

Blockchain Application: The Dairy Supply Chain

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ABSTRACT

The safety and quality of the food supply chain is of utmost importance to producers, processors, regulators, and consumers. Many foods are tested when harvested and at many intermediate points during their processing, but in the case of the dairy supply chain in the United States (US), the testing labs are often owned by or connected with the producers and processors, creating a potential conflict of interest. The system described in this paper uses blockchain technology as a tool to ensure that the test results from milk analysis cannot be adjusted or changed without the knowledge of the other stakeholders, most notably the regulatory agency. This provides increased protection not just for the consumer but also the producer as a means of protecting their reputation in case of any food-related problems downstream.

Keywords: Blockchain, Dairy, Food Supply Chain

INTRODUCTION

The reliability and effectiveness of a civilization's food supply process has always been one of its main concerns, and when it is disrupted, even temporarily, it is a cause for immediate concern. The recent examples of romaine lettuce (US Food and Drug Administration, 2019) and dairy (Rajan, 2018) contamination serve to illustrate the level of importance that both government and industry put on the food supply chain to produce and deliver high-quality food that is safe and free from contaminants. In some cases, the recalls that result are due to the possibility that certain foods have not had the "benefit of inspection" (Pfaeffle, 2019). This phenomenon of food-based problems, such as contamination or low-quality, is a worldwide issue, and organizations such as the United States Department of Agriculture (USDA) and the European Food Safety Authority (EFSA) are just two of the many national and international bodies that seek to create and enforce safe food regulations.

In order to monitor and ensure that the safety and quality of the food chain remains safe and to quickly respond to potential or actual issues, there is a significant need to collect and analyze data at all points in the food chain, from the creation of feeds and fertilizers, right through to the delivery of foods for consumption. In order to accomplish this goal, data must be captured properly and then stored in such a way that it is protected, available, and in a format conducive to analysis. The collection of data is governed by guidelines and procedures published or approved by the local and national organization with

jurisdiction. For example, the procedures that are to be used in the collection of data describing dairy products in the US is the *Standard Methods for the Examination of Dairy Products* (American Public Health Association, 2004). However, the focus of this paper is the storage and management of these data after collection.

Each state in the US mandates the collection of data regarding dairy foods and the analysis of those data to detect various characteristics of the milk produced. Each state maintains their own guidelines, but they are all essentially the same in that they are all compliant with the US Food and Drug Administration (FDA) requirements. In general, the milk collected must meet the following guidelines:

- Temperature $\leq 45^{\circ}$ F (7° C) within two hours after milking.
- Bacterial Limits not to exceed 100,000 per ml.
- Sediment less than 1.5 mg.
- Drugs not to exceed the current applicable standard.
- Somatic cells not to exceed 750,000 per ml.

The milk samples are collected at the time of milk collection from the producer (dairy farmer) by a duly licensed milk collector. The collections take place at various intervals determined by the size of the producer and its past quality levels. The samples are then brought to a laboratory where the necessary tests are performed. The results of the test are stored by the lab for a period as determined by law (usually three years) and a copy

returned to the producer. The lab is certified and inspected by the state on a regular basis and the data must be made available for inspection by the state upon demand.

The labs at which the analysis takes place are all under state regulation, but they can be either independently owned or owned by the milk processor or milk producer. According to one state official consulted for this project, there is a growing trend that milk processors are incorporating the lab portion within their operations rather than using independent labs. This is often a case of vertical integration to reduce costs and increase efficiencies, but it also brings forth a conflict of sorts in that the users of the milk, and therefore those who make money from it, are also those responsible for evaluating its ability to meet quality and safety standards. Self-regulation of this sort is common in many industries, but it is usually accompanied by substantial safeguards. For example, banks are responsible for maintaining their deposits and other funds in accordance with federal and state law, but they are also audited on a periodic basis to ensure their compliance. Part of these audits is concerned with the tools (i. e. computer systems) used to store their data and the mechanisms and processes in place to protect these data. In the case of the dairy industry, the state will inspect the data that is held by the lab but not the mechanism by which the data are stored and secured. The reason for this is largely resource-based, but one state official also pointed out the difficulty of doing so because of the wide array of data storage “technologies” in place, ranging from sophisticated computer systems at major producers to notebooks at small Amish farms. However, it is also true that, discounting the family farm scenario in which fresh milk is sold at the farm itself, all commercial producers use some form of technology to store their test data, and this provides an opportunity to improve the security of the food supply chain (or, in this case, the food information supply chain).

This project proposes the use of blockchain technology to manage, and secure, the information created during the dairy testing process. Blockchain, first introduced by Nakamoto (2008) is a distributed-ledger database that allows for the storage of data such that it can be shared with any party having the permission to access the blockchain but not be changed by any party without the knowledge of other stakeholders. This data immutability is the result of the methods used to add data to the blockchain. Each entity seeking to add a block of data must first solve a “hash puzzle” that requires the application of computing power to solve an encryption problem within a set of prescribed conditions. This puzzle uses cryptographic hash algorithms that require as inputs data from the block

to be added, the last block added, and a random number (the “nonce”). The puzzle requires the data adding entity to guess the nonce that provides a hash reference value (the output from the hash algorithm) that meets certain criteria (e.g. must have three leading zeros). Due to the structure of cryptographic hashing, there is no way to work backwards from the hash reference criteria to the nonce; it can only be guessed at and computed, thus the work involved in solving the puzzle. This is often called the “proof of work” and is both a penalty that must be paid to use blockchain and also the key to its data immutability. Because of the manner in which data are added to the chain, any change in the contents of any block would immediately invalidate all subsequent hash references, thus notifying all stakeholders of the changed data. In other words, once data is added to the chain, the only way to successfully change it is to recompute all of the subsequent hash puzzles, an unrealistic and easily noticed task on most chains.

Additional protection against data tampering comes from the distributed nature of the blockchain environment. If desired, the chain can be resident in many computer installations. Once one of these installations solves the hash and adds the new block, it is immediately shared with all other chains in that particular blockchain ecosystem such that all stakeholders have a copy of the current chain configuration. Any change to the data on one of the chains would cause a mismatch with all other chains, again providing notice of data discrepancies.

LITERATURE REVIEW

The literature supporting this research stems from three sources: the literature of the use of data and information technology (IT) in the dairy industry, the use of blockchain technology in the supply chain, and finally the use of blockchain in the food supply chain.

Data and IT in the Dairy Supply Chain

The collection of data describing both the process of milk collection and the quality of the milk collected has been an important part of dairy farming for a very long time. Quality in the food chain has always been an important aspect of government oversight. And while the collection processes for dairy testing are beyond the scope of this project, the management of dairy data is not. The importance of accurate dairy data has been linked to the overall success of the dairy supply chain and the performance of all of its components (Susanty, Bakhtiar, Jie, & Muthi, 2017). Ding, Fu, Zheng, and Yan (2019) provide evidence that the oversight provided

by governmental agencies serves as a mediating factor in the quality levels of milk, thus further ensuring the competitive advantage of milk producers as well as the overall quality of the milk supply. Because of this, the development of the management processes of dairy data has been the focus of intense efforts around the globe (Bucek et al., 2017) in places such as Ukraine (Monardes, Lefebvre, Christen, Coté, & Beurivage, 2017) and Brazil (Monardes, 2017).

Many recognize that without proper IT tools, the data collected would not provide the improvement that farmers and processors need to remain profitable and produce high-quality products. Cabrera (2018) describes a range of tools available at no charge to dairy farmers to manage a wide variety of dairy farm issues. Many of these tools are powerful decision-support tools that provide guidance using sophisticated analysis tools. Logar and Jeretina (2015) describe the use of web-based decision support tools in Slovenia as another example. The use of advanced analytics tools such as machine learning environments are also becoming more popular (Hermans et al., 2018; Shine et al., 2018). In each case, we must remember that before we engage in these sophisticated analyses using very powerful IT, we must do all we can to guarantee the quality of the data used as inputs.

Blockchain in the Supply Chain

The supply chain is one of the most widely discussed avenues for blockchain application outside of the financial sector. To date, a number of reviews have been published that provide an overview of the current state as well as a research pathway forward (Hughes et al., 2019; Wang, Han, & Beynon-Davies, 2019). Blockchain has been suggested as a means of improving the resiliency of the supply chain to increased risk and uncertainty (Min, 2019), improve its transparency (Polim, Hu, & Tirupatikumara, 2017), and enhance traceability of items in the supply chain (Apte & Petrovsky, 2016; Tian, 2016).

Though there is very little in the way of empirical evidence confirming the benefits of blockchain in the logistics space, there is sufficient guidance to suggest that there exists significant potential, especially utilizing blockchain's data immutability capabilities. Ying, Jia, and Du (2018) provide evidence through a case study that the characteristics of blockchain can provide significant improvements to an organization's internal processes such as the utilization of cryptocurrency, protection of sensitive data, and the elimination of intermediaries. Blockchain can also be very useful in an Internet of Things (IoT) environment (Kshetri, 2018). Wang et al.

(2019) find that blockchain can bring many benefits to the supply chain such as enhanced tracking, visibility, and security of physical movements but also brings challenges such as immature technology, unknown cost parameters, and the disintermediation of the supply chain participants. Finally, Queiroz and Wamba (2019) find that the implementation parameters of blockchain vary across the type of organization and level of national development. Using the US and India as research venues, the authors find that there is a difference in adoption behavior between developed and developing nations and that issues such as trust and infrastructure play an important role in technology adoption in general, and with blockchain in particular.

Blockchain in the Food Supply Chain

A great deal of research has taken place recently surrounding the use of IT in the food supply chain and the use of blockchain specifically. Technological solutions exist to enhance the traceability of food (Dabbene, Gay, & Tortia, 2014; Regattieri, Gamberi, & Manzini, 2007; Wang, Kwok, & Ip, 2010) as well as the quality and safety of the food farmers produce (Akkerman, Farahani, & Grunow, 2010). These technological solutions have resulted in fewer problems with food safety and much lower response times when problems do arise.

The rise in interest in blockchain has also given rise to its proposed use in the food supply chain. The most common approach is to use blockchain to improve the flow of goods and payments throughout the food chain (Lai, 2018) and the traceability of the food as it makes its way from the producer, through the various intermediaries, to the customer (Berti & Semprebon, 2018; Kaijun et al., 2018). Other research suggests the use of blockchain to improve the operations, and thus the profitability, of food coops in developing nations (Manski, 2017).

Another area of interest of blockchain researchers is the improvements in food data security possible when blockchain is used as a data management architecture. Xie, Sun, & Luo (2017) and Tse, Zhang, Yang, Cheng, and Mu (2017) all describe approaches that, when fully implemented, will improve the accuracy of food data and result in a major decrease in food-borne illnesses in China. The security of greenhouse management systems is the subject of a paper by Patil et al. (2018). In this paper, they describe a remote greenhouse management system that provides control of most greenhouse parameters (using Internet of Things technology) while maintaining the security of the system against hacks or other disruptions. In this manner, data can be made freely available to

all interested parties but remain immutable due to blockchain's innate characteristics (Lin et al., 2017).

This review of the literature demonstrates that 1) the use of data to maintain the safety and quality of the dairy consumed by the public is a longstanding requirement and the focus of continuing research, 2) blockchain technology is being suggested for an increasing number of uses in the supply chain literature, and 3) the use of blockchain to enhance the food supply chain is a particularly active area of research. However, it is also true that the dairy sector of the food supply chain has not yet been the focus of any blockchain-focused research, though the use of blockchain would be a very useful enhancement.

OBJECTIVES OF THE STUDY

The objective of this study is to determine the applicability of blockchain technology to the management of data, and the information derived from it, created during the dairy product testing process. The objective stems from the fact that the data used to determine the safety and quality of the milk produced by dairy farmers is often in the hands of the same organizations that process the milk into various products. This is not to say that the organizations testing the milk are not trustworthy; the state regulators consulted for this project could not recall any instances of malfeasance in the dairy data process. However, with increased scrutiny of food safety issues, the seemingly never-ending budget constraints of government inspection organizations, the belief by some that the food and water supply is a national security issue, and the arrival of a technology that could, with very little extra cost, provide an improvement in the process, it seems natural to evaluate the combination of blockchain technology and the dairy supply chain.

METHODOLOGY

Since the objective of this paper is to investigate the applicability of blockchain technology to the management of dairy data, the use of a Design Science Research (DSR) methodology is appropriate. The DSR, first introduced by Hevner, March, and Park (2004), provides a framework within which a system can be designed that provides a platform for a particular technology and creates a foundation on which further exploration of the pairing can be explored. The use of DSR has become well accepted by the IT community and appears in an increasing number of

journal articles (Indulska & Recker, 2010). Table 1 details the steps taken in DSR and how they apply to this project.

The process begins with an in depth understanding of the current data processing and management environment. Representatives of the Department of Agriculture from two states were consulted to clarify both the regulations governing the handling of data and the structure of the dairy processing industry. Two states were considered sufficient because all states are required to be compliant with USDA requirements, therefore each state will have similar processes and industry structure. Then, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted to identify the specific issues to be addressed. The results of the SWOT analysis are as follows:

- **Strengths:** The system as designed has worked well for years and represents a fairly robust, but expensive, system for ensuring the quality and safety of the milk produced.
- **Weaknesses:** The current system suffers from a potential conflict of interest in that the labs that approve the milk are often the same firms that sell the milk. Also, the current system requires that the state inspectors spend significant time checking that records are being kept properly but have no way of inspecting the systems on which they are stored.
- **Opportunities:** The advent of IT tools, specifically blockchain, provide an opportunity to create a data management system that will prevent any changes to the data once derived and stored and enable a much easier, and more effective, method to inspect the data and the processes that create it.
- **Threats:** As the dairy industry becomes more centralized, with larger farms and increased vertical integration, the need for more effective oversight increases. Faced with very tight budgets, state agriculture departments will find that their resources will continue to be stretched, possibly endangering the inspection process.

System Design

The design of the system will follow the framework set forth in Xu et al. (2016) that proposes a set of seven decisions that must be made when designing a blockchain-based solution. The steps are shown in Table 2.

Table 1: Design-Science Research Guidelines (Hevner et al., 2004)

1. Design as an Artifact	This study provides a set of models that describe the system's basic architecture as well as its functionality.
2. Problem Relevance	The relevance of the problem is demonstrated in the Introduction as well as the literature review.
3. Design Evaluation	The design is evaluated within the organization it is developed for in terms of its ability to overcome the problems set forth in the Introduction.
4. Research Contributions	This research contributes in its novel application of an emerging technology (blockchain) and by providing an understanding of how the technology can strengthen current organizational processes.
5. Research Rigor	The rigor of this study rests in its grounding in current, well documented, organizational processes and the level of scrutiny applied by members of the target organization who carry out those processes.
6. Design as a Search Process	The design that results from this study is the product of a search for an appropriate technology to improve a process that contributes to a field of research with significant societal impact (i.e. food safety).
7. Communication of Research	The results of this research will be communicated through its publication in an appropriate research outlet.

Table 2: Design Decision Tradeoffs (Xu et al., 2016)

Blockchain Design Decision 1	Mechanisms of improving transaction processing rate.
Blockchain Design Decision 2	Mechanisms of selecting the next block added to the blockchain.
Application Design Decision 1	Scope: On-chain vs. off-chain
Application Design Decision 2	Public chain vs. private chain
Application Design Decision 3	Single chain vs. multiple chains
Application Design Decision 4	External validation vs. internal validation
Application Design Decision 5	Permissionless vs. permissioned blockchain

To begin the process and to set the basic architecture of the system, Application Design Decision 1 must be addressed. Blockchain gives us the ability to store the data either on the chain (e.g. Bitcoin) or off-chain in a separate storage facility. The underlying question is one of cost, performance, and security. When storing data on the chain, it must be remembered that the data will require additional storage space (and cost) and probably slow down the process of adding blocks to the chain. In addition, data stored on the chain can be vulnerable to being viewed by others unless appropriate encryption is used, which again poses certain overhead costs. The alternative is to leave the data to be stored where it is and only store the hash value of the data on the chain. This will result in a reduced storage load on the chain(s) in the system and remove the worry of unauthorized access. The security needs of dairy data are relatively low, but they still represent a competitive issue and as such do not need to be made available to the competition. With the hash value of the data stored on the chain, it is a straightforward task to compare the hash value on the chain with the hash of the

data stored at the lab. If they match, the data are identical. Otherwise, the data at the facility does not match the data on the chain and the reason for this must be determined. Moreover, since the data on the chain (hash values) cannot be changed without the notice of other stakeholders (state regulators and other milk processors), there is no chance of the data change going unnoticed.

As shown in Fig. 1, the analysis results from a lab (Lab #1 on Fig. 1) are stored in its local data storage location. This could be onsite storage or cloud storage, depending on the lab's technical preferences. Once stored, the data are hashed together using a common cryptographic hash algorithm (typically chosen from the SHA-2 family). The hash algorithm can be used to hash together multiple values in a binary fashion until one hash reference represents the entire set of data. This is called a Merkle Tree and the value at the end of this hashing process is known as the Merkle Root (Drescher, 2017). The Merkle Root is the value stored on the blockchain along with the identification of the sample such as the lab identification number, sample number, etc. (Fig. 2).

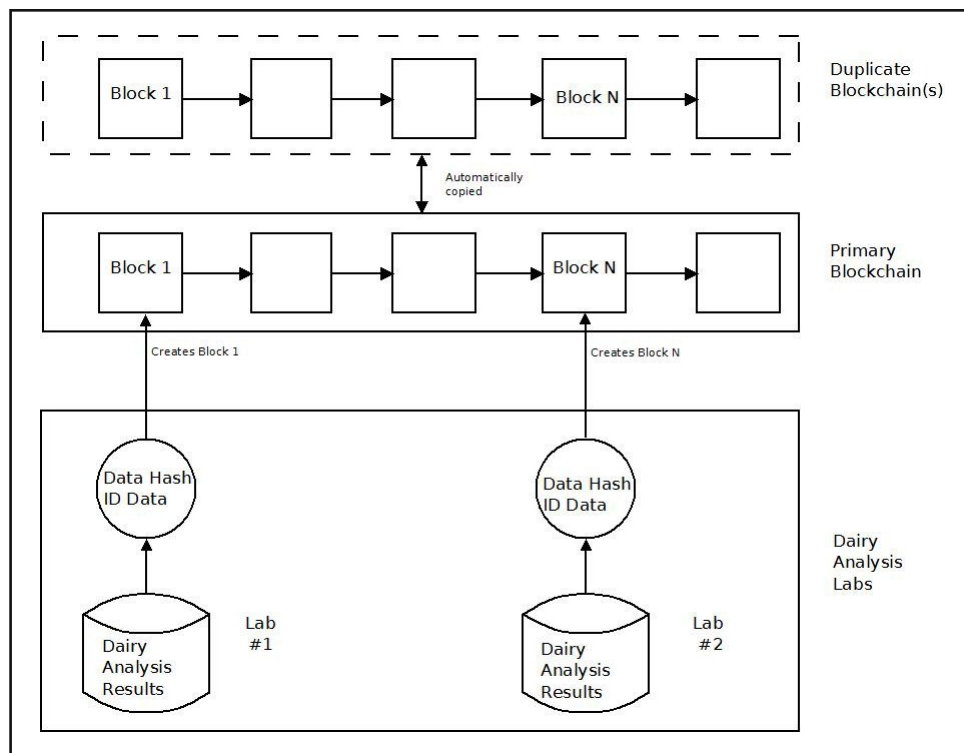


Fig. 1: Basic Blockchain Dairy Data Configuration

Data from subsequent tests, either from the same lab or others, are added to the chain in the same fashion (Lab #2). For each block of data added, the hash puzzle required by the basic blockchain mechanism is solved using data from both the last block in the chain and the new block to be added. As the chain grows, the data becomes more

“permanent” in nature as each block gets buried beneath all those added after it was added. However, the data are all viewable at any time and can be used to verify that the data stored at the lab has not been changed once its hash reference has been added to the chain.

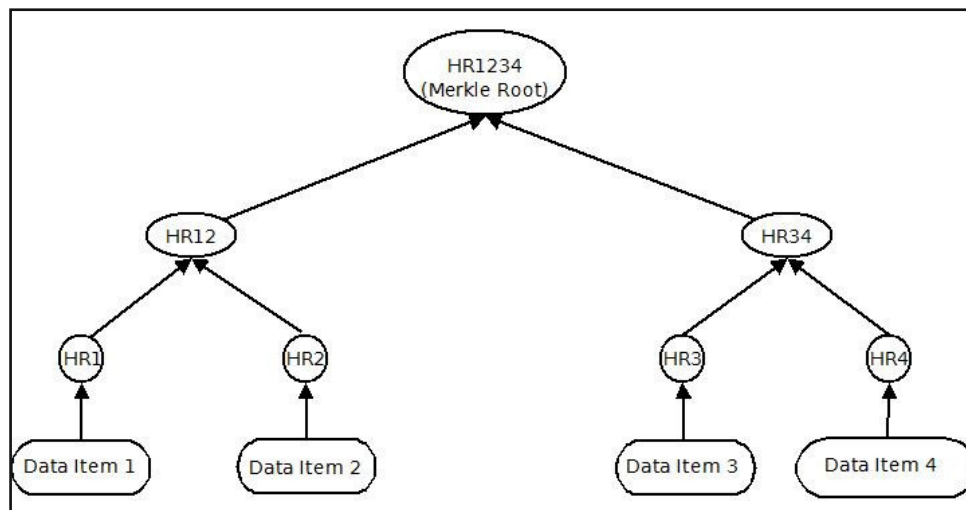


Fig. 2: Depiction of a Merkle Tree

We can now turn to the remaining design decisions outlined by Xu et al. (2016). Blockchain Design Decisions 1 and 2 both focus on improving the performance of the blockchain when it used in a high transaction rate environment such as a cryptocurrency. In the present

application, transaction time is not an important performance characteristic because these data are only accessed when an audit occurs. However, processing cost is an important factor, and that can be reduced by easing the requirements of the hash puzzle allowing for easier

solutions. The hash puzzle cannot be completely removed as that would remove the ability of the blockchain to flag any data that had been changed within the chain. But there is no need to overburden the process, either. A balance between cost and data protection must be struck among the stakeholders. Since this will be a private chain (explained below), the order of blocks to be added can be the same as the order in which the data are sent to the chain. There is no competition to win as in a cryptocurrency, so the order of blocks is unimportant.

A public chain is one in which there are no restrictions about what entity can add or view the data on the chain. Again, this was the original configuration described by Nakamoto (2008) to include all users of Bitcoin. However, the current situation does not require public access, just those entities involved in the milk processing industry. Thus, a private chain is more appropriate with the milk producers in a specific area (county, state, etc.) having block creation privileges and the state inspection service having read access. This will allow the state to check the hash value of specific test results against those housed at the milk lab (or milk processor).

Fig. 1 shows multiple copies of the same blockchain just as the blockchain process was first described (Nakamoto, 2008). This was done to provide a means of ensuring transparency of the transactions on the chain as a replacement for a centralized control mechanism such as a bank. However, in a private chain environment such as this, the only need for multiple chains is to provide redundancy for the data kept on the chain in case of failure. The use of multiple chains, then, is a question of safety and, to a lesser extent, of the cost of maintaining multiple chains and the coordination mechanism to keep them all the same. The single chain option would require an entity to agree to house the chain such that all stakeholders had proper access. This could be the government (state, county, etc.) or possibly a disinterested third party such as an accounting or auditing firm. However, the use of outside entities to house the chain brings with it an unavoidable increase in cost. In the case of multiple chains, the multiple copies could be kept by major processors or other stakeholders in the dairy ecosystem. The additional cost would be minimal as the increase in data stored is very small and the additional processing required also insignificant. This issue, like the complexity of the hash puzzle discussed above, would be a decision for the stakeholders to make collectively.

Application Design Decision 4 asks the designer to consider whether an outside validator is necessary to

validate the data on the chain. This is especially important when the data stored on the chain are transaction records, as in Bitcoin. In the present case, the data stored are only hash values that have been created at the labs, thus any validating would have to happen at the point of hash creation. Lastly, this would be a permissioned blockchain, allowing only those stakeholders that are part of the dairy ecosystem to add or read the data on the chain, as discussed above (Application Design Decision 5).

SYSTEM EVALUATION

The primary objective of this system is to provide a mechanism to identify changed data. It is not a transaction processing system nor are the data stored on the chain to be used in other calculations. Therefore, to evaluate the system in terms of performance or relevance requires that it be evaluated by the stakeholders, in this case state Department of Agriculture officials. The processes and capabilities of the system were presented to these officials, representing two states, and they were asked to evaluate the system based on cost and organizational effectiveness. The cost of maintaining the system would be very little compared to the rest of the state's computing costs. Depending on the option chosen, there could be only one version of the chain and this could be housed either on the state's current hardware or in the cloud with no difference in performance. The cost for hosting this type of process on a cloud provider would be very small because the process requires very little storage and relatively little processing power requirements due to the reduced hash puzzle requirements described above.

In the case of a multi-chain arrangement, the cost of hosting the duplicate chains would be borne by other stakeholders such as major milk providers, processors, or labs. The apparent conflict of interest that arises in this situation is ameliorated by the blockchain's basic processes. This architecture would require certain resource contributions from the other stakeholders. However, the Social Exchange Theory (SET) (Lambe, Wittman, & Spekman, 2001) suggests that the various elements on a supply chain will work together to solve issues that improve the overall performance of the chain in order for the individual firm to be more successful. In this case, the supply chain elements would contribute resources to maintain the high level of their product, thus protecting their reputation and their profitability. It would also provide protection in the event of a food-based issue at a downstream step in the process. The blockchain could provide an assurance of the milk's quality at the beginning of the process. In both states involved in the project, the

dairy industry is worth billions of dollars annually and is a source of pride for the state. A small increase in their IT cost would be a worthwhile investment.

One official suggested that any cost increases on the part of the state would be offset by the cost reduction in inspection. She pointed out that a system that allowed the state to examine the validity of the data held by the lab would reduce the number of data samples they had to take and therefore reduce the amount of time and effort to inspect well controlled processes. This would result in either a lower inspection cost or a more thorough inspection of potentially problematic labs or producers at the same cost, both of which were seen as being very helpful.

CONCLUSION

This paper describes the steps taken to design a blockchain-based system for ensuring that information representing the testing of dairy products as they enter the food chain cannot be corrupted or changed. The system as described provides a process that results in an immutable source of confirmation that the test results have not been changed without the knowledge of all stakeholders, but most importantly regulators. Because this tool enables regulators to quickly examine many more samples from the labs with the same resources, they can leverage their limited resources and extend their ability to inspect more questionable practices.

The two states used as sources of both information on the current processes and sites to evaluate the current design use very similar processes in the regulation of the dairy production. Because all US states must comply with USFDA regulations, it is to be expected that all states will have similar processes in place. Further research will determine the appropriateness of this system to other milk-producing countries. Likewise, this system could also be useful in any other agricultural industry where food is tested in a lab as it enters the food supply chain. If implemented as designed, this system will provide a great deal of visibility on the food chain without any organizational cost to the producers, labs, and processors and with very limited financial costs to the regulatory body.

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