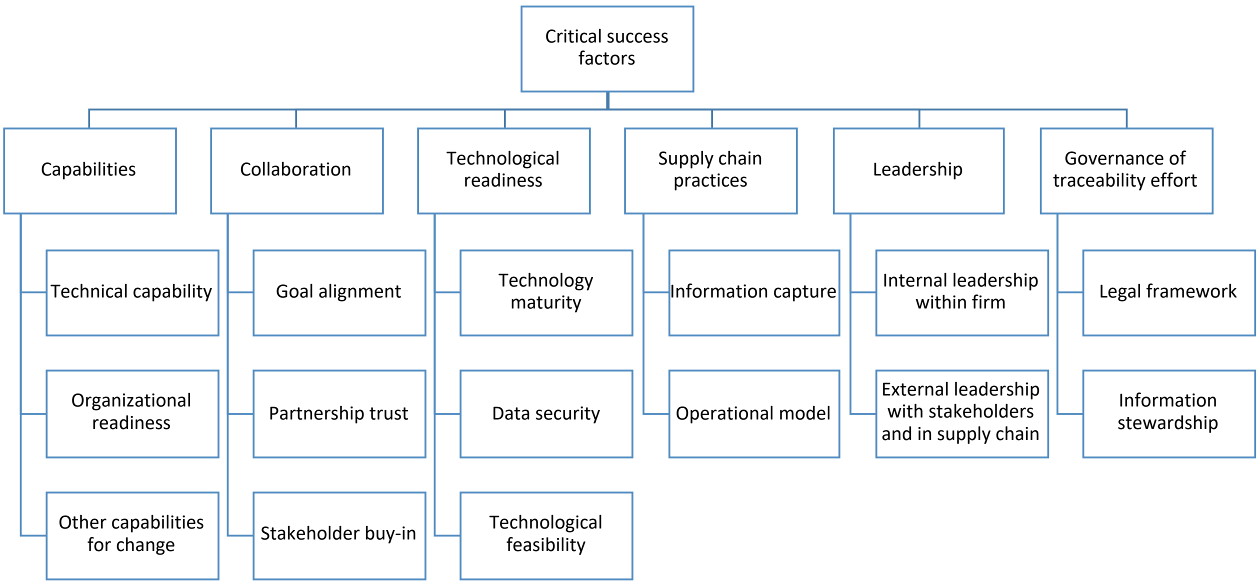

Figure 3: Critical success factor themes and sub-themes, as inferred from thematic analysis

4.2.1 Capabilities

In general, capability refers to the competence, resources, and the know-how that a company needs to execute its main activities (Baruffaldi and Sternberg, 2018). The thematic analysis identified as sub-themes: (a*) technical capability*, (b) *organizational readiness*, and (c) *other capabilities for bringing about change* (**Table 5-1**).

Insert Table 5-1 somewhere here

The lack of ability to understand the technology is a significant barrier to blockchain adoption in a supply chain traceability context (Pour et al., 2018; Edmund, 2018; Chapron, 2017; Chen, 2016). Especially noteworthy is the labor skills gap (Bak, 2018; Calatayud, 2017). Uslay and Yeniyurt (2018) discuss how finance became more attractive for application than supply chain for technology experts. Focal companies have to note that facilitating blockchain adoption requires leveraging existing company resources, investment strength and focus on knowledge development (Bateman, 2015; Jeppsson and Olsson, 2017; Petersen & Jansson, 2017).

4.2.2 Collaboration

Collaboration is required across supply-chain partners to make blockchain integration work in a complex international supply chain (Kuo et al., 2017; Kim and Laskowski, 2017). Sub-themes are (a) *goal alignment* with partners, (b) *partnership trust*, and (c) *stakeholder buy-in* (**Table 5-2**). A supply chain partner's skepticism partner poses a threat to the adoption of traceability solutions across the supply chain (Britchenko et al., 2018). Moreover, blockchain can decentralize market power that threatens a firm seeking to preserve rent (Kim and Kang, 2017). Upstream players are crucial for any traceability solution. These players may resist if they view the system as a threat to their competitive advantage by having to share proprietary information with customers (Edwards, 2017; Badzar, 2016) or even competitors. Illegal or unauthorized business practices at a supply chain partner can also be a cause for resistance to traceability.

Insert Table 5-2 somewhere here

Companies need to prioritize their objectives regarding supply chain traceability when seeking the support of supply-chain partners. Critical areas for agreements include the type of information supported and confidentiality of the transferred data (Jeppsson and Olsson, 2017). Upstream partners need to decide on the input data for identification of the goods traded for standardization across these companies (Chow, 2018). The challenge of developing manufacturing and material management standards depends on the industry. Different types of goods have various identification features like color and clarity for diamonds or lot-tracking for food items (Chow, 2018; Leng et al., 2018). In some industries, collaboration with supply chain partners and even competitors would be critical. Finally, supply chain partners need to agree on how and when to record goods at each aggregation node (Chow, 2018).

4.2.3 Technological readiness

This critical success factor has as sub-themes (a) *technology maturity*, (b) *data security*, and (c) *technology feasibility* (**Table 5-3**). Blockchain technology has limitations as of this writing, including the problem of the speed of recording transactions that degrades with the number of nodes (Zheng et al., 2017). Besides a cost-benefit analysis of implementation, companies need to evaluate even the feasibility of blockchain being implemented in their industries (Tseng et al., 2018; Baruffaldi and Sternberg, 2018; Seebacher and Maleshkova, 2018). They could consider other less resource-intensive alternatives for solving their traceability problems (Britchenko et al., 2018). As such, despite the attractiveness of blockchain technology, organizations are hesitant to commit resources to the investigation of potential applications (Petersen et al., 2017). Adoption and implementation of blockchain have been slow in the supply chain, and there are only a few cases of use (Armbruster and MacDonell, 2017; Seebacher and Maleshkova, 2018; Thomasson, 2019) as of this writing.

Insert Table 5-3 somewhere here

The information in the supply chain is intended to reflect a physical reality regarding inventory, goods, or orders. While data is secure on the blockchain, we cannot say that the data entered truly reflects the real situation (Apte and Petrovsky, 2016). Just as one can falsify data by misrepresenting material reality while still using existing means of authentication, data falsification can happen with the blockchain as well. Support technologies necessary to link information on the blockchain with the physical world – NFC, RFID tags, and QR-codes – are also corruptible (Visser and Hanich, 2017).

Also, we could question how practical blockchain would be for remote suppliers such as small farmers in rural areas with limited technological access or skills (Uslay and Yeniyurt, 2018). Other limitations, such as slow transaction speed/throughput capacity, scalability issues, and high energy consumption also need consideration (Mengelkamp et al., 2018). All in all, companies need to consider blockchain's level of technological maturity, including security and user privacy as pertinent to the supply chain (Toyoda et al., 2017).

One study found 77 percent of industry executives uninterested in implementing blockchain with only one percent having integrated it into their operations (Patrick, 2018). This lack of interest could be because companies and their supply chain partners do not want to adopt the technology without seeing benefits from the implementation by others first (Patrick, 2018). Blockchain not only requires regulatory buy-in but also manufacturers support to scale (Mackey and Nayyar, 2017). As such, some industry executives are seeking to establish minimal but viable ecosystems for blockchain to figure out benefits from a reduced network (Rabah, 2017; PRNewswire, 2017; Wentworth, 2018). On a positive note, early adopters could set the industry standard and gain a competitive edge (Edwards, 2017). Multiple blockchains solutions would be difficult to sustain in the same industry.

4.2.4 Supply chain practices

Practices include, at a high level, those relating to (a) *information capture*, and to (b) the *operations model* (**Table 5-4**). Timely collection of standardized data and storing and processing metrics at different levels are prerequisites for a successful traceability system across the supply chain (Armbruster and MacDonell, 2017; Debabrata and Albert, 2018; Calatayud et al., 2018). However, data collection practices and traceability processes are not standard across the supply chain. Also, data structures may differ from one actor to another for different types of information exchanged between parties (Francisco and Swanson, 2018). Lack of standards hinders interoperability when attempting to implement a traceability system. The solution is standardizing processes and establishing best practices (Tian, 2017; Mattila et al., 2016). However, a company would share best practices only after having full records of raw material sources with access to their suppliers' IT infrastructure (Francisco and Swanson, 2018; Abeyratne and Monfared, 2016). Suppliers may not be comfortable sharing such information.

Insert Table 5-4 somewhere here

Lack of interoperability also characterizes industries where multiple companies are creating blockchains for their supply chains to different standards and different practices. Companies in the same industry cannot realize network synergies when suppliers are required to use different blockchains for different customers (Tian, 2017).

The supply chain network also affects the achievement of intended outcomes. A traceability solution, whether using blockchain or not, is not going to be beneficial for a company by itself (Patrick, 2018). Such a solution can face opposition both within the firm and in the supply chain at large. Also, horizontal or vertical competitors may perceive their competitive advantage threatened. They may also prefer to sit out as they wait to learn from the mistakes of others. Finally, the emergence of multiple traceability systems in the same industry sector can make suppliers resistant to adopting any of these systems.

4.2.5 Leadership

Leadership, whether *internal*ly within the firm or *external*ly with stakeholders, including those in the supply chain, is an essential enabler for blockchain adoption (**Table 5-5**). Leadership is either within the supply chain motivating supply chain partners or externally in communicating support of the technology (Jeppsson and Olsson, 2017; Chow, 2018; Catalini and Gans, 2016). In general, companies are more likely to commit resources if there is acceptance of blockchain in their industry already under the leadership of specific companies (Petersen et al., 2017). The agri-food sector has been the focus of blockchain adoption for the supply chain as well as related research (Lefroy, 2018; Tian, 2017; Leng et al., 2018) in part because of the leadership of retail giants such as Carrefour and Wal-Mart. The companies have been early adopters of the technology, paving the way for smaller actors (Britchenko et al., 2018; Kim and Laskowski, 2017; Thomassen, 2019).

<u>Insert Table 5-5 somewhere here</u>

A company may also need to take a leadership role because any initiative would fail if the company cannot engage the various companies in its supply chain (Bateman, 2015). The company would have to bring the supply chain partners together, share challenges and opportunities with others in the supply chain and the industry, and learn from existing blockchain initiatives.

4.2.6 Governance of traceability effort

Governance entails (a) working within the *legal framework*, and (b) enforcing *information stewardship* (**Table 5-6**). In a survey of 155 supply chain experts' regarding their expectations from blockchain technology, Petersen et al. (2017) found that 56% of the participant view 'regulatory uncertainty' as the foremost barrier to blockchain adoption. For global supply chains, blockchain or any other technology would need to adhere to various laws, regulations, and jurisdictions, to agreement restrictions surrounding data governance and ownership, as well as commercial rules (Kshetri, 2018; Rabah, 2017; de Vos, 2017). Existing laws are insufficient to regulate cryptographic activities, and a review of the current legal framework is much needed (Badzar, 2016).

<u>Insert Table 5-6 somewhere here</u>

5. Conclusions

We have outlined the requirements focal businesses have of any traceability system, including meeting stakeholders' needs as well as the factors critical to the success of any supply-chain-wide implementation. Based on this early-stage research, there are implications for researchers and managers.

5.1 Implications for research

The themes and sub-themes on business requirements and critical success factors provide us with concepts that can help with case study research leading to conceptual development. Empirical researchers can use to develop instruments using the proposed sub-themes as constructs with a subset of the codes as items (**Tables 4 and 5**). Normative researchers can look at the tradeoffs needed across business requirements, given the constraints indicated by the critical success factors. Given the different stakeholders, including those that are part of the supply chain, game-theoretic aspects around building and operating such a system are also a way to understand the tensions analytically. Another theme is developing solution architecture from the business requirements given the existing ERP and extra-enterprise systems as well as proposed blockchain solutions. Thus, the themes identified in this paper can provide a basis for further descriptive research, instrumental research, and normative research.

One line of research can be delineating practices from blockchain or other implementation for improving traceability in the supply chain. If the technology is not ready or otherwise too risky, a natural question is how companies can initially develop traceability practices even without the use of any technology. According to Mougayar (2015, p. 70), 80 percent of the blockchain implementation effort is about changes in business processes – only 20 percent of the effort is the implementation of the technology itself. The split in effort suggests that companies can implement the bulk of the traceability efforts with process changes before implementing blockchain. Indeed, Swedish engineering conglomerate ABB changed its processes over three years to activity-based costing before implementing these processes in SAP (Economist, 1998). As the Head of Blockchain Policy at the World Economic Forum put it, "We are prototyping, iterating, testing, scaling…the technology is not the hard part" (Naylor, 2018). Conversely, the use of blockchain alone could not have prevented the horsemeat scandal with the beef supply chain in Europe in 2012 (Cordon and Bris, 2019) because of the incentive to cheat. Therefore, process changes and incentives are essential in their own right.

Blockchain is only one possible technology to implement traceability. There are many examples of apparel companies having tried web-based technology to provide provenance-related information to consumers and the public at large (Sodhi and Tang, 2019). In such cases, the supply chains have fewer layers than, say, electronics, and most of the supply chain is within the control of the original equipment manufacturer (OEM). For instance, wool-based apparel provider, Icebreaker, used to provide a 'BaaCode' with their apparel. Consumers could type the BaaCode of their purchased item into a website to see which particular Merino wool farm in New Zealand from which the wool in their purchased item came. However, this is possible only because IceBreaker purchases wool from specific farms only, so provenance is not a concern; instead, it is a selling point. Icebreaker's example motivates two questions. One is about what supply chain characteristics influence the technology to implement traceability. The other related question is how business requirements and critical success factors change (or are simplified) in contexts where other technologies besides blockchain are being considered or used.

5.2 Implications for practice

Although many industries face social and environmental sustainability challenges, managers are concerned about how ready blockchain technology is for traceability. Given the business requirements and critical success factors outlined in our research, there needs to be a technological evaluation and ways to develop a business case. Such a business case needs to include bringing small suppliers in remote areas into the traceability system.

Managers also have to think about their existing systems, given the extensive set of business requirements (Section 4). It is unlikely that a single blockchain system could meet all these requirements. Companies have already invested in ERP, APS, CRM, or other IT systems. Therefore, the blockchain-based solution would have to integrate with these existing systems to varying degrees. Moreover, these companies and their supply chain partners would have to redesign processes around the use of these systems. Companies and their existing enterprise vendors may prefer to extend the capabilities of their current systems rather than develop blockchain-based solutions. Extending the existing system is especially attractive when the motivation is only to meet regulatory or a particular customer’s requirements. In any case, centralized systems such as a company's extended ERP solution are much faster at handling transactions than a blockchain solution. The transaction speed in blockchain-based systems can degrade rapidly with the addition of more nodes that are added as necessary to reflect the network. For these reasons, it may well be that the traceability solution for an industry or a company is a hybrid with blockchain being a small, albeit significant, component of the overall architecture.

Managers have to understand how they can build the right capabilities in their own or their supply-chain partners' organizations for building and operating traceability systems. They also have to bridge the skills gap by attracting new talent. Managers need to understand the role of blockchain IT or logistics providers and decide how much they want to depend on a particular provider's expertise and experience (Southey, 2018). On the other hand, managers also have to have confidence in their domain knowledge to develop solutions with different IT providers. Managers must also judge how much transparency to provide to the general public on their products' provenance and the supply chain in general. Transparency is a factor in the level of traceability needed from the system based on blockchain or some other technology.

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Table 1: Sources for thematic analysis, in order of appearance on Google Scholar

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Table 2. Stakeholders and underlying codes

No.	Stakeholders	Underlying codes	Reference
1	**Suppliers & other upstream providers**	Supply chain partners, growers, farmers, producers, warehouses, logistics and transport providers, suppliers, manufacturers, distributors, wholesalers, retailers, upstream SC, downstream SC, sellers, OEMs, 3PLs	1, 2, 3, 7, 9, 11, 15, 16, 18, 20, 21, 23, 24, 25, 28, 29, 31, 32, 40, 42, 43, 44, 45, 47, 50, 51, 52, 53, 54, 55, 56, 59, 60, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 75
2	**Consumers**	Consumers, patients, users, clients, customers, second-tier customers, buyers	1, 3, 4, 7, 8, 11, 10, 12, 13, 15, 18, 22, 23, 24, 25, 27, 29, 30, 33, 34, 35, 41, 43, 44, 45, 46, 47, 48, 51, 52, 53, 54, 59, 60, 64, 65, 66, 68, 69, 70, 75
3	**Governments & regulators**	Governments, regulators, government agencies, law makers, European Commission, politicians, authority, customs, registrars,	1, 2, 6, 7, 8, 10, 11, 18, 24, 26, 30, 34, 37, 40, 41, 44, 52, 53, 61, 60, 63, 65, 71, 74, 75
4	**NGOs**	Non-governmental organizations, NGOs, Fair Trade, certifiers, WWF, IPLA, Amnesty, European Timber Regulation, WHO	2, 3, 12, 26, 30, 36, 38, 48, 51, 73
5	**Trade associations**	OECD, CCCMC, RCI, Huayou Cobalt, London Metals Exchange, private sector institutions, global trading markets, Food and Drug Administration, MHRA, WTO	3, 15, 30, 36, 43, 48, 53
6	**Research community**	Researchers, universities, academic journals, research centers	2, 23, 38, 40, 42, 53
7	**Investors and other stakeholders**	Local communities, workers, SMEs, society, information deprived parties, IT platform providers/software developers (Ethereum, Bitcoin, OrigiChain, Provenance), public sector, intermediaries, investors, low income societies, third-party traceability service provider	19, 34, 37, 53, 57, 66, 69, 70, 71, 74, 75

Table 3: Stakeholder needs

Underlying codes	Corpus References
Customer information asymmetry, supplier information asymmetry, life cycle transparency, improved integrity pressure, customer confidence/trust, regulatory requirements, ethics, transparency, visibility, government pressure, compliance	2, 3, 4, 6, 8, 10, 18, 23, 24, 30, 32, 36, 44, 59, 61, 64, 73

Table 4-1: Business requirements – Meeting stakeholder needs

Sub-theme	Underlying codes	Corpus Reference
Transparency	Customer information asymmetry, supplier information asymmetry, power asymmetry, life cycle transparency, information coordination challenges, SC opaqueness elimination, visibility	2, 3, 4, 6, 8, 9, 11, 12, 36, 44, 59, 64, 70
Compliance	Regulatory requirements, regulatory induced change, governmental pressure, conformity, compliant production processes, contractual fulfillment verification, organizational accountability	4, 10, 12, 18, 20, 23, 24, 30, 31, 52, 59, 61, 63, 65, 69, 72
Demonstrate integrity	Improved integrity, customer confidence/trust, trust in business intentions, ethical business practices, ethical business conduct, end-to-end integrity control, data trustworthiness	4, 6, 8, 13, 31, 59, 64, 65, 69, 73, 70, 73

Table 4-2: Business requirements – Curbing illicit business practices

Sub-theme	Underlying codes	Corpus Reference
Dishonesty	Falsified data, manipulated information, dishonest communication, misleading communication, immoral labor utilization, validity of information, plagiarism, verification of information, provenance issue	2, 16, 17, 20, 22, 24, 25, 26, 46, 48, 50
Fraud	Counterfeiting, product tampering, mutable product, adulteration, relabeling, trace product composites, authenticity, counterfeit protection, tamper-proof production	1, 2, 10, 14, 15, 20, 22, 24, 25, 26, 30, 33, 40, 43, 42, 46, 54, 56, 59, 63, 65, 67, 68, 70, 71
Corruption	Corruption, corrupt business practices, unethical business behavior, governance corruption, providing illicit benefits, abuse of power, abnormal returns, rent-seeking	11, 17, 15, 30, 33, 55, 57, 74
Criminal activity	Illegal trade, illegal extraction, black market trading, thievery, illegal conduct, illegal business practices	12, 23, 33, 41, 46, 74

Table 4-3: Business requirements – Improving sustainability performance

Sub-theme	Underlying codes	Corpus Reference
Social issues	Child labor, rural poverty trap, Fair Trade, prosperous local economy and community, standard of living, resource right, CSR scrutiny and accountability, human rights abuse, conflict resource, circular economy, developing-country exploitation	3, 4, 6, 7, 12, 13, 16, 21, 29, 36, 47, 55, 57, 58, 65, 66, 70, 73

Environmental issues	Waste control, pollution, environmental impact, fair trade, emission standards and monitoring, illegal harvest/extraction and trade, natural resource exploitation and depletion, monitor/reduce carbon footprint, healthy ecosystems, reinvent ecosystems, hazardous spread, safeguard nature,	1, 3, 4, 11, 21, 23, 26, 29, 41, 46, 49, 57, 58, 59, 66, 73, 74, 75
Adoption of sustainable practices (social, environmental)	Sustainable procurement and acquisition processes, sustainable production, sustainable business practices, circular supply chain, excessive production, certified supply chains, supply chain sustainability responsibility, stakeholder sustainability pressure, sustainable actions verified, agriculture sustainability, renewable energy, auditable carbon footprint	7, 10, 18, 20, 21, 23, 26, 34, 36, 55, 57, 64, 66, 73

Table 4-4: Business requirements – Improving operational efficiency

Sub-theme	Underlying codes	Corpus Reference
Error elimination	Quality management, root-cause analysis, eliminate human error, minimize system errors, performance measurement, cost savings, reduce waste, eliminate wasted time, forecast accuracy, cost-efficiency, lower production cost, cost optimizing	4, 11, 14, 24, 25, 32, 33, 35, 36, 42, 46, 51, 56, 65, 71
Process streamlining	On-demand manufacturing, non-fragmented product data/product-centric information management, consistency, process transparency, process speed, activity measurement, productivity gains, streamline SC, improved efficiency, eliminate physical documents, improved recall processing, efficiency of processing, reassess traditional information processes, time optimizing	5, 9, 11, 14, 18, 20, 35, 36, 38, 42, 45, 50, 52, 66, 71
Activity overview	Real-time tracking/overview, transparent transaction log, monitor product lifetime, operational overview, information granularity, facilitate data reconciliation, product progress visibility, smart diagnostic and maintenance scheduling, operational efficiency, process traceability, auditable processes	1, 5, 7, 8, 13, 22, 27, 35, 37, 45, 46, 49, 50, 56, 63, 65, 69, 70
Improved order-fulfilment	Scalability, platform enhancer, dynamic optimization, extract business intelligence, tactical planning, improved inventory management, increased responsiveness/decision making	22, 45, 52, 54, 56, 60, 65

Table 4-5: Business requirements – Enhancing supply chain management

Sub-theme	Underlying codes	Corpus Reference
Partner cooperation	Power decentralization, resource sharing, network and transaction cost savings, SC partner communication/cooperation, improved supplier relationships, improved value chain procedures, multi-partner collaborations, partner interdependencies, closer cooperation suppliers and customers, integrated SC management system, connected SC	4, 6, 10, 11, 18, 19, 28, 29, 32, 40, 43, 44, 53, 54, 57, 60, 67, 68, 70, 71

Competitive advantage	Robust SC management, market adaptation, business advantage, SC competitiveness, dynamic SC, streamline SC, optimize SC value output	6, 4, 16, 22, 43, 45, 68, 75
Supply-chain information flow	Information transparency, e-configuring, information asymmetries, immutable audit trail, disparate partner IT system, contractual fulfilment/coordination, information coordination challenge, end-to-end integrity, less contract ambiguity, real-time tracking and visibility	1, 2, 3, 4, 6, 9, 11, 13, 22, 27, 35, 45, 57, 67, 70
Governance of supply chain partnerships	rent-seeking, trustless collaboration, supplier insight and compliancy, mitigate SC risk, SC governance, enforcement mechanism, intermediary removal, SC partner complexity, remove reliance, falsified information, compliant production process	5, 8, 11, 12, 14, 19, 20, 21, 23, 25, 31, 39, 41, 49, 54, 57, 60, 70, 72

Table 4-6: Business requirements – Sensing market trends and forces

Sub-theme	**Underlying codes**	**Corpus Reference**
Globalization	rapid international trade development, worldwide economic integration, increased market competitiveness, resource sharing, global collaboration, increasing food demand, population growth, outsourcing, economic integration and dependencies, increased supply chain rivalry	2, 4, 10, 18, 23, 29, 34, 40, 43, 44, 45, 53, 67, 68, 69, 70, 72
Supply chain risk and uncertainty	Fluctuating/changing demand patterns, political instability, opaque and multi-layered supply chains, amount of SC partners, consumer distance, diverse supply chains, growing IT complexity, scarce resources, organizational complexity, many intermediaries, disruptive industry effect	1, 7, 10, 11, 13, 14, 16, 18, 19, 21, 24, 29, 30, 37, 39, 49, 41, 42, 43, 53, 54, 59, 60, 67, 68, 70, 71, 72
Business innovation	Renewables, local economy/community focus, innovation, rapid NPD (new product development), new business models/markets, rapid technological development, first mover advantage desirable, startups, legacy industries disruption	7, 16, 19, 29, 38, 46, 47, 55, 57, 58, 65
Other trends	Corporate social responsibility and scrutiny, sustainability promotion, awareness and monitoring, growing consumer power/pressure, circular economy, strategic procurement, product life cycle	3, 4, 6, 21, 29, 33, 36, 44, 55, 57, 63, 64, 66, 69, 73, 74

Table 5-1: Critical success factors – Capabilities

Sub-themes	Underlying codes	Corpus Reference
Technical capability	IT capability (deploying and leveraging), big data capabilities, software implementation skills, information system readiness, poor understanding of technology	7, 10, 18, 23, 28, 40, 53, 59, 68, 69
Organizational readiness	Know-how, capability to assess suitability/context of application, skills shortage, knowledge gap, ability to engage others, capability doubt, adaptive, organizational capability, expert knowledge requirement, familiarity, education, leverage existing company resources,	14, 21, 28, 32, 38, 41, 52, 57, 59, 61, 62, 69, 71
Other capabilities for change	Dynamic and operational capability, financial liquidity, investment strength, access to finances	1, 3, 6, 13, 28, 46, 53, 55

Table 5-2: Critical success factors – Collaboration

Sub-themes	Underlying codes	Corpus Reference
Goal alignment	Conflicting business objectives, common production and material stewardship standards, data features agreement, intra-company synergies clarified, key actor benefit awareness, impractical for remote actors	3, 23, 36, 68, 71
Partnership trust	Skepticism, information integration, information exchange resistance, decentralization of power and information, information as competitive advantage, producer transparency resistance, incumbents' resistance, loss of business leverage	1, 3, 4, 14, 43, 40, 56, 57, 65, 66, 70
Stakeholder acceptance	Participation, value chain cooperation, consumer engagement, complex international supply chains, collaboration with trading partners/academia/competitors/industry associations, SC party coordination problem, local community engagement, minority adoption, common language development, business-culture adoption	2, 6, 12, 13, 14, 17, 18, 34, 35, 36, 40, 46, 55, 56, 59, 60, 61, 66, 71

Table 5-3: Critical success factors – Technological readiness

Sub-themes	Underlying codes	Corpus Reference
Technology maturity	nascent technology, limited research available, few practical application examples, low adaptation, technological imperfections, immature infrastructure	1, 6, 10, 13, 14, 15, 21, 22, 27, 34, 36, 38, 40, 46, 53, 58, 59, 62, 63, 65
Data security	software vulnerabilities/security, platform credibility, data credibility, corruptible support technology (RFID, QR), user privacy, security protection, data governance, data corruption	5, 11, 12, 13, 15, 21, 27, 37, 38, 39, 44, 53, 56, 66, 70, 71
Technological feasibility	Cost-benefit analysis, assess operational suitability, remote supplier practicality, understanding why blockchain, material world congruency flaw, IT system integration/congruency,	3, 12, 13, 14, 18, 21, 23, 37, 38, 46, 50, 58, 59, 63, 69

	energy consumption, level of transparency, integration cost, legacy system integration, scalability constraints	

Table 5-4: Critical success factors – Supply chain practices

Sub-themes	**Underlying codes**	**Corpus Reference**
Information capture	Timely and accurate data collection/storing/processing, incomplete supply chain sourcing information, KPI and metrics capturing, legacy system integration, stakeholder IT infrastructure,	3, 4, 6, 7, 16, 17, 21, 23, 34, 38, 46, 60, 62, 72, 75
Operational model	Level of decentralization of supply chain information, best and risk management practices, supply chain value stream mapping, due diligence, process flowcharts, complexity of process standardization, lack of process standardization	1, 6, 4, 8, 11, 13, 14, 15, 25, 26, 36, 40, 44, 49, 52, 75

Table 5-5: Critical success factors – Leadership

Sub-themes	**Underlying codes**	**Corpus Reference**
Internal leadership within firm	Incentives, leadership support, skepticism/acceptance, user motivation, ability to engage others, human behavior/behavioral, intention, acceptance, participation, top-down leadership approach	6, 13, 15, 19, 23, 28, 27, 29, 35, 36, 38, 59, 69
External leadership with stakeholders and others in supply chain	NGO support, market evolution, worker involvement, customer awareness, small player involvement, market leader resistance, incumbent strategies to preserve rent, governance corruption, excessive bureaucracy, network effect	12, 16, 30, 35, 49, 55, 56, 54, 57, 70, 73

Table 5-6: Critical success factors – Governance of traceability effort

Sub-themes	**Underlying codes**	**Corpus Reference**
Legal framework	Legal framework for cryptographic activities, regulatory uncertainty, political uncertainty, policy structure and making issues, law stipulated tracking, regulatory pressure, varying regulations/laws/institutions across countries	4, 5, 18, 27, 30, 34, 35, 48, 53, 57, 60, 63, 70, 71, 74
Information stewardship	Data governance, data ownership complexities, lack of standards, agreement restrictions prohibiting blockchain, common standards, material stewardship standards	4, 9, 13, 36, 46, 66, 70