Design principles for use cases of blockchain in food supply chains

Completed Research

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Abstract

Consider the dilemma of food consumers at outlets such as grocery stores, cafes, restaurants and e-tailers; a myriad of certifications such as "organic", "fair-trade", "non-GMO", "expiry dates" confront the choice that they make. Implicit in that choice is the "trust" consumers have for the brands and merchants. What if the entire food chain could be placed on a "trust-less" platform where transactions are transparent, traceable, tamper-evident, immutable and compliant? Such a "3TIC" mechanism would also allow food producers and resellers to create and capture value. This paper describes the use case of Blockchain and augmented technologies in validating the safety and security of food supply. Design principles that address the "what" question and their derivative design rules that address the "how" question are developed using an approach known as Soft Systems Methodology.

Keywords

Food safety and security, soft systems modeling.

Introduction

The supply chain of agricultural products is a time-bound and mission critical agri-business challenge. A nascent technology which appears to show promise of a solution is the Blockchain along with associated tools and techniques for its implementation such as Artificial Intelligence, the Internet of Things and Data Analytics. Consider the problem of consumers shopping in supermarkets with their distinct preferences about food quality and value. Labels on produce and products are non-standard and often difficult to trust. Further, a host of claims – eg "organic", "non-GMO", "green", "fair-trade", "safe for infants" – are bewildering to the consumer as there is no other way of authentication but to rely on the brand name on the produce or product. This paper proposes a conceptual design for such a use case and signals our intention to develop an instantiated artifact in the form of a Minimum Viable Solution. The application of blockchain and augmented technologies such as IoT, big data and analytics is proposed for validating claims made on labels. Specifically, the supply chain for dairy products is used as a test for a blockchain-based, trust-less platform and its efficacy examined. It is the intent of this research that consumers may be "nudged" to make more informed and intelligent choices. This is a contribution to research efforts in digital farming, precision agriculture and, more specifically, the digital twining of supply chains for tamper-evident produce.

In essence, the blockchain is a distributed ledger technology in the form of a non-centralised transactional database, secured by cryptography, and governed by a consensus mechanism. In an early description, a blockchain is essentially a record of digital events. However, it is not "just a record," since it can also contain so-called smart contracts, which are programs stored on the blockchain that run as implemented without any risk of downtime, censorship, or fraud (Beck et al. 2017). This definition captures the key characteristics of blockchains. They are: 1) distributed without central control, 2) secured by encryption, 3) governed by transparent, persistent contracts, and, 4) resilient as a result. Similar to other knowledge networks, blockchains may be open or closed, public or private, and hybrid implementations have emerged as proofs-of-concept.

Though it was initially developed and used in the context of Bitcoin and other cryptocurrencies (Nakamoto, 2008), it emerged that this concept could also be applied to any problem domain where actors must reliably record decentralized transactions. For instance, the blockchain could enable "smart contracts" embedded in digital property or representations by encoding rules for business transactions (such as triggering payments or authorizing access) and autonomously enforce these rules by making breaches expensive. Hence the blockchain may be a solution in environments where not all parties, whether humans or machines, can be fully trusted. Beyond business transactions, the blockchain could also be well-suited for recording public information such as titles, deeds, ownership records, or schedule of updates. However, to date, the blockchain is a technology still in search of critical use cases (Beck et al. 2017).

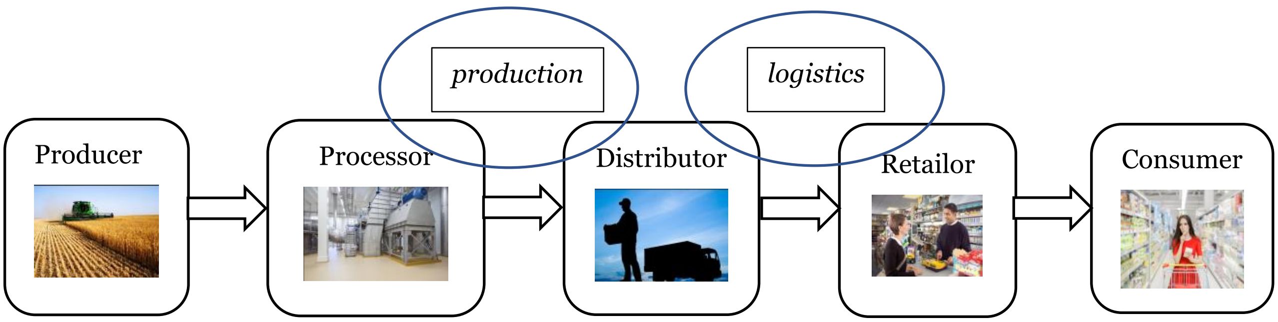

Figure 1. Typical Value Chain for Food.

The research context is the agriculture industry in New Zealand. Figure 1 illustrates the typical supply chain for food products. The "Produced in New Zealand" brand is well-known for its quality and standards. With a host of certifications such as "organic", "fair-trade", "non-GMO", etc. and others which refer to expiry dates and storage conditions, the physical assets (in this case, produce) have to be tracked through the production and distribution chain to ensure trust in the labelling. A host of issues concerning the supply chain of agricultural produce – food safety, supply, recall, tracking, etc – emerge. It is in the interests of both producers and consumers that such issues are resolved. Previous attempts have run into problems with the commodity being uniquely identifiable. This paper describes the application of blockchain in the end-to-end channel from producer(s) to consumer(s) so as to assure trust. While the creation of smart contracts and distributed ledgers may seem trivial in such conditions, the fundamental problem is in labelling and tracking (with IoT, GPS?) the physical assets so that they are remain tamper-proof. For example, in the production and distribution of diary.

This paper provides the conceptual basis for a set of design principles and rules that validate the application of blockchain and augmented technologies such as IoT, AI and data analytics for food supply chains. Such design rules may be applied to use cases in order to develop instantiated artifacts that provide a Minimum Viable Solution. Specifically, the supply chain for dairy products is used as a test for a blockchain-based, trust-less platform and its efficacy examined. It is the intent of this research that consumers may be "nudged" to make more informed and sustainable decisions. It would be a contribution to research efforts in digital farming, precision agriculture and, more specifically, the digital twining of supply chains for tamper-evident produce.

Background Review

Blockchain technology is rapidly becoming a game-changer in various industries and promises to solve many problems associated with a lack of trust. Blockchain uses a combination of technologies, which has a significant history in computer science. They are public key cryptography, hashing, database technologies and so on. Blockchain provides an immutable record distributed among all peers and enables tampering the record computationally hard and it is highly important in tracking and tracing the origin of any agricultural product. Since consumers are concerned with the origin of specific agricultural products at the point of purchase; specifically, their origin, labeling, ingredients, handling and shelf-life. Blockchain has been applied to achieve this requirement in leading organizations like Walmart. In our research, we proceed beyond tracking and tracing. The following review is focused on the application of blockchain technologies for food security concerns, application of IBM Hyperledger for these implementations, application of IoT for dairy manufacturing, application of fuzzy related technologies in the dairy industry and elaborated with connecting fuzzy logic based programs in blockchain.

Tse et al. (2017) present a significant use case of blockchain for food security in China. They highlighted frequent food safety incidents including low-quality milk powder, which is matching with the concerns on our research. Other than the low-quality milk powder, “Sudan Red” hot sauce, “hair rice”, toxic rice and so on. Sudan red is a coloring which may cause cancer. Therefore, the consumers want to ensure the item they purchase does not contain any cancer causing material in their food. In dairy products, the product’s security needs to ensure by reliable and practical manner. Their proposed solution provides a tamper-resistant record using distributed ledger technology as an ideal replacement of paper-based tracking systems, which is prone to forging and tempering. They established two main postulates: 1) Blockchain ensures the traceability and reliability of each transaction in the food supply chain, and 2) Blockchain can fulfill the demand of regulators, producers and consumers. These two hypotheses are significant since validation includes establishing regulatory feasibility and technical feasibility. They highlighted that the application of blockchain without central authority as a key advantage and an optimal solution for secured food origin traceability. Furthermore, the establishment of the previous hypothesis provides an improved system addressing management flaws existing in the current systems to ensure new regulatory requirements for food safety. With augmented technologies such as IoT and analytics, blockchain could improve the supply chain efficiency by replacing the manual documentation work with an automated system. Therefore, the research provides more motivation to us, to elaborate on the research as it reflects the application of distributed ledger technology for food security and its feasibility in different perspectives.

Aitken et al. (2017) found that in each year, one in 10 people will be affected by foodborne diseases. Also, it is awful to see that around 420,000 people die due to food diseases. Globally, it is essential to have a food security consideration to eliminate the mentioned problems. They have highlighted that the application of distributed ledger technologies will be the best solution to validate the origin, movements, storage conditions and so on. The blockchain will contain significant insights such as inspection records, enroute stoppages and other system failures. A pilot program was conducted with Walmart, one of the world’s topmost retailers. It confirmed that the application of blockchain to trace food cut the time to trace a package of mangoes from the farm to the store up to two seconds. They too used IBM Hyperledger Fabric for their implementation. It provides a motivation on our research, justifying the technical feasibility of our chosen platform, the IBM Hyperledger Fabric. As of July 2018, there were greater than 350,000 food data transactions on the IBM Food Trust platform (Wolfson, 2018). In November 2018, IBM commercially launched its Food Trust.. The IBM Hyperledger platform allows any private company or organisation to set up a trusted network, which would allow stakeholders to share information freely. Furthermore, the Hyperledger Fabric supports a modular architecture, which defines levels of trust as well as optimized performance and scalability.

Ogunyale et al. (2012) presents an interesting solution for risk analysis of milk products. The main objective of this work was to develop an intelligent system capable of analyzing and evaluating risks in dairy products manufacturing systems. The proposed work is applicable and significantly matching with our research. They figure out that contaminations of the dairy product may cause hazardous health related problems. They have categorized the risks of dairy product into four main categories as physical, biological, chemical and environmental risks. They have proposed a well-connected Mamdani Fuzzy Inference System (FIS) to address these dilemmas. The output of the first four FIS will be fed into the fifth FIS to categorize the level of risk.

Failure Mode and Effective Analysis (FMEA) and Risk Priority Number (RPN) are widely used approaches in quality assurance processes including laboratories. Not only in the dairy industry, but also in food manufacturing and other industries utilized FMEA and RPN for risk assessment and quality improvement in various industries. But there are significant issues have been recorded in traditional FMEA and RPN based approaches; such as how different arrangements can give the same output, the lack of expert’s opinion in identifying the failure modes and how a zero value in the criteria indicate no failure or risk.

The proposed five-Mamdani FIS arrangement using the expert opinion, and quantitative, linguistic terms ranked the FMEA RPN criteria (Occurrence, Severity, and Detectability). This assumes that the research will undermine the associated failures and risks of the dairy products manufactured and greatly minimize the risks across the four categories they identified, as physical, biological, chemical and environmental risks. They ensure that these will reduce risks associated with dairy product manufacturing systems.

The proposed model was implemented as a two-stage with five-FIS systems. The first stage consists of four FIS will analyze the dairy products risks using the FMEA criteria, the inputs (Occurrence, Severity, and Detectability) with expert's knowledge and opinion. The output of each one of the Physical, Chemical, Biological and Environmental Failures from the first stage. These Failures are fed as inputs to the final stage FIS; where the final manufacturing system ranking is done.

Establishment of the fuzzy rule is the most significant event of any fuzzy system. Membership functions play a vital role in defining fuzzy rules. Fuzzy rule derivation can be achieved in two different ways. They are opinions and knowledge of the experts and process of fuzzy mode. For the proposed work, there were 1125 fuzzy rules were established. Our research mainly focused on the application of blockchain and development of fuzzy based smart contracts, it is important to formulate the significant fuzzy rules as a smart contract and integrate them in the blockchain as a value addition to ensure they are guaranteed to be immutable to enhance the trust.

Use Case of Dairy

Dairy food production is a benchmarked industry in New Zealand. With the climatic condition and ample grazing area as well as centuries-old historic specialty and renowned maturity, New Zealand plays a vital role in the dairy food manufacturing industry internationally. Especially, tracking and tracing is a key factor for the food security concerns, which will be an essential feature anticipated by the consumer in the dairy food industry too.

Sangtash et al. (2012) describes an important application of fuzzy logic to grade raw milk. They highlight that the quality of raw milk is an essential consideration not only for the consumer but also for the regulatory authorities. Microbiological and physicochemical analyses are important in order to monitor the quality of raw milk and its products. Input parameters of the system were as total aerobic microorganism count, somatic cell count, coliform count, fat and solid non-fat percentages. This input data classifies raw milk as excellent, very good, good, bad and very bad. In total, this study employed 675 rules with the logical "AND" operator, Mamdani implication, and centroid method for de-fuzzification. Results yielded that fuzzy logic provided the means for more stringent classification of the quality of raw milk than the presently employed system. Results obtained from the developed fuzzy inference system scheme were 82.5%. They highlighted that fuzzy logic yielded significantly accurate results in raw milk classification. The fuzzy system is far ahead in the decision supporting than comparing with laboratory data directly with standard specifications. They also pointed out that incorporation of artificial neural networks with genetic algorithms will increase the accuracy of raw milk categorization. From a blockchain point of view, defining the fuzzy rules as a smart contract will assure the immutability and the accuracy of the result. Therefore, the regulatory authorities also can get extensive advantages over the immutable nature.

Tian (2017) provides an analysis on the application of IoT for smart dairy farming in China. Smart cow collars were utilized in their use-case to identify the oestrus period of the cow, for optimized successful breeding. As a step to improve the efficiency of large-scale farming, dairy farms have applied smart cow collars to optimize oestrus detection and breeding results. The project was driven by China Telecom and Huawei and appropriately, applied the utilization of IoT technologies to ensure dairy food security. The solution ensures low power consumption and massive connection with wide coverage. The sensors provide a wide coverage with an assurance of 5 years to operate on battery power. Altogether, in addition to the aforesaid advantages, the automation will too preserve manpower for efficient management of the farm.

More relevant to dairy supply chains, the information captured from similar sensors can be stored in the distributed ledger. The stored information can be retrieved and displayed through the associated mobile application. The consumer will have a rich picture of the dairy product from the data stored in the distributed ledger. The application of IoT will provide rich insights into the manufacturing process of the dairy product. Especially the records in cattle health, the medicines provided to the cattle, more insights on food will provide a competitive advantage to our proposed research as the consumer will have a bigger picture of the purchasing item and enhanced trust of its health worthiness over the logging on the distributed ledger.

Tian (2017) also remarked that confidence in food safety has been tarnished due to issues such as mad cow disease, genetically modified foods, toxic milk powder and so on. Even though many supply chain traceability technologies exist in the market, almost all of them are centralized. The monopolistic nature of these systems will reduce the trustworthiness on consumer since the consumers see these systems are prone to tampering and falsifying the information. Blockchain technology, with its decentralized nature, provides a distributed and tamper-proof immutable ledger, which will enhance the trust of the customer. They have proposed a real-time food tracing system aligned with HACCP (Hazard Analysis and Critical Control Points) and implemented using blockchain and internet of things. They ensure that they can provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability, and security. Furthermore, they introduced BigChainDB to fill the gap in decentralized system scalability.

HACCP food supply chain has been divided into five major processes, similar to figure 1. They are: production, processing, warehousing, distribution, and retail. In the production phase, they have provided a concrete example of production of plant crops. They recorded all the background environmental conditions to be monitored. These included the quality of soil, water etc. In dairy supply-chain perspective, the production phase will record some information about the farm as well as importantly the information of cattle. The use of IoT could be feasible for record-keeping this information in the blockchain. In the warehousing link, the cold storage conditions will be recorded in the distributed ledger. This will ensure that the storage of the milk was aligned with the regulatory requirements within the supply chain. Other than that, the warehousing management practices can be checked whether they have aligned with best practices defined by HACCP. The implementation has features of a generic distributed system. The use of IoT such as RFID, Wireless Sensors and GPS to collect the generic information, is novel. There are many members in the supply chain including suppliers, producers, manufacturers, distributors, retailers, consumers, and certifiers.

Data acquisition for storage on the blockchain at each link of HACCP supply chain is important to focus and important to our planned research. In the production link, the crop plants are labeled with RFID tags. Background information such as quality of soil and air as well as the quality of seed, growth conditions and practices like information and also the information related to pesticides applied will be signed and stored in BigChainDB through handheld tag reader or wireless sensor network. In the processing link, the required processing profile applicable to the specific plant will be retrieved by the RFID tags. The processing includes temperature controlling, additives and disinfection will be executed. Essentially, each activity will be logged in the distributed ledger and new tags will be added replacing the previous tags. Warehouse management link will utilize the RFID tags. This will ensure the dynamic management of an enterprise's requirements. For an instance, spoilage control, wastage control and adhering to in-house standards will be traced over the RFID.

In the distribution process, the 3T principle (Time, Temperature and Tolerance) is identified as the key factors in ensuring the safety and quality of food products. The vehicle-mounted safety monitoring system can be established for setting temperature and humidity sensors in different temperature areas. They provided value addition by alarming the deviations of required temperature standards. GPS based trackers will ensure that the distribution route is perfectly aligned with the established standard. Also, an optimal distribution route can be identified with minimum distribution time. Retailer link is the most important phase, which portraits consumer the "bigger picture" of production. The RFID tags or a QR code will be the pointers to the consumer to access the whole set of information logged in the blockchain. In addition to the consumers, regulators will have access to trusted logs to check whether the product lifecycle is within the regulatory requirements. The 3TIC solution is one of the most significant evidence that our proposed platform is feasible technically. Also, aligning to a regulatory framework such as HACCP will yield better results for our research in terms of generalisability and application.

Marwala et al. (2018) is another major source of inspiration for our research. They found that the contribution of AI (Artificial Intelligence) and blockchain is significant in the 4th industrial revolution. They too highlighted that smart contracts and the losses from the previous history including Ethereum's parity wallet hack. They further suggested the application of AI for AI assisted smart contract testing. Furthermore, the AI and blockchain's united approach was highlighted. The association of AI and blockchain opens up us a new avenue and a different perspective in our research outcome.

To recap the highlights of the research literature, Tse et al. (2017) provided motivation to the requirement of food security and its global requirement. Sangatash et al. (2012) demonstrated the application of fuzzy systems for dairy product risk assessment. Ogunyale & Mayorga, (2017) elaborated on fuzzy systems and its applications as well as accuracy in raw milk classification. Tian (2017) is more specific towards our research and augers that our system is technically feasible. Finally, Wolfson (2018) provides justification for the combined application of AI and smart contracts as an ideal solution.

Field Research Approach

Figure 2. Rich Picture of Key SSM Activities.

The development and validation of use cases that address the major challenges identified above requires a design-oriented approach rather than a survey-oriented one. The Soft System Methodology (SSM) is a tried and tested method of action research if the goal is to clarify ill-defined system requirements (Checkland & Scholes 1999). In the case of the dairy industry, this would refer to the trusted labelling and tracking of the produce and its distribution under conditions deemed safe (eg temperature, humidity control, expiry dates). In Blockchain applications, such requirements are built into "Smart Contracts". A key feature of SSM is the expression of key requirements through the drawing of rich pictures, which follow the stages of the model's root definition and framework design. The resulting model is then validated by testing the design of "artefacts" in a production environment (eg the dairy industry from farm to retail outlet). The model validation in this case would refer to conducting interviews of "actors" and corroboration with evidence of business processes, systems etc. that examine whether any proposed blockchain-based system can fulfil requirements of trust and non-repudiation. Overall, SSM consists of five steps as shown in the "rich picture" in figure 2, adopted from Checkland & Poulter (2010, p 235).

Applying the method from "problem situation" to "action to improve" (with the Blockchain, AI, IoT etc) would result in the design specifications of a prototype which can be implemented with trial participants as a proof-of-concept. The ethereum community recently formalized ERC721 (to be finalised, but the current state is considered a working, implementable draft) which essentially creates a standard for non-fungible tokens, helpful for building a system like the agricultural tracking one. The design principles and rules will therefore establish a feasible architecture and Proof-of-Concept (PoC) for our proposed dairy Blockchain.

The major steps of the design research are highlighted and briefly described below.

1. Reverse engineer design artefacts with use cases of blockchain platforms

In this phase, we identify the industry requirement for the application of blockchain for agriculture. Essentially, the distributed ledger technology provides an immutable distributed and public record of the dairy product. First, we identify the problems exist in the market and the relevant solutions. Using an approach pioneered by Peter Checkland and his co-workers (Checkland & Scholes, 1999) known as Soft Systems Methodology (SSM) allows the elicitation of user needs as well as specification of system-level features and characteristics. Since New Zealand is renowned for dairy production it will be a convenient use case and obtain significant insights into the current problem through SSM. We can undertake some informal and unstructured interviews of the stakeholders in an existing dairy production system. Furthermore, we plan to undertake a survey on the online materials to develop a "rich picture". This will be an iterative process. Once the rich picture has been developed, the key players of the proposed system with their responsibilities will be identified. In the application of blockchain for the distribution of dairy products, the stakeholders would typically be farmers, food safety regulators, food producers / processors, logistics partners, value-added resellers. With SSM, the stakeholders will be portrayed with the roles associated with them as "rich pictures". Following from this (ie the rich picture developed) a conceptual model is required to be developed to the proposed system. In the conceptual model, essentially the use cases of the proposed system will be clearly defined.

2. Development of design specifications for a PoC

(a) Establish design rules for technical feasibility: Once the requirements have been finalized, a conceptual set of design rules for the PoC will be developed. Essentially, the prominent features of the system will be included in the PoC. The significant / major boundaries can be drawn between the front end and the back end. The front end would be the distributed ledger and IoT. The backend will be the analytical approach for the data captured over the IoT. Essentially, our platform incorporates a fuzzy logic controller on Smart Contracts. This will add to the "blockchain" value of the data analysis. The PoC will be functional with the significant specifications required in the final solution. The PoC will incorporate IoT devices to ingest the real-time cattle information in the farm. This is a key benefit of the solution. In addition, the baseline of the relevant fuzzy logic will be developed as smart contracts.

(b) Establish design rules for user-centric desirability: Application of blockchain technology will be important for regulatory assurance and end-user desirability. Logging key events in distributed ledger will ensure that the records are not altered and guaranteed to be valid. Furthermore, the fuzzy embedded smart contracts will ensure that the raw milk validation is guaranteed to be accurate and unaltered. Organic labeling requires monitoring pointers to the food and medicine blockchains. This will provide that the produced milk or dairy product is aligned with the regulatory requirements. The blockchain will record the storage conditions and delivery milestones as well. With all of these features, the consumer, as well as the regulatory authorities, can retrieve the useful information about the labeling of the dairy product.

(c) Establish design rules for economic viability: The key requirement of ensuring economic viability is to identify the net benefits of the blockchain supply chain to the stakeholders. It is essential to execute a cost-benefit analysis of the platform and focus on the value additions for the use case. Specifically, application of blockchain technology and smart contracts for automated raw milk categorization will ensure customer trust on consumer products and eventually increase sales value. As blockchain and augmented technologies serve as key verification and validation mechanism for organic or sustainable or ethical practices in milk production, this will enhance consumer satisfaction in a differentiated manner and lead to increase the value added. Usage of automated fuzzy based smart contracts and other tamper-evident labeling will reduce costs of the manual validation of raw milk quality. Establishment of a "big data" sensor network in the farm to ingest real-time information of the cattle can reduce the costs of existing operations. Each and every value-added component of the system will be analyzed in depth to ensure the economic feasibility.

3. Field trial of PoC

The design artifacts (namely, the PoC) may be validated with existing dairy farms. The Blockchain platform and augmented technologies (such as IoT, AI, smart contracts, etc.) will then be ready for beta-testing. The field trial is required to identify the operational issues encountered in the system and secure regulatory approvals and audits. A commercially-available platform is IBM's "Blockchain as a Service", which is based on the open source Hyperledger Fabric, version 1.0 from The Linux Foundation. It is a public cloud service that customers can use to build secure blockchain networks making it suitable for adoption in our research. With the IBM Hyperledger Fabric's "Private Channel" feature, a rapid prototype platform can be developed for dairy producers, processors, distributors and retailers. These next steps are on-going research.

Concluding Remarks

The design research procedures of the SSM steps outlined in the previous section resulted in Table 1 below. It summarises the key "3TIC"design principles of blockchain systems across the three major components of a supply chain for food. The table is populated with rules that were derived using some of the technical solutions reviewed in sections 2 and 3 such as the features and functionalities of IoT, AI, analytics, HACCP, smart contracts, mamdani fuzzy logic, RFID, GPS. Following the construction of a PoC, the matrix below may be extended to a 3rd dimension by segmenting the food supply chain in order to develop the desirability, viability and feasibility rules for the design of a Minimum Viable Solution (MVS). However, it is beyond the scope of this paper and is offered as a suggestion for further work.

Table 1 suggests that by constructing a prototype MVS with the application of blockchain and augmented technologies, and then validating its use-case using techniques from SSM to determine the design criteria of customer desirability, economic viability and technical feasibility, we may apply the design rules that have been conceptually derived. Whereas design principles address "what" is to be built into an artefact, design rules specify "how" that feature or characteristic is to be implemented. The validated rules hence make a theoretical, practical and methodological contribution to the digital twining of the supply chain of agricultural produce such as dairy. Gregor & Hevner (2013) refer to such an approach to "inventing new solutions to new problems" (p 345) where the research opportunity and knowledge contribution comprise a relatively untried solution to an unchartered application domain. Given the nascent emergence of digital farming and precision agriculture, the 3TIC framework and the application of Blockchain and augmented technologies described in this paper fills a specific gap in the design of a dairy supply chain platform. For that matter, it may be applied to a host of other value nets such as the production, logistics and retail of: fashion and apparels, jewelry, wine, art and sculpture, and the like.

Principles / ***Stages***	**Transparent**	**Tamper-Evident**	**Traceable & Immutable**	**Compliant**
Production	*The establishment of a secure database with mandated data protection procedures.*	*Rules for data access and modification are established by procedures using smart contract functionalities.*	*Audit trails and data assurance procedures are regularly performed to conform to HACCP.*	*Tools for clear demarcations of data collection, storage and utilization at the production stage.*
Logistics	*System components such as IoT, fuzzy logic controllers and blockchain smart contracts are open and transparent in terms of data capture and reporting.*	*The blockchain is protected by smart contracts which assign RWED permission to users of the supply chain.*	*Authorisation and accounting features of blockchain augmented by IoT, RFID and GPS provide all stakeholders verification and validation of HACCP.*	*Private or permissioned blockchain is implemented with platform features for access controls.*
Retail	*The blockchain platform is implemented with smart contracts and fuzzy logic controllers for monitoring and reporting unauthorized write, edit or delete operations.*	*Tamper sensors such as RFID labels and IoT-based location tracking prevent the abuse of unauthorized modifications and provide validation of food labels.*	*A combination of design features for validation and augmented technologies for verification of HACCP promote trust in the blockchain.*	*IoT and big data analytics along the food supply chain report exceptions in real-time as established in the smart contract. These may be verified by consumers.*

Table 1. Deriving Design Rules

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