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Using system dynamics to analyze the societal impacts of blockchain technology in milk supply chainsrefer

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ABSTRACT

The integration of blockchain technologies in the food sector has significant social impacts. The objectives of this research are firstly, to map the milk supply chains to explore information flow among different members for higher traceability; secondly, to investigate the societal impacts of blockchain technology in a milk supply chain to build social sustainability. The systems theory in integration with system dynamics (SD) provides the necessary theoretical underpinning to this research. We collect data from an agricultural development cooperative founded to support dairy farmers in Turkey. This work evaluates the societal impacts of blockchain technology on farmers, the community and animals using parameters such as local embedding, rural development, decreasing food fraud, animal health and welfare, proximity to food markets, food security, educating and promoting people towards healthy eating, assisting food access and social acceptability for transparency. In the last 18 years, the cooperative has encouraged dairy farmers in the district to become partners with a resultant increase in milk production from 30 thousand tons in 2002 to 330 thousand tons in 2019. According to our findings, population growth of the country and adult population increases in the district, it is expected that by 2025 the number of partners will rise to approximately 2800. The increase in number of partners proves the network expansion. Furthermore, blockchain technology can be incorporated into the existing system so that transparent and end-to-end accurate tracking of the supply chain is made possible, while creating decentralized recording of transactions. Moreover, the critical traceability points of a milk supply chain are evaluated with the blockchain adoption. This will help achieve the sustainable development goals (SDGs) of providing safe food, promoting good health and better well-being for everyone.

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1. Introduction

Blockchain is a digitally signed account transaction with a highly trusted record (Morkunas et al., 2019; Cai et al., 2020; Choi et al., 2020a). Transparency, traceability and auditability provided by blockchain help minimize system corruption and fraud while keeping the system under control (Hastig and Sodhi, 2019; Choi, 2020). Recently, it has become extremely important to integrate blockchain into a supply chain to create a structure that enables product tracking and to find solutions of big data problems about supply chains (Govindan et al., 2018; Choi and Luo, 2019; Choi et al., 2020b). The transfer of all kinds of values and data between parties is possible with blockchain technology, without the need for an intermediary (Cole et al., 2019; Shen et al., 2020; Yang, 2019). In this way, there is enhanced transparency provided by physical traceability in supply chains, information and financial security in management systems, leading to an increase in overall efficiency (Choi and Luo, 2019; Dutta et al., 2020; Orji et al., 2020; Li et al., 2020a, 2020b).

The food industry is important for national economies in terms of added value and employment to ensure industrial production. The food supply chain is composed of various activities such as production, processing, distribution and consumption (Shankar, et al., 2018; Ghadge et al., 2020). The food processing industry turns raw materials from primary producers (farmers, breeders, hunters etc.) into final products. There is great awareness of safety concerns, food traceability and transparency in the concept of the food supply chain (Saberi et al., 2019; Ling and Wahab, 2020). Since these issues are essential to manage a food supply chain effectively, scholars should aim at reducing food waste with the help of increasing transparency and improving food supply chain efficiency.

Blockchain technology can be integrated into food supply chains, not only to improve organizational performance environmentally and economically, but also socially by providing reliable (Choi et al., 2020c), traceable, transparent products while minimizing losses. These losses can be experienced at every stage of the food supply chain (Aung and Chang, 2014; Tsang et al., 2019). Local embedding, rural development, food fraud, animal welfare, food security etc. are some of the societal impacts of blockchain technologies in food supply chains. Thus, it becomes extremely important to analyze the societal impacts of blockchain technologies in the food supply chain. Based on previous research, various studies have examined the economic and environmental impacts of blockchain technologies in food supply chains (Ala-Harja and Helo, 2015; Wang et al., 2018). However, there are no studies on the societal impacts of blockchain technologies in food supply chains, especially in the context of emerging economies.

Traceability and transparency are essential for all food supply chains (Daud et al., 2015), especially milk products and more vulnerable types of food (Fahim et al., 2017). Milk products need to be able to be traced in milk supply chains based on blockchain technologies to ensure the quality of the raw milk, storage situations, technologies, animal welfare and the environment (Charlebois and Haratifar, 2015).

There are huge amounts of food losses in food supply chains due to a lack of technological infrastructure and a range of organizational problems in food supply chains (Food and Agriculture Organisation (FAO), 2013). Moreover, agriculture and animal husbandry are the country's primary source of livelihoods (FAO, 2013a). As in many developing countries, food losses and waste in Turkey in food supply chains is caused by a lack of data related to the locations and amounts available (European Bank for Reconstruction and Development, 2019). Salihoglu et al. (2018) stated that total edible food loss and waste in Turkey is almost 26.04 million tons/year. Besides, as in many other countries, the quality of data on food losses is poor in Turkey. The biggest problem is that the stakeholders in food supply chains do not use any monitoring systems. However, food losses can be reduced by increasing innovative technological investments in the supply chain and introducing product tracking technologies such as blockchain technologies. This will lead to better predicting and identifying food supply chain losses.

The main losses in milk occur during the production phase. Food losses in milk production are mostly caused by antibiotic residue due to failure to comply with the necessary regulations regarding calving and antibiotic treatment. In addition, another problem in milk supply chains is waste water caused by milk production. However, due to the general scarcity of food loss data during the production phase, food waste is substantial at this stage (Redlingshöfer et al., 2017). Tracking systems using blockchain technologies offer benefits to minimize food waste during the production phase. Besides, animal diseases result from animal deaths and insufficient health protection practices in farms. The lack of necessary applications leads to animal diseases and deaths (FAO, 2013b). Other reasons for milk losses and waste are negative environmental conditions, improper nutrition practices and lack of awareness of the farmers.

As a result, in this study, our aim is to accomplish the following research objectives:

i. Mapping milk supply chains to explore information flow among different members for higher traceability
ii. Investigating the societal impacts of adopting blockchain technology in milk supply chains to improve social sustainability

In order to achieve the above-mentioned research objectives, initially, a detailed literature review on blockchain technologies and its societal impacts in the food sector, especially in the context of milk supply chains, is conducted. The systems theory provides the necessary theoretical underpinning to this research. This study is based on collecting data from an agricultural development cooperative founded to support dairy farmers. It is the biggest cooperative of dairy farmers in Turkey. Firstly, with the increase in the number of cooperative partners and the increase in the number of farmers, the structure of the milk supply chain, which has a complex and developing network, has been analyzed with system dynamics; the necessity of traceability and analysis of social impacts are thus revealed. We hope to investigate the societal impacts of adopting blockchain technology in milk supply chains to improve social sustainability. Therefore, when blockchain technology is adopted, the societal impact of the supply chain can be increased for future benefits. After that, possible opportunities and application areas of blockchain technology in a milk supply chain have been proposed in this study.

To the best of our knowledge, this is the first study to focus on societal impacts of Blockchain technologies in milk supply chains using system theory in integration with system dynamics (SD) modelling. Adding to that, the main contribution of the study is to map milk supply chains to explore information flow towards traceability and to investigate the societal impacts of adopting blockchain technology in milk supply chains. Moreover, with the contribution of this study, it is easier to show the effects of blockchain technologies on milk supply chains and the wider society. The novelty of this study is to reveal how well milk supply chains adopt blockchain technology and how this will affect society. From the literature review, we have examined areas such as local embedding, rural development, decreasing food fraud, animal health and welfare, proximity to food markets, food security, educating and promoting people towards healthy eating, assisting food access, social acceptability by transparency and the improvement of social sustainability. Another feature of this study is that improvements can be achieved in important issues addressed through the proposed blockchain technologies.

The remainder of the paper is structured as follows. Section 2 represents the relevant literature. Section 3 covers the problem definition. Section 4 describes the SD methodology; a case study in milk supply chain is explained in Section 5. Furthermore, Section 6 consists of the discussions and implications. In Section 7 covers the conclusions.

2. Theoretical background

2.1. Blockchain Technologies, the food sector and societal impacts

Blockchain is an example of a promising digital technology that provides a transparent food supply chain (Choi et al., 2019; Koh et al., 2020; Rogerson and Parry, 2020). Many benefits can be observed by implementing blockchain technologies in food supply chains. These include increasing traceability in the entire chain, promoting small farms, supporting rural farmers by providing information, finance and insurance, creating a safe and healthy environment in the whole supply chain (Chang et al., 2020; Saetta and Caldarelli, 2020), enabling financial transactions in developing countries, consumer awareness and empowerment, supporting purchasing decisions, obtaining more data related to all food supply chains, decreasing waste and loss, ensuring less fraud, better quality products, improving animal welfare and decreasing foodborne diseases in the food industry (Duan et al., 2020).

Blockchain technologies also help to improve social aspects of sustainability, creating a better health and safety environment. Clear recording of processes and products through traceability enables customers to purchase from ethical sources (Saberi et al., 2019; Tian et al., 2020). In addition, these technologies entail traceability in the whole supply chain since blockchain technology offers a distributed database with information shared among all agents involved (Crosby et al. 2016; Saberi et al., 2019; Pournader et al., 2020). Data collection, storage and management of products and supplies are obtained through chain knowledge.

Nowadays, food supply chain management has gained importance because of the rapid growth of the population and a subsequent increase in food demand. Regrettably, almost one-third of food is wasted in food supply chains in the world annually. With the increasing use of digital technologies such as blockchain technologies, food safety, transparency and traceability can be provided for food supply chain operations (Demestichas et al., 2020; Kamble et al., 2020), especially in emerging countries. Food traceability is considered as necessary to ensure food safety and quality (Behnke and Janssen, 2020; Liu et al., 2012; Resende-Filho and Hurley, 2012). Therefore, to achieve more efficient and sustainable food supply chains, traceability through all stages of food supply chain operations is required (Pohlmann et al., 2020).

Food waste is a global challenge that needs to be deal with effectively. There are several reasons for the generation of food waste such as absence of detailed data on amount, time and systems used (Jagtap and Rahimifard, 2019). Improved operational efficiencies, using blockchain technologies in supply chain stages or management practices, provide overall improvement in productivity (Irani et al., 2018). Considering food safety and traceability, one in ten people catch foodborne diseases, which account for 420,000 deaths every year according to WHO (2015). Food contamination is often caused by the lack of transparency in the food supply chain due to the absence of standards for storing and handling (Crossey, 2018).

Pant et. al. (2015) created a framework for increasing transparency and information flow in the food sector using focus group interviews. Similarly, this paper analyzes the complexity of dairy products and operations based on parameters and their impact on the dairy supply chain. All stakeholders can access relevant product information without delay or bother due to the transparency of the dairy food supply chain. This paper mainly focuses on the literature of transparency and traceability issues of dairy supply chain networks. Jagtap and Rahimifard (2019) indicated that food waste is decreased by 60.7% via a digital food waste tracking system based on blockchain technologies; this is called an IoT-based food waste tracking system. Tracking systems can bring many benefits to firms in order to minimize their food waste. These systems enable brainstorming among all stakeholders and pave the way for new ideas and initiatives to decrease food waste.

Bumblauskas et al. (2020) discussed applications of blockchain technologies during all stages of an egg supply chain. The main aim of this study is to monitor products from farm to customer via blockchain and internet of things (IoT) using case design as a pilot project. Bumblauskas et al. (2020) aimed at providing more traceability in the supply chain for the customer to obtain information related to products; this increases efficiency by reducing the risk of food recalls, fraud and product damage. This paper was supported by a case study tracking eggs in a supply chain from farm to consumer; food traceability is achieved by using blockchain. Consumers in this pilot study can scan a QR code on product packaging and collect data from stages of the supply chain (Bumblauskas et al., 2020). Similarly, IBM's blockchain platform has provided data on food collected from the farm to packing houses and during transportation systems. They have done this through smart IoT devices with storage related information by using blockchain technologies (Ivanov et al., 2018). Therefore, customers can access any information from this platform to provide food safety and quality by using a code on the final food package (IBM, 2017; Alexandre, 2018; Fan et al., 2020). Other significant applications of coupling IoT with blockchain technology based on Industry 4.0 have led to valuable tracking systems for environment properties (Tang and Veelenturf, 2019).

Temperature and pressure, especially in perishable food products with aspects of a 'cold chain', can be monitored via warning sensors that enable tracing of unexpected situations during the cold chain. Zhao et al. (2019) have adopted blockchain technologies in an agri-food supply chain to increase food safety, food traceability and quality. Similarly, Kamilaris et al., (2019) have stated that blockchain technology enables many initiatives to provide transparent supply chains of food and to examine food related issues. Tian (2016) and Biswal et al. (2018) analyzed the roles of radio frequency identification (RFID) and blockchain technology, recommending the pros and cons of using RFID and blockchain technology in food supply chains to improve the traceability system. By using these technologies, confidential information in the whole agri-food supply chain can be gathered and shared to improve traceability and general food safety (Tian 2016). Biswal et al. (2018) used a newsvendor model to demonstrate this problem in their study.

Traceability is significant for all food supply chains; however, the milk and dairy produce industry needs to focus on traceability to ensure the quality of milk used (Tan and Ngan, 2020). This can depend on the health of the dairy herd, quality of the raw milk, storage

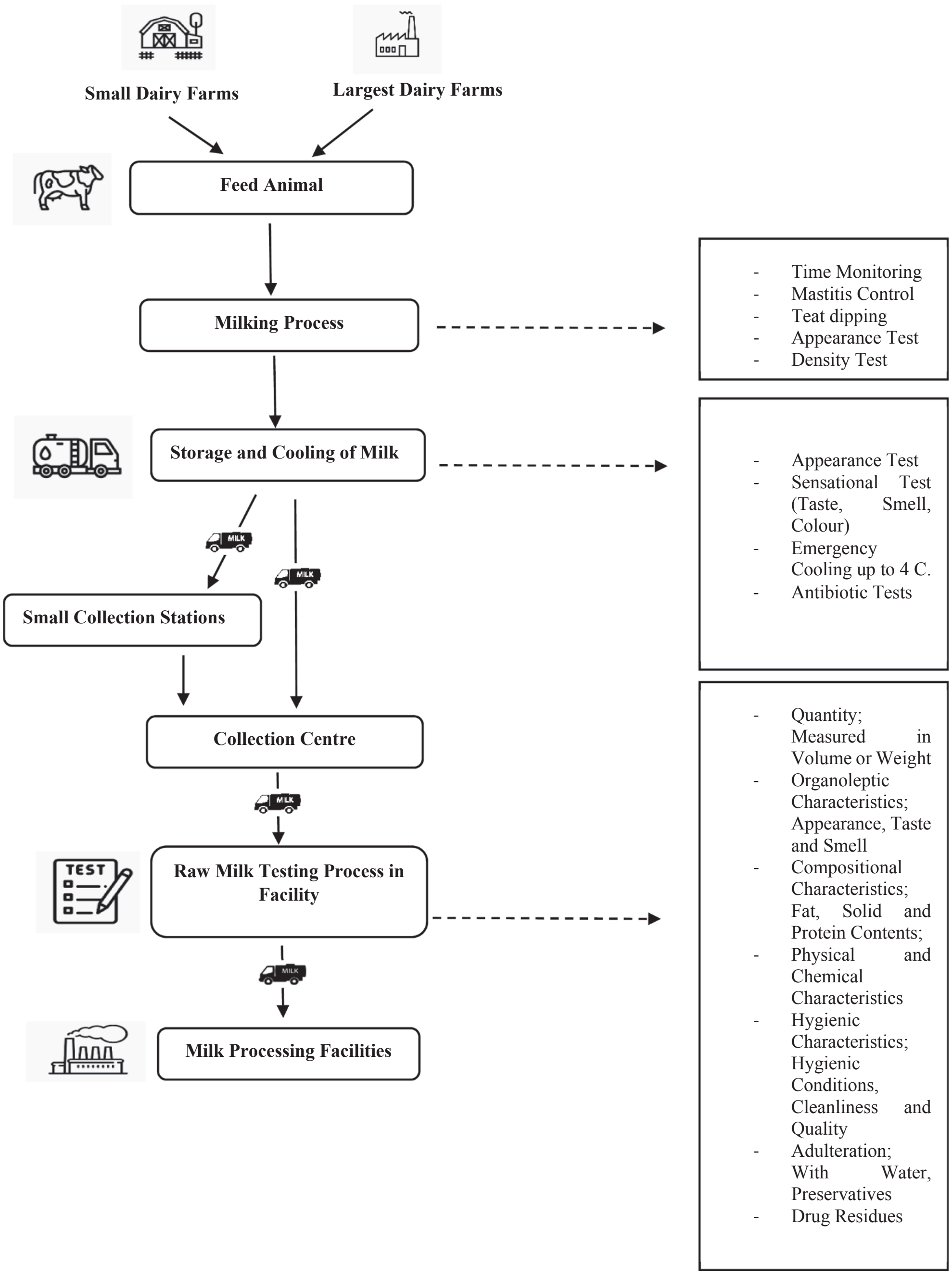

Fig. 1. General structure of milk supply chain.

situations, technologies used, the general hygiene of the animals, animal welfare, environment and the methods employed by the workers (de las Morenas et al., 2014; Charlebois and Haratifar, 2015). Challenges to the milk supply chain can come from chemical hazards and contaminants, animal husbandry and poor industry practices (FAO, 2013c; Hao et al., 2020). Therefore, to investigate effective traceability of the milk supply chain, we should consider all processes starting from the farm level to customers. The food waste for dairy products such as milk is very significant because of expiry dates and the short shelf life. Some of these products can thus be rejected due to the quality standards in place. However, buyers and suppliers can agree on minimum order quantity and lead-time (Li et al., 2019) to decrease food waste. If this is done properly, food waste can be reduced by 32.5% (Jagtap and Rahimifard, 2019).

From the presented theoretical background, current studies mainly contribute to theoretical knowledge though not from a holistic view. As a research gap, these studies do not consider societal impacts of blockchain technologies on the food supply chain. In addition, the literature remains incomplete in subjects such as mapping the addressed supply chain and making block chain recommendations; resolving these problems in the supply chain is another research question. This study mainly focuses on an analysis of the societal impacts of blockchain technologies on the food supply chain. Because of the various stakeholders and dynamics actors, the food supply chain has become more complex and is affected by various conditions (Tsaples and Tarnanidis, 2020). Dealing with these challenges and measuring the societal impacts of blockchain technologies can only be achieved by taking a systematic and holistic view.

2.2. System theory

System theory has developed since the beginning of the 1900′s. Systems thinking, which descended from the history of science, has become a prominent theory in the 20th century. Since problem solving is required, the system integrity and analysis of the system components need to be investigated within the unity of the system. Although system dynamics initially emerged as a system theory, it has been used in a wide range of fields over time. Systems theory provides a basis for many different disciplines (Zelbst et al., 2019). Using system theory as a theoretical basis serves as a bridge in reflecting real systems that provide synergy to identify relationships that enrich areas of expertise with systemic innovations (Monasterolo et al., 2016). Fantazy et al. (2015), by providing a holistic foundation of system theory, offered a competitive environment to adapt to changes such as technology. This theory provides the necessary background to deal with a complex dynamic system with the aim of making these systems more sustainable.

The multi-dimensional and complex structure of ensuring food safety in a sustainable and healthy environment requires to be addressed through system theory (Monasterolo et al., 2016). Based on system theory approaches, SD provides conceptual and structural advantages that can overcome the challenges of food system complexity because of its non-linear structure. Simulation models that mimic the behavior of the system by investigating functional relationships are highly powerful tools for investigation of the complex structure of the food supply chain. A SD modelling approach was created to represent the dynamics of the complex nature of systems to improve the sustainability of the system with non-linear structure, causal feedback and a variety of policies. System theory approach provides long-term plans with an integrated approach by determining ways to deal with different social parameters and by proposing different policies. Zelbst et al. (2019) analyzed how digital technologies are related to effectiveness and efficiency and suggested that they have a positive impact on both corporate and supply chain performance through system theory approaches. Due to system theory, the actions taken at an organization provide a basis for explaining how it will affect other shareholders of the supply chain. Based on the information received by the supply chain, various relationships are established transparently and aim to access all information throughout the system (Zelbst et al., 2019; Azzi et al., 2019).

3. Problem definition and research highlights

Milk is an important type of food, problematic in terms of perishability and short shelf life; it is also an important source of employment (SafeFood, 2008). The milk supply chain covers feeding animals, the milking process, storage and cooling of milk, small collection stations, collection centres (Huang et al., 2019), raw milk testing systems in the facility and milk processing facilities (Miranda and Ramachandran, 2014) as shown in Fig. 1. Due to globalization, all types of supply chains, especially milk supply chains, need to be resilient (Hosseini et al., 2019).

Various problems are encountered in the milk supply chain, from animal feeding to delivery of the product (Daud et al., 2015). Customers often do not know where milk comes from; they are unaware of hygiene levels in the milking process, chemicals used in animal nutrition and other areas of concern (Fahim et al., 2017). The high level of informal production in milk supply chains, especially in emerging economies, indicates that there is a lack of systematic management in various stages of the value chain; traceability is not ensured, milk safety and quality are at risk and animal welfare may not reach the desired level (Navarro, 2014). In addition to animal welfare, problems in the milk supply chain may also threaten human health (Millogo et al., 2010).

Various technological and manual controls and tests performed in the milk supply chain are shown in Fig. 1. These controls are the main controls that should be implemented, even in an underdeveloped milk supply chain (Habtamu Lemma et al., 2018). After animal feeding is completed and ready for milk production, the milking process begins by implementing some technologies such as time monitoring, mastitis control (Fahim et al., 2017), teat dipping, appearance test, density test (SNV, 2017) etc. to determine if there is any problem with the raw milk in the initial stage of the milk production (Ingalls, 2011; Fahim et al., 2017). After the milking process, it is critical to store and cool the milk. The quality of milk is monitored through tests such as appearance test, sensational test (taste, odor, colour), emergency cooling up to 4C and antibiotic tests (SNV, 2017). After collection of the milk, it reaches the facility.

When milk reaches the facility, initial tests are carried out. These tests act as controls that help measure the quality, strength and content of the milk; areas examined are quantity (measured in volume or weight), organoleptic characteristics (appearance, taste and smell), compositional characteristics (fat, solid and protein contents), physical, chemical and hygienic characteristics (hygienic conditions, cleanliness and quality), adulteration (with water, preservatives), drug residues (Rashid Chaudhry et al., 2015; Miranda and Ramachandran, 2014).

In this study, the milk supply chain is considered as the focus area. As mentioned before, milk is a very perishable and sensitive food. In addition, it is one of the most important products in developing countries. Manual tests, lack of control in transportation and lack of information in the milking process cause many losses in the milk supply chain. The losses suffered are a threat not only financially, but also to human health. It is necessary to prevent these losses and to ensure traceability and transparency at every stage of the supply chain. In other words, tests and controls employed need to be fully technological or highly scrutinised; some that are manual may give discrepancies about the quality of milk produced. Therefore, blockchain technologies are needed to ensure traceability, transparency, improvement of the quality control mechanism and prevention of frauds in the milk supply chain (Pant et al., 2015).

There are various societal impacts of blockchain technologies in milk supply chains that have been discussed in previous studies. This study considers different societal impacts of blockchain technologies in milk supply chains, as can be seen in Table 1. The quality of animal products is related to the genetic characteristics of the animal, the production ethics and animal welfare systems in place (Broom, 2010). Sustainability of a milk supply chain can be enriched by the use of local foods (Fernando et al., 2018; Hingley et al., 2011), promoting social assistance especially in rural areas (Gnansounou et al., 2015), working in proximity to food markets (Fernando et al, 2018), through adhering to regulations and initiatives, by increasing technical education and by promoting healthy eating (Leat et al., 2011).

Increasing food security (Balaman, 2019) and thus decreasing food fraud (Broom, 2010) can be accomplished by increased transparency; adapting blockchain technologies to the milk supply chain helps to achieve this (Francisco and Swanson, 2018).

To sum up, blockchain technologies in milk supply chains impact on society in a significant way. Therefore, in this work, a SD based model, a sub-concept of system theory, is developed to analyze social impacts (Tsaples and Tarnanidis, 2020). Thus, it can be shown that societal impacts and social sustainability can be improved by adopting blockchain technology.

4. Methodology

The system theory and system dynamics modelling approaches are integrated as the solution methodology in this research. The SD model was initially developed by Prof. Forrester in 1961. The main features of the SD model are to evaluate the behavior of the system (Minegishi and Thiel, 2000). The complex and non-linear relationships, plus uncertain system behavior is generally characterized in terms of feedback loops (Forrester, 1994). Forrester originally developed the SD methodology in the context of supply chain management. The supply chain includes various actors involving the flow of materials and goods with information sharing embedded in the system. Supply chain processes have a complex structure; the behavior of the system is also dynamic in nature (Rebs et al., 2019; Simões et al., 2020). SD has now become a powerful tool for different sectors in supply chains by modelling real-world problems.

SD provides an understanding of the relationships between system components by providing a holistic view of entire systems. With the help of system dynamics, future effects of decisions can be observed and long-term results can be investigated at low cost. Moreover, by analyzing the main structure of the system, it is easier to see the whole picture and then to focus on the problematic points of the system. The application of SD provides long-term analysis of decisions. SD also requires the system to be handled with a holistic view (Ekinci et al., 2020). Researchers can also work with different variables, but when dealing with multivariate real-world problems, it can sometimes become difficult to deal with causal loop diagrams and modelling. However, this model helps managers and policy makers to analyze the behavior of a system and evaluate the possible effect of future decisions for policy implications.

The structure of a system in SD modelling and relationships among variables are illustrated using causal loop diagram. Two types of diagrams, negative (balancing) and positive (reinforcing) feedback loops represent major feedback mechanisms. The definition of the

Table 1
Proposed societal impacts of blockchain technologies in milk supply chain.

Societal Impacts	Brief Descriptions
Local Embedding	Term incorporates the employment of local economy as part of a value chain, including local partners to support agricultural production (Fernando et al., 2018; Hingley et al., 2011).
Rural Development	Rural development involves the creation of job opportunities, generation of income and improvement of living standards in the rural communities of the country (Gnansounou et al., 2015).
Decreasing food fraud	Food fraud covers not conforming with food law, miscommunication of foodstuff intentionally and gaining economical advantage in the end (Lotta and Bogue, 2015).
Animal health and welfare	When the system interacts with animals, societal benefits can be achieved by sustaining animal health and welfare. As benefits, unnecessary use of resources can be eliminated, the consumption of safe products protects public health, wild-life can be preserved, etc. (Broom, 2010).
Proximity to food markets	This term articulates closeness to the point of consumption for products (Fernando et al., 2018). In the case of fresh food supplies, this indicator can be an indicator of food quality.
Food security	Food security used in this article concentrates on the price volatility of the product due to supply and demand in the region (Balaman, 2019).
Educating and promoting healthy eating	Systems that support people in healthy eating and guide them to request healthy food have societal benefits (Leat et al, 2011).
Assisting food access	As a social contribution of the system, outputs of the system can be made accessible to those people in need, providing nutritious and healthy food (Leat et al, 2011).
Social acceptability by transparency	Use of transparency in the system increases trust with consumers or stakeholders by minimizing risk and sharing knowledge and information (Francisco and Swanson, 2018).

boundaries for the system under examination is the initial step of SD (Georgiadis et al., 2005). Following that, the structure of a dynamic system model is expressed by stock (state) and flow (rate) variables. Using stock and flow diagrams, inter-relationships among the variables are shown. Since the food supply chain has a multi-stakeholder, complex and dynamic structure, it is necessary to manage and track it effectively. To be able to deal with many factors simultaneously and to observe the long-term effects of the system and its related factors, system dynamics are essential. Therefore, a system thinking perspective and SD modelling is employed in analyzing the complex nature of food supply chain systems; by considering the case of milk supply chains in this research, a more sustainable decision-making environment can be created. Flow of methodology used in this study has been represented in Fig. 2. Parameters used in this model are discussed in detail in Section 5.

5. A case study

5.1. Case description and data analysis evaluation

In this study, an agricultural development cooperative founded to support dairy farmers has been examined in order to understand the societal impacts of Blockchain technology. It is the biggest cooperative of dairy farmers in Turkey, located in a district of Izmir. Due to various projects aimed at improving cost efficiency and productivity, the cooperative received an award from the Food and Agriculture Organization of United Nations in 2012 as the best case of an agricultural development model. Besides, the cooperative aims to deliver high quality, safe milk to the end customer by targeting reliable milk production and milk production in accordance with quality standards. The cooperative regularly takes samples from the farms and calculates the milk quality values according to the analysis results. The suitability of milk supplied from milk purchasing centres established in 62 collection centres has to be monitored and controlled. The company aims to ensure the control and traceability of the milk it supplies from these collection centres throughout the supply chain. While the aim is to increase reliability through official certification, the company also plans to make investments that will increase traceability in order to ensure safe milk production.

The reason for using blockchain in the dairy industry is to reduce the risks of milk spoilage that can be encountered throughout the supply chain. These risks are reduced by recording information on quality and hygiene in the supply chain. Via blockchain technology, all steps of the actors during the entire supply chain are recorded and dates, locations, distribution channels and all transactions of the milk are tracked for each product group (Kayikci et al., 2020). In addition, food-related data records, milk quality records, milk temperature records and moisture records can be recorded throughout the supply chain. For example, temperature, humidity, expiry date, hygiene conditions plus various standards and regulations are established (Tan and Ngan, 2020; Casino et al., 2020). Thus, the social pillar of sustainability is achieved by protecting both animal welfare and public health. In addition, another reason for using blockchain technology in the dairy industry is that it can overcome the difficulty of tracking the source of milk supplied from many different milk producers (Deloitte 2017).

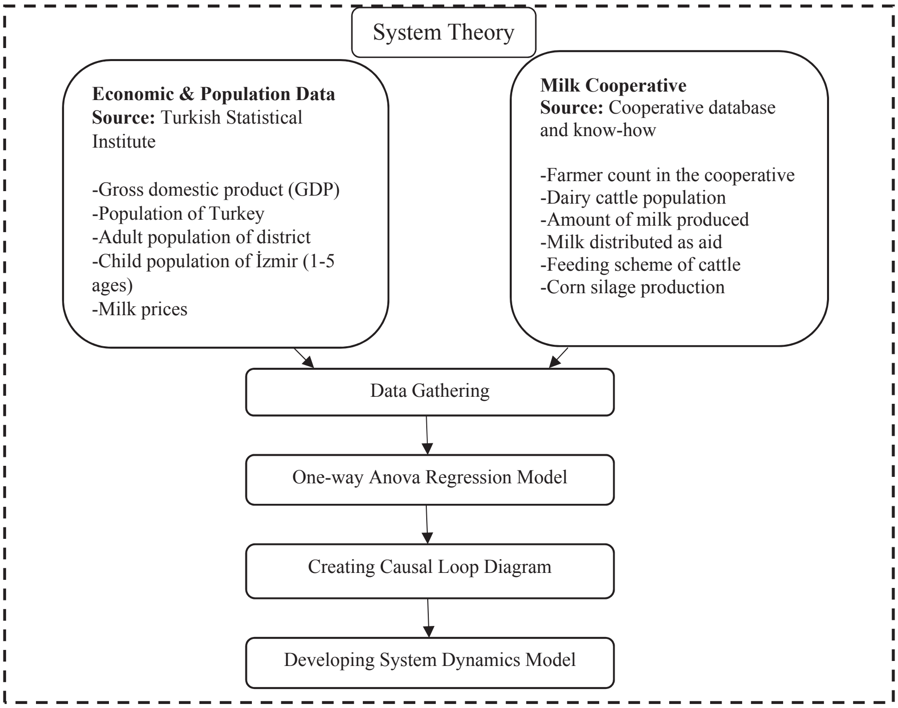

Fig. 2. Flowchart of Methodology.

The system supporting dairy farmers has been described in Fig. 3. In order to understand the flow, reviews with ten experts from the cooperative including management, veterinary section, agriculture engineering, planning and procurement have been carried out. Also, to understand their perspective, dairy farmers who are partners of the cooperative have been interviewed.

In this study, the part of the supply chain from the farmers to the producer will be considered as the area of interest. Dairy farmers in Turkey are mostly small producers who do not have bargaining power or cannot guarantee that their products would be bought by the large milk factories. Also, they are struggling with cost fluctuations that are mainly caused by;

- Increase in exchange rates
- High dependency on feed that is imported
- Increases in cost of gasoline, electricity, fertilizer and medicine
- Increase in imports of dairy products

In most cases, they cannot handle these fluctuations and milk production becomes unprofitable. Therefore, many are forced to quit the business; this is one of the main reasons for the decrease in the country of the rural population. In this specific district of Izmir, 70% of the dairy farmers have less than 10 cattle and less than 50 acres of land; 20% of dairy farmers have 10 to 20 cattle and 51 to 200 acres of land; the remaining 10% represents the big dairy farmers with more than 20 cattle and more than 200 acres of land. Farmers collect milk usually twice on a daily basis, perform some basic tests and carry their milk to the closest one of the 62 collection centres located around the district. In these collection centres, other tests that were mentioned previously in Fig. 1 have to be performed. After milk has been accumulated in the collection centre, trucks transfer the milk to the factory. The factory is owned by the cooperative; in the factory itself some detailed tests have to be performed (see Fig. 1). Milk is processed into various dairy products, labeled with the brand of the cooperative and shipped to retailers. As part of a food aid program, some of the milk produced is shared with İzmir municipality. In this way, the part of the supply chain that has been selected for this study behaves like a closed loop supply chain. The cooperative buys the milk from the farmers; it also provides the basic resources needed by the farmers. Currently there are approximately 2100 dairy farmers connected to the cooperative; this increases the bargaining power of the cooperative management when purchasing basic inputs for the farmers. In order to decrease input costs, farmers are encouraged to grow their own feed in their farms. There are two types of feed needed for use by the dairy farmers: roughage and concentrate. Concentrate feed is mainly bought from feed factories and contains a high level of protein. However, using an excessive amount of concentrate feed can cause metabolic disorders (FAO, 2012). Dairy farmers are exposed to price fluctuations of the feed producers. If necessary, corn silage can be used as roughage as it can provide the high level of dry matter required by the cattle in feeding, preventing any metabolic disorders. In order to support dairy farmers in corn silage production, the cooperative supplies the required corn seeds and fertilizers. The cooperative also provides tractors, gasoline and all other equipment needed in silage preparation processes. Moreover, the cooperative store sells basic household requirements to dairy farmers without profit.

To anticipate the expected growth of the cooperative, milk supply and requirement analysis of the dairy farmers, a SD model has

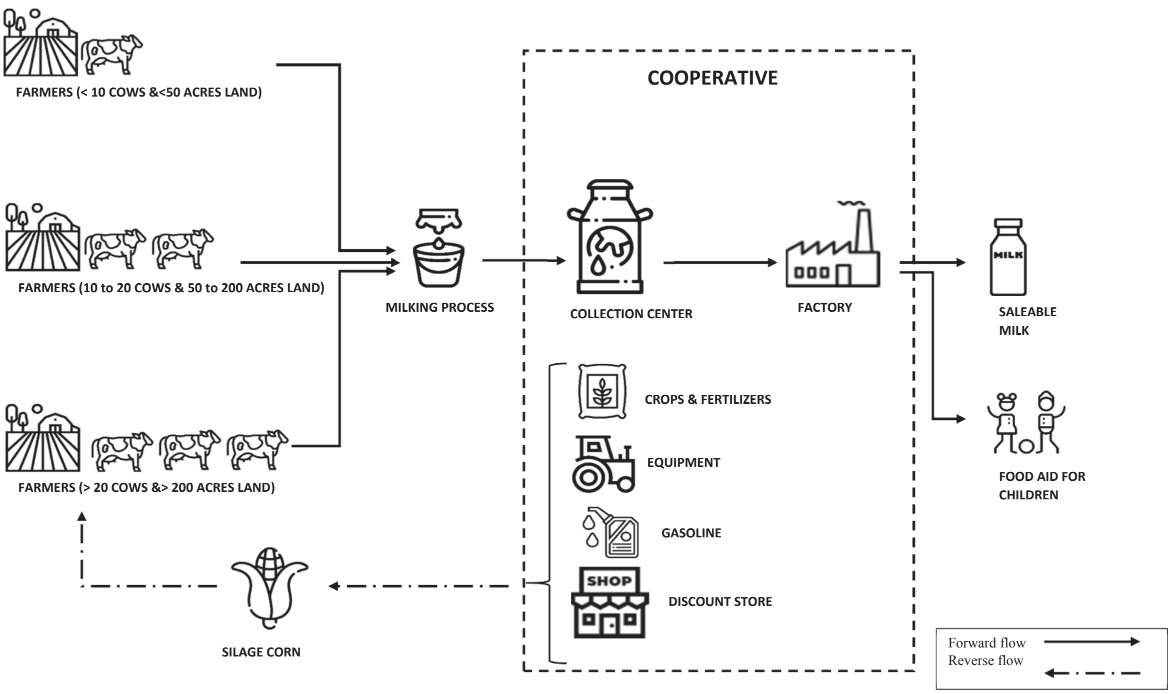

Fig. 3. Flowchart of cooperative's milk supply chain.

been developed. The number of farmers in the cooperative, dairy cattle population, amount of milk produced, milk distributed as aid, feeding scheme of cattle and corn silage production are all used as parameters in this model; this data and information has been gathered during interviews with the experts in the cooperative. The gross domestic product (GDP), population of Turkey, adult population of the district, child population of İzmir and milk prices are used as parameters; data about population, gross domestic product and milk prices are taken from the Turkish Statistical Institute. STELLA software is used to simulate the model from 2002 to 2025 on a quarterly basis. A one-way ANOVA test has been applied to data before the year 2019 to test validity; it can be concluded that there is no evidence that simulation results are statistically different from the actual data (with 95% confidence level). A causal loop diagram of the model is provided in Fig. 4.

In order to represent the economic growth of the country, gross domestic product (GDP) figures are used. Partners (dairy farmers) of the cooperative have increased considerably between 2002 and 2018, from 460 to 2100. Based on the expected economic growth, population growth of the country and adult population increases in the district, it is expected that by 2025 the number of partners will rise to approximately 2800 as shown in Fig. 5. The method used to forecast partner count is given in Equation (1)

$$PartnerCount(t) = c_1 + c_2{*}QuarteroftheYear(t) + c_3{*}GDP(t)$$

$$+ c_4{*}Population\_Turkey(t) + c_5{*}Adult\_population\_of\_district(t) \quad (1)$$

$$where c_1 = -6416, c_2 = -25.56, c_3 = -3.77E-22, c_4 = 5.78E-05 and c_5 = 0.056 are coefficients$$

Dairy cattle population is correlated with the price level of milk produced in the region. The unit price of milk increased from 0.59 TL/kg in 2005 to 1.94 TL/kg in 2019 in İzmir city region. Economic growth, rural population increase in the district and number of farmers in the cooperative are the other factors that influence the dairy cattle population. As can be seen in Table 2, the cattle population of 17,000 in 2004 has increased to 50,000 in 2019. For milk price calculations, Equation (2) has been used:

$$MilkPrice(t) = c_6 + c_7{*}time(t) + c_8{*}QuarteroftheYear(t) + c_9{*}GDP(t) \quad (2)$$

$$where c_6 = 0.39, c_7 = 0.0022, c_8 = -0.02382 and c_9 = -1.08E-09 are coefficients$$

For cattle population, Equation (3) has been employed:

$$CattlePopulation(t) = c_{10} + c_{11}{*}Farmers < 10cattle(t) + c_{12}{*}Farmers10to20cattle(t) + c_{13}{*}Farmers > 20cattle(t) + c_{14}{*}GDP(t) + c_{15}{*}MilkPrice(t) \quad (3)$$

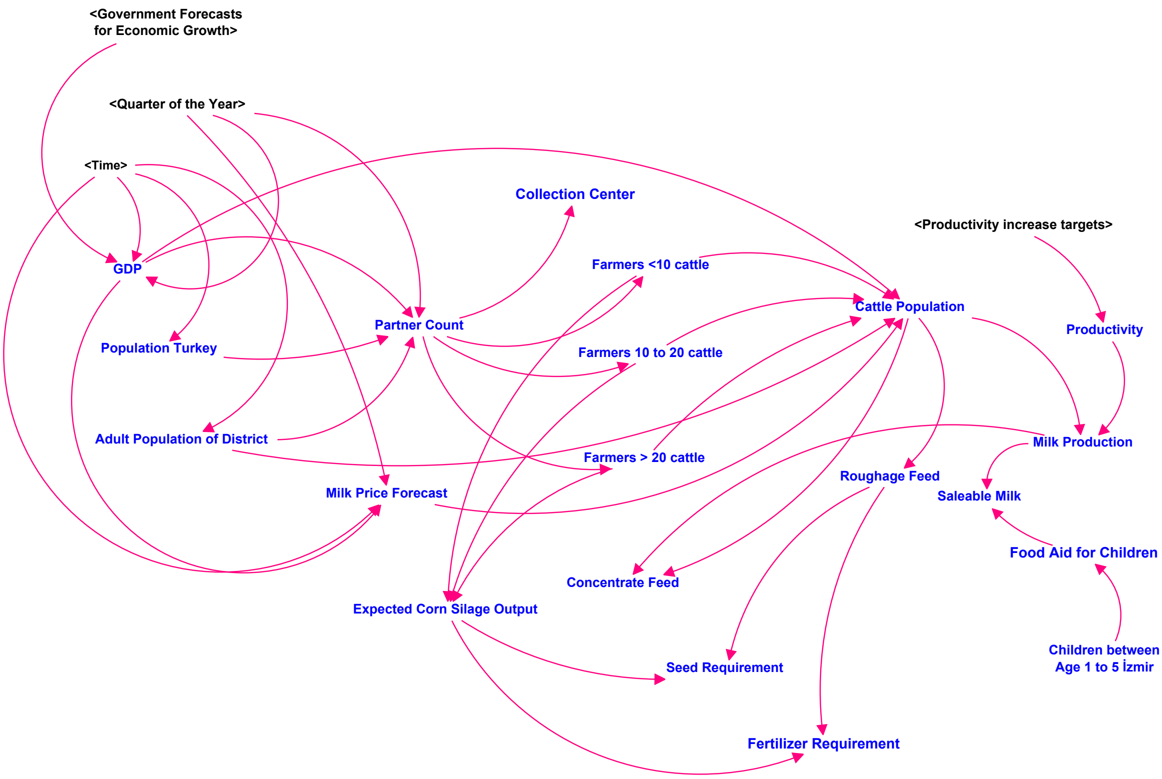

Fig. 4. . Causal Loop of milk supply chain.

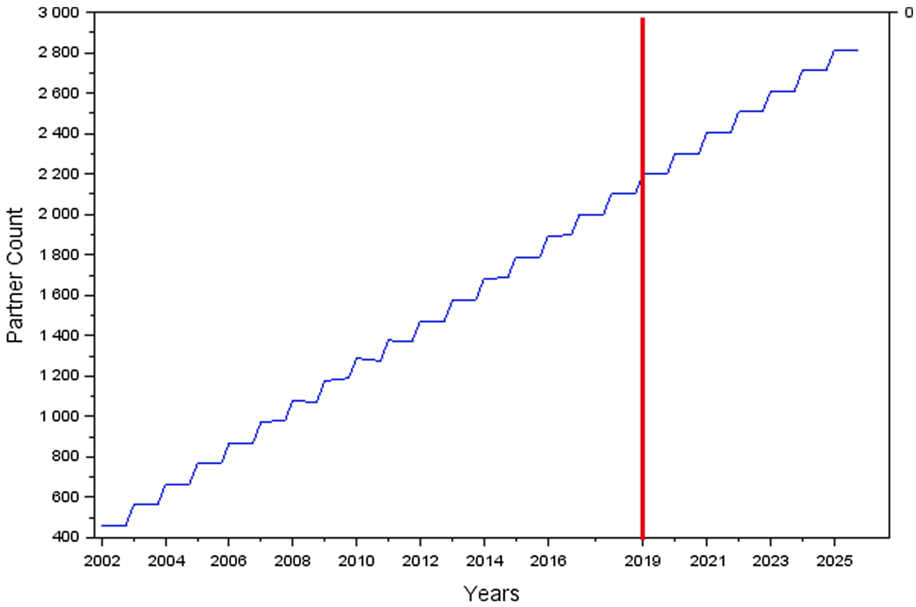

Fig. 5. Partner (dairy farmer) count in the cooperative.

Table 2
Milk prices in Izmir and cattle population in cooperative district.

Year	Milk Price (TL/kg)	Cattle Population
Actual		
2002	Not available	Not available
2003	Not available	Not available
2004	Not available	17,072
2005	0.56	17,432
2006	0.66	19,328
2007	0.7	20,400
2008	0.62	23,924
2009	0.79	23,312
2010	0.8	17,732
2011	0.78	16,663
2012	0.83	20,118
2013	0.95	19,728
2014	1.15	31,694
2015	1.29	34,620
2016	1.09	32,988
2017	1.28	41,214
2018	1.56	48,945
2019	1.94	52,828
Forecast		
2020	2.03	59,862
2021	2.23	66,719
2022	2.41	73,259
2023	2.6	80,055
2024	2.81	87,590
2025	3.05	95,939

$$where c_{10} = -10150, c_{11} = -42512, c_{12} = 208379, c_{13} = -119257, c_{14} = 0.000069 and c_{15} = -23541 are coefficients$$

Besides the rise of cattle population in the district, through the help of shared know-how and support of the cooperative, milk production by cow has more than tripled between 2002 and 2019. It is noted that in developed countries, milk productivity per cow increases over the years. For instance, as one of the biggest milk producers in the world, in USA a cow has an average productivity of 10.6 tons of milk per year (Statista, 2020). To encourage productivity increase, the cooperative has set a target of 8.5 tons of milk production per year per cow for the year 2025, giving an overall milk production of 730,000 tons. In Table 3, productivity figures per cow and total milk production for the past years and forecasts are shown.

A considerable amount of milk produced is taken by the İzmir municipality to be distributed to families with children between the

Table 3
Milk productivity per cow per year and yearly milk production of the cooperative.

Year	Productivity (tons/cow/year)	Milk Production (tons)
Actual		
2002	1.95	30,911
2003	2.24	36,931
2004	2.52	43,309
2005	2.81	49,651
2006	3.09	56,876
2007	3.37	63,529
2008	3.66	71,397
2009	3.94	75,196
2010	4.23	85,312
2011	4.51	99,677
2012	4.8	112,484
2013	5.08	129,535
2014	5.37	147,382
2015	5.65	169,872
2016	5.94	192,256
2017	6.22	231,604
2018	6.51	280,985
2019	6.79	329,432
Forecast		
2020	7.08	386,952
2021	7.36	444,524
2022	7.65	505,602
2023	7.93	571,764
2024	8.22	646,715
2025	8.5	731,576

ages 1 to 5 as a food aid. This project started in 2013; the municipality distributes 8 kg milk per child every month to those families having children in the specified age group. In Table 4, the milk distributed both as food aid and the total amount of saleable milk is provided. The milk produced can be sold as fresh milk or used in dairy products of the cooperative brand.

The cooperative supports the farmers in feed production or purchasing. As roughage feed, farmers can grow corn silage in their lands. Corn seed and fertilizers are provided by the cooperative and during production, tractors and other required equipment can be borrowed from the cooperative. If corn silage produced on the land is not enough, the cooperative can make purchases on behalf of the dairy farmers. Therefore, the planning process is critical to obtain cost reductions during the year. In cattle feeding, the percentage of

Table 4
Milk distributed as food aid and milk used for the cooperative brand.

Year	Food Aid Distributed (tons)	Milk Sold or Used in Dairy Products (tons)
Actual		
2002		30,911
2003		36,931
2004		43,309
2005		49,651
2006		56,876
2007		63,529
2008		71,397
2009		75,196
2010		85,312
2011		99,677
2012		112,484
2013	11,915	117,620
2014	12,185	135,197
2015	12,455	157,417
2016	12,724	179,531
2017	12,994	218,610
2018	13,264	267,722
2019	13,534	315,899
Forecast		
2020	13,803	373,149
2021	14,073	430,451
2022	14,343	491,259
2023	14,612	557,152
2024	14,882	631,833
2025	15,152	716,424

roughage versus concentrate feeding can differ with respect to cattle lactation stage, milk fat concentration, and productivity level or cattle type. However, in this study, such detailed information is not available.

We have therefore considered an average cattle weight of 500 kg providing milk with 4% of fat concentration for feed requirement analysis. The productivity increase of the cows has been considered; as the milk production per cow increases, their feed consumption will increase. Only roughage feed is enough to support up to 7 kg of daily milk production. However, as daily milk productivity per cow increases, more concentrate feed requirement will be needed (Fig. 6). In Table 5, roughage and concentrate feed requirements are shown. Roughage and concentrate feed requirements are calculated using Equations (4) and (5):

$$RoughageFeed(t) = CattlePopulation(t)*RoughageConsumptionRate \tag{4}$$

$$where RoughageConsumption is 20 kg per day per cow$$

$$ConcentrateFeed(t) = if(MilkProduction(t) < CattlePopulation(t)*MinProductivityConcentrateFeed)then 0$$

$$else(MilkProduction(t) - CattlePopulation(t)*MinProductivityConcentrateFeed)*ConcentrateConsumptionRate \tag{5}$$

$$where MinProductivityConcentrateFeed is 7 kg per cow per day and$$

$$ConcentrateConsumptionRate is 0.5 kg per additional 1 kg of milk production$$

In the region, corn silage is most commonly used as roughage feed. In one acre of land, approximately 1.2 ton of corn silage can be harvested. The productivity of the land while growing corn is highly dependent on the soil concentration in terms of minerals present; soil tests need to be conducted to understand the fertilizer requirement. In this analysis, it has been assumed that one acre of land requires 47 kg of fertilizer containing the elements Nitrogen (N), Phosphorus (P) and Potassium (K). In Table 6, by considering cattle feed requirements and available land owned by the partners, corn seed and fertilizer requirements are forecast. Corns can be planted in the second quarter of the year and need roughly three months to grow. However, if the land is used for planting other crops, it could also be planted as a second crop after harvesting the primary product in the third quarter of the year.

5.2. Evaluation of potential societal impacts of blockchain technology

The cooperative participating in this study has been founded in order to support agricultural development in the district for dairy farmers. The existence of this cooperative is responsible for many societal benefits for the farmers, community and animals. The societal impacts of the supply chain can be fostered for greater benefit if blockchain technology can be adopted. In this section, possible opportunities and implementation areas of blockchain technology for the milk supply chain will be discussed. As discussed in Section 3, the possible societal advantages of using blockchain can be local embedding, rural development, decreasing food fraud, animal health and welfare, proximity to food markets, food security, educating and promoting people towards healthy eating, assisting food access and social acceptability through greater transparency.

As mentioned previously, in the last 18 years the cooperative has encouraged dairy farmers in the district to become partners with a

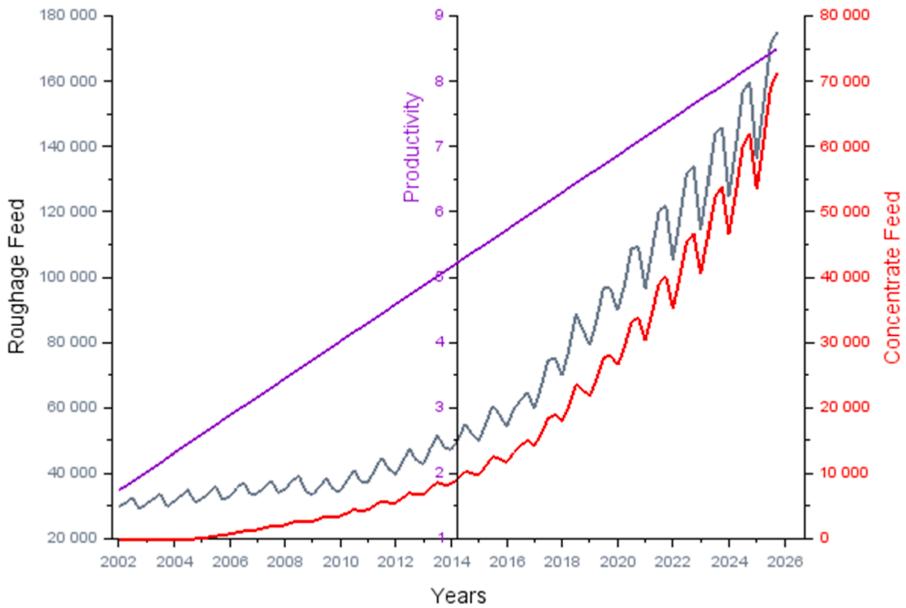

Fig. 6. Productivity and feed requirement.

Table 5
Roughage and concentrate feed requirements.

Year	Roughage Feed (tons)	Concentrate Feed (tons)
Actual		
2002	122,402	–
2003	126,679	–
2004	130,984	–
2005	134,309	1,321
2006	139,132	4,090
2007	141,884	6,935
2008	146,701	10,026
2009	142,982	12,576
2010	150,978	16,235
2011	164,983	20,967
2012	174,890	25,636
2013	189,875	31,539
2014	204,350	37,930
2015	223,389	45,843
2016	240,466	54,046
2017	276,121	67,481
2018	320,160	84,465
2019	359,373	101,826
Forecast		
2020	404,888	122,621
2021	446,829	144,067
2022	489,034	167,220
2023	532,908	192,623
2024	581,607	221,576
2025	635,613	254,556

Table 6
Corn seed and fertilizer requirement.

Year	Corn Seed Requirement (tons)	Fertilizer (tons)
2020	6,748	63,432
2021	7,447	70,003
2022	8,109	76,224
2023	8,616	80,987
2024	9,159	86,092
2025	9,655	90,756

resultant increase in milk production from 30 thousand tons in 2002 to 330 thousand tons in 2019. In the district, both cattle population and productivity have more than tripled. The cooperative has founded its own dairy processing factory and meat processing factory. In the next five years, the cooperative expects new partners to join; plans have been made to start new projects, reduce costs and increase productivity. According to Hume et al. (2011), productivity increase and sustainability in livestock systems can be achieved by minimizing losses due to diseases, stress and nutrition; maximizing the welfare of animals becomes possible. Collecting the relevant data and transforming it into useful information is made easier by employing appropriate technologies. It is desirable to improve management and information sharing/tracking among more than 2000 partners, cooperative offices (veterinary, account management, agriculture engineering team, planning and procurement team) and cooperative factory departments (quality control, production planning, distribution planning); blockchain technology can be incorporated into the existing system so that transparent and end-to-end accurate tracking of the supply chain is made possible, while creating decentralized recording of transactions.

In Table 7, possible areas that can be traced using blockchain technology are listed. According to each traceability point, the societal impacts of using blockchain are explained. Robustness of proposed blockchain implementation has been ensured by selecting the traceability points which rely on the existing literature about dairy production. Therefore, areas of proposed blockchain implementation can be applicable to any organization in any country, since they are key to essential tracking systems needed to improve the quality and quantity of the milk production.

All improvements in the traceability points using blockchain encourage rural development in the district. The most beneficial point for tracing the milk supply chain is collection of cattle and milk test data. Even though there are multiple entrants of data into the system - the dairy farmer, collection centre, factory - in the end, these transactions provide useful information to the system about the health of the cattle, milk quality, traceability of the problematic results, preventing food fraud and encouraging people to look for quality and healthy products.

Local embedding and rural development can be achieved in nearly all of the traceability points, as being part of this cooperative will generate income and increase the living standards of the dairy farmers. As a result of this data sharing, they will have guidance on maintaining the health of their animals, feeding schemes, guaranteed low cost purchasing for their supplies and assured sales for their

Table 7
Societal impacts of blockchain technology in the milk supply chain.

Trace what?	Articles About Trace Areas	When to register?	Whom to register?	Whom to use?	Trace why?	Societal Impact
GENERAL REQUIREMENTS OF THE MILK SUPPLY CHAIN TO TRACE						
Cattle and milk test results (Tests are provided in Fig. 1)	• Nielsen, et al. (2005) • Fröhling, et al. (2010) • Toni, et al. (2011)	• Milking process (twice a day while milking) • Collection centre (as the farmer delivers) • Cooperative milk processing factory (as arrived from collection centre)	• Entry by the dairy farmer • Entry by collection centre • Entry by quality control	• Cooperative veterinary & factory quality control • Cooperative veterinary & factory quality control • Cooperative veterinary, factory planning, factory summary reports	• tracking animal health • following milk quality • embedding into product packaging to inform customers	
Cattle ID and state (Vaccines, lactation or dry state, diseases, weight, real time monitoring data - respiration, heart rate, movements	• Borcherschang • et al. (2016) • Stewart, et al. (2017) • Habtamu Lemma, et al. (2018)	• By regular visits of the cooperative veterinary • Real time monitoring data	• Entry by the veterinary • Automated real time entry by sensors	Cooperative veterinary, cooperative planning & procurement team, factory planning team	• tracking animal health condition • planning production capacity of factory • planning requirements for cooperative such as feed purchasing	
Cold chain activities	• Daud, et al. (2015) • Tian (2016) • Costa, et al. (2013)	Starting from collection centre	Using RFID technology as input for blockchain technology	Factory quality control	• reducing food loss due to spoilage	
Cattle feeding process	• Borchers et al. (2016) • Daud, et al. (2015)	• Regular entry about the feeding of cattle • Real time monitoring data about feeding	• Entry by dairy farmer • Automated real time entry by sensors • Combining already entered cattle ID, state and enter milk test results in the system	Cooperative veterinary, cooperative planning & procurement team	• suggesting appropriate roughage and concentrate feeding scheme • minimizing unnecessary feed usage (cost reduction) • planning feed production and requirements of each partner	
Land owning	• Daud, et al. (2015)	On registry of the dairy farmer, owned land information (acres)	Entry by cooperative agriculture engineering section	Cooperative planning & procurement team	• planning feed production and requirements of each partner	
Silage corn planting process	• Daud, et al. (2015)	• Each year planned planting time and acres to be planted can be registered (at the year-end) • Regular feedback about fertilizer usage, status of crops, etc.	Entry by the dairy farmer	Cooperative planning & procurement team	• planning feed production • planning seed and fertilizer requirement • planning equipment and tractor requirements	

(continued on next page)

Table 7 (*continued*)

Trace what?	Articles About Trace Areas	When to register?	Whom to register?	Whom to use?	Trace why?	Societal Impact
Product distribution network	• Daud, et al. (2015) • Tian (2016)	Orders raised by customers	Entry by factory sales team	Factory distribution planning team, factory planning team	• planning production capacity of factory • planning distributions • understanding possible areas with sales potential	
CASE BASED REQUIREMENTS OF THE MILK SUPPLY CHAIN TO TRACE						
Monetary transactions		• As the time of the transaction happens, it can be recorded into farmers ID. • During milk supply to the cooperative and purchasing any kind of input from the cooperative	• Entry by collection centre during milk supply. • Entry by cooperative clerks as any input is bought	Cooperative account management	• minimizing and simplifying monetary transactions between partners and cooperative	
Basic household purchases of partners		At the time of the transaction, it can be recorded into farmers ID.	Entry by the cooperative shop	Cooperative account management, cooperative shop management	• minimize and simplify monetary transactions between partners and cooperative (no money transfer in the shop) • planning stock control in the cooperative shop	
Food aid project for children		Regular updates from municipality about locations of children	Entry from municipality	Factory distribution planning team, factory planning team	• planning production capacity of factory • planning distributions to support municipality	

milk production.

With the entry of milk test results, cattle ID and condition (lactation or dry stage, weight, test results, fat concentrate of the milk, existing diseases), cooperative veterinary personnel can provide guidance in order to sustain animal health and welfare. According to Nielsen, et al. (2005), Fröhling et al. (2010) and Toni et al. (2011), tracking milk constituents will guide the farmers to better understand the health status of their animals. Real time monitoring of the cattle (feeding, respiration, heart rate) can be employed for remote monitoring of the animal and farm welfare (Brochers, et al. 2016; Stewart et al., 2017). Veterinary visits and diagnosed diseases should be tracked for animal welfare (Habtamu Lemma et al., 2018). Based on the existing status of the cows (dry period, lactation period etc.), feeding schemes can be planned and the cooperative can arrange accurate feed requirements of the partners to carry out low-cost bulk purchases on time. Based on Daud et al. (2015), major risks in a milk supply chain are sustaining feed availability and transportation of milk with minimum loss and contamination. Suggested feeding plans for the cooperative cattle population should be converted to silage corn planting arrangements, purchasing plans for seeds and fertilizers, plus scheduling of equipment and tractors. Efficient transportation of the milk produced requires rigorous planning; areas to be monitored are distribution, use of appropriate vehicles to prevent contamination and possible temperature changes during a journey (Tian, 2016; Costa et al., 2013). Tracing distribution networks, vehicle locations, temperature and contamination levels using RFID technology are all beneficial for the milk supply chain; this will increase sales, reduce losses and eventually increase the income of the dairy farmers.

A significant benefit of blockchain technology is in enabling the cooperative to cope with price volatility by forecasting and planning accurately. By having the exact information about cattle population, their condition and feeding schemes, the cooperative can better manage the costs incurred during the milk production process. With an understanding of the order potential in the region and aid programs in the municipality, there is a greater ability to manage the sales potential and capacity plan. This advantage can be considered as food security, since in the long run, dairy farmers will feel confident to stay in the market and continue milk production.

The cooperative in this case enjoys special benefits from blockchain technology, as all transactions between the partners and cooperative can be recorded - including milk sales, gasoline, feed, fertilizer, household purchases - without physical money transfer. Reconciliations of incoming and outgoing money transfers can be performed by the accounting department at the period end. The cooperative shop (non-profit shop) also allows cheaper basic household purchases by dairy farmers, enabling better food access in the district for the partners. Food aid data of each municipality can also be embedded into the blockchain to improve the planning performance of the cooperative.

In Fig. 7, the abovementioned blockchain transactions are shown by indicating the origin of entry for each record type. While deciding the technical infrastructure of blockchain technology, a growing number of entrants who create records should be considered. Taking into account the traceability points, stakeholders of the supply chain should be made responsible for the accuracy of their entries in order to support the decision-making process. All of the transactions recorded eventually result in databases containing information about:

- Cattle population: All information concerning animal breeds, diseases, vaccines, milk quality (fat concentrate, bacteria count etc.), productivity, feeding scheme, sources of feed can be handled with the help of this database. The cooperative can use this information to make decisions regarding animal health, welfare, productivity and quality of products.
- Planning and procurement: Information about land usage, input requirements (feed, fertilizer, gasoline, non-profit cooperative shop inventory etc.), tractor and equipment requirements can guide planners to gauge capacity, production and procurement.
- Accounting: The physical money flow between dairy farmers and the cooperative needs to be minimized and simplified. Cash inflow and outflow can be tracked using the database for reconciliation purposes at the end of each period.

6. Discussions and research implications

In this section, a discussion of findings and suggested research implications are presented.

6.1. Discussion of findings

In line with this work, Tian (2016) stated that food safety could be achieved effectively with traceability through reliable information across the supply chain. Similarly, Tipmontian et al. (2020) developed a SD model to evaluate the impact of blockchain technology adoption for food supply chains. Due to the advanced network of blockchain technologies, businesses can prevent quality losses in milk and prevent frauds, such as sales and production, via informal means (Deloitte, 2017). In addition, blockchain provides traceability in every stage of the milk supply chain as well as in transportation and storage. Transparency in this process increases demand for the product and eliminates the concerns of the consumer about human health, environmental sustainability (Li et al., 2020c) and welfare (Sánchez-Flores et al., 2020). Galvez et al. (2018) suggested that tracking in the food supply chain is critical to identify and address critical sources within the chain. Similarly, according to Broom (2010), a system that results in poor animal welfare cannot be sustained because it is considered both unacceptable to society and proves to be a poor quality and inefficient system for the business.

Blockchain technologies provide milk safety and quality by providing traceability and transparency in the supply chain from feeding the animals to reaching the consumer. This further provides easy monitoring at every stage of the milk supply chain (Connolly, 2018). Behnke and Janssen (2020) conclude that blockchain technology is used to build trust and increase traceability. All stakeholders, internal and external actors can be monitored throughout the chain by ensuring traceability via blockchain technology. Therefore, blockchain in the milk supply chain increases confidence in the product, improves consumer confidence and enhances the reputation of the sellers in the community. With the proposed model, Casino et al. (2020) also suggested that the overall quality and safety can be increased through blockchain technologies. Besides, food safety is vital for public health and business operations.

Kamble et al. (2020) stated that understanding and accessing product information without loss, noise, delay and deterioration can be achieved to the extent that all stakeholders share transparency in a perishable food supply chain. This effective traceability system manages both food quality and safety risks and is necessary to promote an improvement in effective milk supply chain management.

6.2. Implications

This research proposes several managerial, policy and academic implications after analyzing the societal impact of blockchain technologies in the food sector by considering milk supply chains. In the following section, managerial implications are given.

6.2.1. Managerial implications

The study charts the development of a cooperative working with 460 partners in 2002, the number of partners reached 2100 in 2018. With the growth of cooperatives in Turkey, the number of farmers is increasing. Decision makers can use the findings of this research to effectively manage the increasingly complex structure of the industry. The growth of cooperatives contributes to the increase of rural development by improving the quality of life and economic well-being of rural people. An increasing number of farmers and greater numbers of cows have been responsible for an increase in milk productivity. Therefore, managers should take initiatives to support cooperatives to enhance the efficiency of the milk supply chain. Animal health and welfare is important in achieving high quality products and less waste with continuous traceability.

With the increase in the number of cooperative partners and the increase in the number of farmers, the developing networks will cause more data to be produced; it needs to be recorded. More tests should be conducted and subsequently, suitable policies to increase

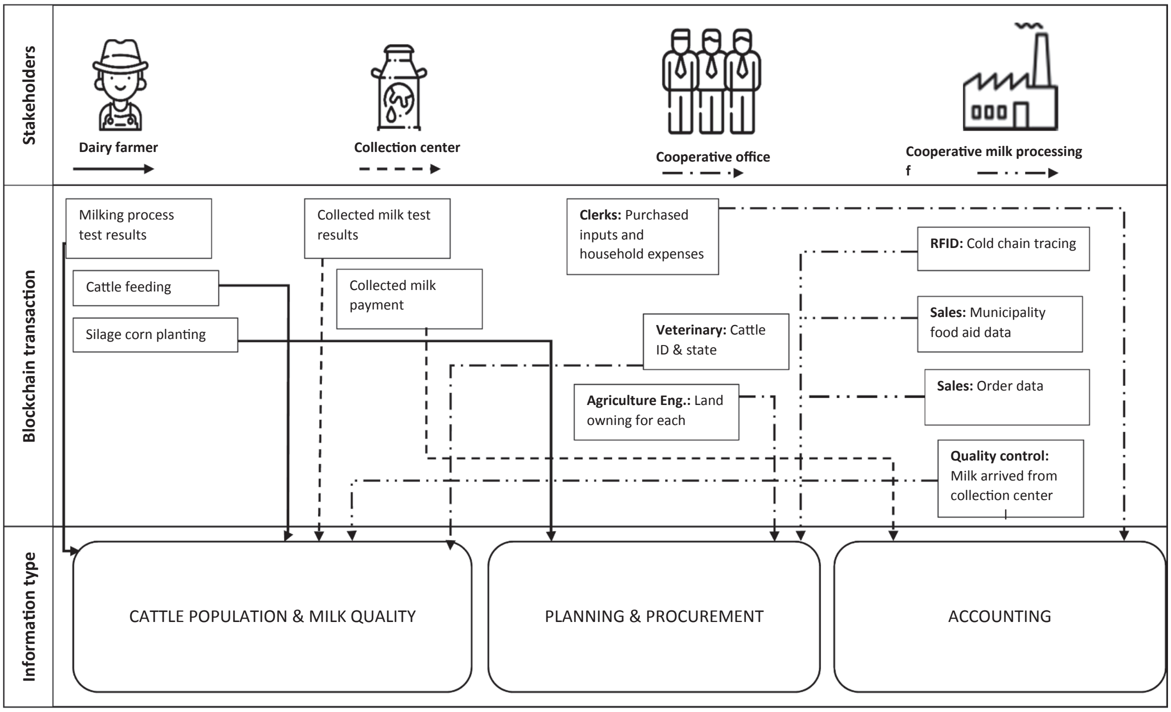

Fig. 7. Data entry for blockchain of milk supply chain.

traceability should be implemented in order to ensure quality and reduce food waste. In addition, increasing cooperative networks will provide proximity to markets, ensure fresh produce, improve product quality and prevent waste.

The development of cooperatives ensures the formation of closed supply chains. While farmers provide a milk supply for co-operatives, cooperatives facilitate sales of seeds, fertilizer, tools, equipment, and fuel and provide basic food support. As a result, rural development is enriched due to the social impacts of blockchain technology.

Although the organization discussed in this paper began by working as a cooperative, it now works with national retailers all over the country. Therefore, the use of blockchain technologies proposed in this study can be considered as important in terms of managing product distribution both locally and further afield.

The cooperative needs to consider procurement. Analysis has to take place to determine whether the feeds produced for all partners are sufficient or not; if it is insufficient, the purchase is made. At this stage, a blockchain is necessary for the sustainability of the financial operations of the cooperative and the supporting systems for partners.

For supply chain managers, the environmental impact of milk supply chains is measured, but the societal impact is often neglected. This study gives information to logistics managers about which data to collect from the blockchain to measure the societal impact.

Lastly, in addition, the roadmap presented can be used to measure the societal impact of blockchain and similar (I40, IoT, cloud) technologies.

Besides these managerial implications, there are implications for policy makers and academicians as explained below.

6.2.2. Policy makers and academic implications

Policy makers may consider this research as a tool to draw up regulations aimed at increasing local embedding and urban development. Blockchain technologies provide a more efficient and sustainable milk supply chain by tracing all stages of the chain. Increased traceability has led to more efficient management of milk tests and better storage conditions. Through blockchain technologies, traceability and transparency will increase and solutions to problems such as tracking food products at risk of food fraud can be found. Decision-makers can use this research to improve public health. In addition, the public should be better educated and encouraged to adopt healthy nutrition with traceability in the value chain.

Another important benefit of traceability is the reduction of food waste and an increase in quality of milk. With less milk waste, governments have the opportunity to facilitate better food access for more vulnerable members of our society.

In terms of cooperative managers, data security can be provided with "smart contracts" based on blockchain technologies. This research can be useful in determining the critical traceability points of a milk supply chain; hence, managers can learn to evaluate the societal impacts in strategic decisions of blockchain adoption.

Supply chain issues have always been a subject of study for academics. This paper will hopefully motivate scholars to further explore blockchain technologies and perhaps suggest different types of technology to improve and enhance supply chains in the longer term.

7. Conclusions

Blockchain offers a powerful system by combining accessibility with security and privacy. Blockchain technology can be adopted in all processes of the food supply chain from the procurement stage to the delivery of the product. In the case of the dairy sector, products are particularly vulnerable, so the adoption of blockchain technologies in milk supply chains has significant societal impacts in terms of improving milk quality, animal welfare, milk safety, etc. Traceability and transparency are essential issues for milk supply chains since the quality and safety of milk changes, depending on supply chain processes such as storage situations (Wu et al., 2018), the health of the dairy herd and methods of working.

Therefore, in this study, the aim is to measure the societal impact of blockchain technologies in the food sector by considering a milk supply chain. More specifically, system theory in integration with SD modelling is implemented to map the milk supply chains to explore information flow towards traceability and to investigate the potential effect of adopting blockchain technology in milk supply chains to improve its social sustainability. To sum up, the main contribution of this study is to establish the effects of blockchain technologies on milk supply chains and the wider society based on important areas such as local embedding, decreasing food fraud, rural development, animal health and welfare plus food security while educating and promoting people towards healthy eating. To assist researchers, this study aims to set out a road map for managers and policy makers regarding blockchain technologies on milk supply chains.

As an implementation, a cooperative, the biggest in Turkey, with a complex and crowded structure is considered. In practical terms, it is difficult to ensure coordination between the stakeholders, firms and agencies of the cooperative. Therefore, blockchain technologies would be very useful in the context of this milk supply chain.

A limitation of this study arose because of the difficulty of collecting the data needed to be applied in SD modelling; data is not always available. Moreover, while blockchain policies can be created easily, transforming them into supply chain management can be more difficult and may take time for companies to achieve. Since the study covers only one cooperative, the largest in Turkey, more cooperatives could be researched in future work. In this study, the supply chain process is evaluated from milking to the factory. For future studies, the supply chain process can be evaluated from milking to the end consumer. However, the study can be integrated with optimization models, to ensure a decrease in waste and minimal loss in food supply chains. Moreover, with proposed blockchain technologies, the performance analysis can be made to show how blockchain technologies impact on a specific part of a supply chain. Finally, the model and supply chain structure applied in this study can be integrated with network design.

8. Author contribution statement

- **There is no conflict of interests among author (s).**
- **All author (s) have contributed equally and significantly throughout the manuscript.**

CRediT authorship contribution statement

Sachin Kumar Mangla: Writing - original draft, Conceptualization, Formal analysis, Methodology, Supervision. **Yigit Kazancoglu:** Investigation, Project administration, Writing - original draft. **Esra Ekinci:** Formal analysis, Methodology, Software, Validation. **Mengqi Liu:** Conceptualization. **Melisa Özbiltekin:** Conceptualization, Data curation. **Muruvvet Deniz Sezer:** Data curation, Software, Methodology.

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