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Research Article

Service-Oriented Modeling for Blockchain-Enabled Supply Chain Quality Information Systems

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Quality management is one of the most critical issues in supply chain management. The rapid growth of information technologies, such as blockchain technology, has facilitated effective information systems development to support supply chain quality management. However, a significant challenge in developing blockchain-enabled supply chain quality information systems is how to deal with information asymmetry and the conflicting interests of supply chain partners. Taking a service-dominant view, this research proposes a Blockchain-Oriented Service Modeling (BOSM) approach for blockchain-enabled supply chain quality information systems. We provide a visual language for modeling the coordination and integration of business processes and domain knowledge at the knowledge level to facilitate the alignment of blockchain technology with supply chain quality management. The proposed approach bridges operational service computing with strategic service management in blockchain-enabled supply chain quality management and facilitates the communication between business people in supply chain management and software professionals in blockchain-based service computing. A case study on a dairy supply chain is presented to show advantages of the modeling framework under the service-dominant view, separating the cause of quality from the carrier of quality in the design of blockchain-enabled supply chain quality information systems.

1. Introduction

Managing quality is one of the most important factors in supply chains that involve many organizations collaborating to provide products or services. If the quality of materials from suppliers is not appropriately controlled, it may affect the end product's quality and lead to serious outcomes. The systematic collaboration between supply chain organizations in producing products makes it important to conduct quality management at a supply chain level. Robinson and Malhotra [1] reviewed the literature on quality management and supply chain management and argued that quality practice must advance from traditional firm-centric and product-based mindsets to an interorganizational supply chain orientation involving customers, suppliers, and other partners. Supply Chain Quality Management (SCQM) is defined as a system-based approach for performance improvement that leverages the opportunities created by upstream and downstream linkages with suppliers and customers [2, 3].

Quality management at a supply chain level faces many challenges. Supply chain partner enterprises are usually geographically diverse and belong to organizations with different interests. There is no perfect inspection technology to accurately measure product quality. Thus, as a result of information asymmetry on product quality, the moral hazard effect exists in supply chain quality inspection, which may cause an inefficient supply chain. To tackle the SCQM problem, one approach is to leverage advanced information technology to build quality information systems. Among other solutions, blockchain has emerged as a leading technology since it provides secure traceability and control, immutability, and trust creation among stakeholders in a low-cost IT solution [4]. Many recent studies have discussed on how to improve SCQM by adopting blockchain technology [5–8], finding that "trackability" and "traceability" are considered as the prime success factors of a blockchain-based supply chain [9].

However, there are few studies exploring blockchain-oriented software engineering [10], in particular, the requirement modeling methods for blockchain-enabled supply chain quality management. This can be attributed to the lack of an appropriate modeling perspective that synthesizes the nature of supply chain quality management with the characteristics of blockchain technology. SCQM needs to consider quality initiatives along supply chains, including upstream and downstream parties; thus, an appropriate modeling framework for blockchain-enabled Supply Chain Quality Information Systems (SCQIS) should consider both decentralized and network features. As blockchain technology is centered around a peer-to-peer network, enabling collaboration between different parties, it becomes an enabler of service systems [11]. In the service-dominant (S-D) logic perspective, service refers to the application of specialized competences (knowledge and skills) through deeds, processes, and performances for the benefit of another entity or the entity itself. While a service system is such a configuration of different entities or resources that relies on trusted and shared information [12], blockchain provides a platform in which interacting supply chain parties can transparently and precisely interact with each other (i.e., through the definition of coded contracts), facilitating the formation and coordination of service systems.

In this paper, we take a service-oriented perspective and propose a Blockchain-Oriented Service Modeling (BOSM) approach to facilitate the design and development of blockchain-enabled SCQIS. Our approach presents a visual language for knowledge-level modeling. This approach provides a foundation for the encapsulation, coordination, and integration of services in supply chains to measure, analyze, and continually improve the quality of products, services, and processes. We conduct a case study in a dairy supply chain context to illustrate how the proposed modeling approach can be applied to real-world situations to direct the construction of blockchain-enabled SCQIS.

The major contributions of this research are as follows. (1) We propose a service-oriented modeling approach to support quality inspection in blockchain-enabled supply chain quality management, which brings operational service computing to strategic service management in the SCQM domain. It considers the strategic goals and intentions of partner enterprises. (2) The proposed modeling approach bridges the gap between business services and software services in the context of quality management applications. It enables communication between business people in supply chain management and software professionals in service computing. (3) We extend the service-dominant view and reconceptualize the supply chain as a network of service systems. We classify the enterprises' resources into operant resources and operand resources, which separates the causes of quality from the carriers of quality to facilitate the analysis and design of blockchain-enabled quality information systems. (4) We investigate the application of the proposed modeling approach in a dairy supply chain environment, which has significant practical implications.

2. Literature Review

2.1. Supply Chain Quality Management. Quality management in supply chains is widely covered in the operations management and information systems literature. From a supply chain perspective, previous studies often focus on how the contract should be set up to mitigate the moral hazard problem and control supply quality. The supply chain contract mechanisms complementing or supplanting quality inspection often include appraisal, certification, and warranty contracts. For example, Hwang et al. [13] compared the inspection strategy with the certification regime in supply chain quality management. Because an inspection method provides noisy information on a supplier's quality management efforts, the supplier can be induced to perform unwanted/preemptive inspection. Balachandran and Radhakrishnan [14] examined a warranty/penalty contract between the buyer and the supplier based on information from inspections and external failures. The relationships between product architecture, supply chain performance metrics, and supply chain efficiency are also discussed to address the incentive contracting issue in supply chains [15].

From a manufacturing perspective, quality inspection policies are another important aspect in the quality management literature. Inspections are carried out to measure the goods provided by suppliers based on technical requirements. If the goods meet the technical requirements, they can be put into further steps of processing. In the food safety domain, Starbird and Amanor-Boadu [16] found that the effectiveness of supply chain inspection contracts and traceability depends on the accuracy of the inspection, the cost of failing to inspect, the cost of causing a food-borne illness, and the proportion of these costs paid by the supplier. Note that excessive inspection can lead to incurring higher costs than competitors, whereas inadequate inspection can lead to significant inspection errors and failure in quality assurance. Thus, the research on inspection policy is often framed as a mathematical optimization problem to allocate the inspection resources (testing methods) to different stations in production [17].

From an information systems perspective, acquiring upstream and downstream information is also critical for SCQM since quality decision-making needs to be conducted in the scope of the entire supply chain. Zhu et al. [18] considered the quality improvement decisions in a co-operative supply chain and showed that the buyer's involvement can have a significant impact on the profits of both parties. Mayer et al. [19] examined the relationship between product inspection and supplier plant inspection and suggested that a buyer's ability to commit to the intensity of supply inspection is the key to analyzing whether product and plant inspections complement or supplant each other. The rationale is that if the process lies comfortably within the specification limits, most of the product output will conform to the quality standard. Thus, how to leverage the information in supply chains to develop information systems and support quality inspection is an important direction in supply chain quality management.

Information systems have been used in quality management to support decision-making by collecting and analyzing quality information such as customer requirements, quality goal, product/service design, material inspection, process control, storage, shipment, packaging, and delivery [20, 21]. Naveh and Halevy [22] proposed a framework with three levels for handling quality information, with the aim of improving quality and productivity in an organization: control of the process, evaluation of the process, and organizational assessment. Yeung et al. [23] investigated the existence of different patterns of quality information systems and the relationship between such patterns and organizational performance, identifying four patterns of quality information systems: undeveloped, frame, accommodating, and strategic. McMeekin et al. [24] provided a state-of-the-art review of the information systems applied in food safety management, which showed tremendous research and application opportunities for information systems in quality management.

2.2. Blockchain-Enabled SCQIS. There are two major challenges in designing effective SCQIS, namely, information asymmetry in production processes and measuring product quality, for which blockchain technology provides possible solutions [5]. First, information asymmetry is an important obstacle that hinders the development of SCQIS. Wankhade and Dabade [25] analyzed and validated the existence of quality uncertainty against the backdrop of information asymmetry and found that it is important to measure the quality uncertainty due to both information asymmetry and commensurate revenue loss of the company. Hobbs [26] identified three functions of SCQIS, including ex post reactive systems that allow the trace back of affected products in the event of a contamination problem to minimize social costs, ex post systems that facilitate the allocation of liability, and information systems that provide ex ante quality verification. Although information technologies have reduced information asymmetry, Longo et al. [27] conducted an experimental study showing that the companies participating in a supply chain are less inclined to share data when information is sensitive and partners cannot be fully trusted, while blockchain technology can minimize the negative consequences of information asymmetry over the echelons of a supply chain and discourage companies from any misconduct (e.g., counterfeiting data or low data accuracy). Many recent studies suggest that blockchain technology facilitates companies to directly share data with supply chain partners and thereby reduce information asymmetry [28–30]. Moreover, blockchain can effectively guarantee the security and verifiability of information and provides a solution when the supply chain is under attack [31]. Nevertheless, Chen et al. [6] found that the complexity of information systems integration remains one of the major challenges for current blockchain adoption. In other words, although the blockchain technology could enable supply chain transparency to reduce information asymmetry, it is a significant undertaking to integrate multiple datasets and platforms from all supply chain partners into the conceptual modeling of blockchain-based systems.

Measuring product quality is complex, as it requires sufficiently validated scales. Quality inspection is a widely adopted practice in SCQIS to ensure that suppliers provide goods of sufficient quality. Decision-making on quality inspection is a knowledge reasoning process that relates to domain-specific knowledge of product and inspection technologies. How to represent and leverage domain knowledge and information is a major challenge in building SCQIS. Traditional modeling methodologies in management science and operations management mainly focus on mathematical modeling and analysis of conflicting goals between supply chain partners, which lack an effective representation mechanism to model the domain-specific knowledge. To fill this gap, Kim [32] proposed measurement ontology and traceability ontology to represent and reason about quality based on enterprise models. He also introduced measurement ontology for semantic web applications, which represents not only units of measurement and quantities but also measurement concepts such as sampling, mean values, and evaluation of quality [33]. Tan et al. [21] proposed a quality information system structure within the WWW-based intranet infrastructure and discussed the role of quality information systems in the e-commerce integrated environment. However, as indicated by Lau et al. [34], there is a shortage of literature on intelligent systems for quality inspection, including the shortage of system infrastructure models synthesizing the nature of quality measurement. As suppliers may update their defrauding methods daily, the inspection capability, inspection errors, and other related parameters are always dynamically changing. The SCQIS, including the knowledge it captured, needs to evolve according to the dynamic and uncertain world. Blockchain brings a new hope for SCQIS that ensures traceability right across nodes to the involved stakeholders in the value chain and ensures product quality to consumers through a specified measurement of product quality. George et al. [35] proposed a restaurant prototype using blockchain that captures data from various stakeholders across the food supply chain, segregates it, and applies the Food Quality Index (FQI) algorithm to measure product quality. The challenges and difficulties of modeling quality inspection in SCQM require a modeling approach that will overcome the limitations of traditional modeling methodologies and can connect knowledge representation with reasoning mechanisms for decision-making.

2.3. Contemporary Modeling Languages and Techniques for SCQM. Business process modeling and service modeling play a central role in SCQM, and many modeling languages and techniques have been proposed. Essentially, a model is a simplified abstract view of a complex reality, and thus the objective of modeling languages and techniques is to have a representation of some phenomenon to interpret the reality.

Typically, only some aspects of the reality are referred to as a model, and two models of the same phenomenon may be essentially different. This may be due to the differing requirements of the model's end users or due to the modelers' conceptual or esthetic differences and decisions made during the modeling process.

Van der Aalst [36] reviewed business process modeling languages and classified them into three classes: formal languages, conceptual languages, and execution languages. Formal languages, such as Petri Net, are languages with unambiguous semantics and allow for analysis. Conceptual languages are typically informal, do not have well-defined semantics, and do not allow for analysis. Examples of conceptual languages for business process modeling include BPMN (Business Process Modeling Notation), EPCs (event-driven process chains), and UML activity diagrams. Execution languages, such as BPEL (Business Process Execution Language), are concerned with implementation details and are executable for specifying actions within a business process.

Due to the rigorous semantics (making it impossible to leave things intentionally vague) and low-level nature, business users in practice often have problems using formal languages or execution languages and, therefore, typically prefer to use higher-level languages, that is, conceptual languages [36]. BPMN which is commonly used as a representative conceptual language for business process modeling is considered the state-of-the-art in the field and is an industry standard maintained by Object Management Group (see https://www.omg.org). BPMN is commonly used as the basis for business process representation, simulation, and automation, which are important in the contemporary service-oriented architectures common in information technology. The BPMN diagram has been designed for ease of use and understanding, offering a very complex expressive model of business processes. BPMN is a complex language that undergoes constant revisions and extensions. It contains a larger set of constructs in contrast to competing languages and offers a multitude of options for conceptual modeling.

Goal-oriented business process modeling was identified as one of the most important issues in driving business processes towards their goals [37]. It aims to extend traditional business process modeling that addresses the "how" of the business process, which is concerned with efficient execution, to also include the "why" to ensure the effectiveness of business processes [37]. Goal orientation is often regarded as an aspect of an individual's motivation that describes the goals they choose and the methods used to pursue those goals. The goal-oriented view of business process engineering dictates that business goals are the driving force for structuring and evaluating business processes [37]. The i^* framework [38], originating in the field of requirements engineering, provides the best compromise in the field of goal-oriented process modeling [37] as it allows for complex goal classification structures according to goal types and facilitates the modeling of logical, causal, and influencing relationships between goals and business processes.

Nowadays, ontologies and semantic web have been widely adopted to represent services and business processes [39]. A form of ontology represents a common understanding of a domain or domains, including a shared vocabulary and the types or concepts of objects and their attributes and relationships existing in specific fields [40]. In the definition of service-oriented modeling, several existing international standards define ontologies, models, and metamodels to describe evaluated services, including service-oriented architecture modeling language (SoaML), SOA Reference Model (SOA RM), SOA Reference Architecture (SOA RA), SOA Ontology (SOAO), and Web Services Architecture (WSA). Based on ontology representation, a semantic web is not an independent web, but rather it is an extension of the current web, in which information is given a clear meaning so that computers and people can work together better [41]. Based on ontologies, it can understand words and concepts but also the logical relationship between them, which can make communication more efficient and valuable. The main goals of semantic web can be summarized as follows: allowing software agents to automatically obtain information, integrating content from different sources, optimizing search, and realizing trust on the web. Using a semantic web means adopting a brand-new data description and retrieval paradigm [42]. The semantic web concept introduces the use of ontology to construct information in machine-readable format, and it also improves the clarity of understanding difference information [43]. Now there are many languages that can realize semantic description, such as RDF (Resource Description Framework), RDFS (RDF Schema), OWL (Web Ontology Language), and WSMO (Web Service Modeling Ontology) [44].

There are three major problems in applying the existing modeling languages: (1) the complexity of the modeling languages, which makes it costly to teach business users the existing model notations to deal with a particular business scenario [45]; (2) the ontological deficiencies of the modeling languages, which include construct deficit, construct redundancy, construct overload, and construct excess [46]; and (3) the conceptual mismatch between the design and the execution of modeling languages. There is a lack of semantics in conceptual modeling languages, making it impossible to directly execute them [36]. On the other hand, there is a conceptual mismatch between the mapping of conceptual languages and execution languages [47]. These three problems also pose challenges in applying modeling languages and techniques to supply chain quality management, which motivates us to propose a modeling approach for the service-oriented analysis and design of supply chain quality information systems. The modeling approach is based on the extension and simplification of the aforementioned modeling languages and techniques that is simple enough for business users to easily understand while expressive enough to represent and solve the supply chain quality inspection problem and, furthermore, executable to easily implement the quality information system.

3. Motivational Context: A Dairy Supply Chain

To facilitate the discussion in the paper, we put this research in the context of a food supply chain, specifically a dairy product supply chain. Food production is an application domain with high quality requirements, which fits the purpose of our proposed approach.

As shown in Figure 1, the stakeholders along the dairy supply chain include raw milk suppliers, a dairy firm, and end consumers. In dairy product production, the dairy firm often uses HACCP (hazard analysis critical control point) systems to control food safety. The HACCP system is implemented within the dairy firm to test products at critical control points, such as the reception of raw milk, storage in silo tanks, clarification, separation, standardization, pasteurization, and homogenization. Blockchain technology provides an efficient way to track items throughout the supply chain. However, the raw milk suppliers, who control raw milk production, may have different interests from dairy firms. Business process modeling is needed to leverage different stakeholders' available information for quality control. In this paper, we propose a modeling framework that can support the analysis and design of such blockchain-enabled SCQIS.

4. A Service-Oriented Modeling Framework

We propose that effective information system building for blockchain-enabled SCQM should incorporate institutional analysis and adopt a service-dominant business strategy to guide the service-oriented IT modeling. The service-dominant logic offers a different view from the traditional good-dominant logic to model blockchain-enabled SCQIS [48]. Prior studies have suggested that blockchain technology enables the formation and coordination of a service system, particularly in a supply chain context [10, 49]. In this section, we propose a Blockchain-Oriented Service Modeling (BOSM) approach for blockchain-enabled SCQIS.

4.1. Modeling Guidelines.

4.1. Modeling Guidelines. The concept of service and service-oriented modeling has shifted since Lusch and Vargo [48] introduced service-dominant logic. They defined a service as "the application of specialized competences (knowledge and skills) through deeds, processes, and performances for the benefit of another entity or the entity itself." A service-dominant view is inherently a resource-based view of the firm that emphasizes the strategic value of a firm's skill and cultural competencies [50], and it extends the resource-based view by further differentiating operand resources (those on which an act or operation is performed) and operant resources (those that act on other resources) [51]. It shifted the thinking of value from operand resources—usually tangible, static resources—to operant resources—usually intangible, dynamic resources. It is also aligned with the service-oriented architecture developed in information technology [52].

Based on the service-dominant view, we re-conceptualize the supply chain as a network of service systems, each representing a role with distinct resources. Supply chain partners exchange operand resources to acquire services of operant resources, and the blockchain records the exchange of operand resources. Each service has an effect that will lead to the achievement of a goal. In other words, each service exchange takes place because one entity relies on another entity's service to achieve their goal. Operant resources, such as manufacturing skills and knowledge [53], are the focus for service. Technology, including SCQIS and blockchain, can be conceptualized as operant resources that are capable of acting on other resources to create values [54]. The application of operant resources in providing services is associated with several operand resources that can be tangibly recorded in SCQIS, including tangible products (raw materials, prototypes), procedure specifications of service execution, inputs or outputs of the service, the plant, and conditions of service provision. The applications of knowledge and skills in providing service may have their constraints. For example, specific manufacturing plants and conditions may be required to accomplish the provision of a specific service. The constraints of service provision should be modeled as an operand resource. Overall, we derive four design guidelines for blockchain-enabled SCQIS following a service-dominant view (Figure 2).

4.2. A Service Model for SCQIS Requirement Modeling. In this study, we develop a conceptual model to represent the service-oriented modeling in a blockchain-enabled supply chain context. Figure 3 shows the visual representations we give to these concepts and relations. In our modeling framework, a service is built on four classes of concepts, actor, goal, resources, and tasks, and the relationship between the concepts. Figure 4 shows a portion of a simplified ontology for service provision in a supply chain. Because of the complexity of this figure, many links, such as Part of, Instance_of, Object_property and Datatype_property, have been omitted. The ontology is produced at three levels: metaclass level, domain level, and instance level. The entities at the instance level correspond to the instances of domain classes, while the domain classes inherit attributes from the metaclass level. As OWL has flexible modeling ability and powerful knowledge reasoning ability, it will work well in our context involving many supply chain participants with varied knowledge and can be used as our ontology implementation language.

In light of the service-dominant view and guidelines we discussed above, we differentiate resources to operant resource and operand resource in our visual language. Furthermore, a blockchain-enabled SCQIS may be concerned with functional requirements (specific functions or services of the service) and nonfunctional requirements (criteria or quality attributes of the service). Since nonfunctional requirements are usually stated informally and may have conflicts, Mylopoulos et al. [55] proposed the concept of the soft goal for modeling and analyzing nonfunctional requirements. In this research, we also differentiate soft goal and hard goal in our visual language. The service components in our visual language are as follows:

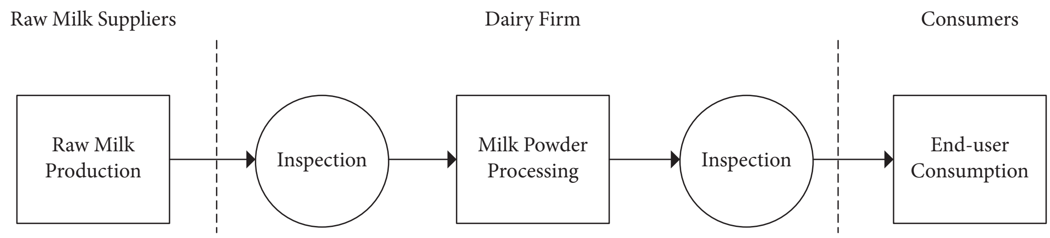

Figure 1: Case illustration.

Guideline 1: *Supply chain entities should be modeled as roles of a service provider possessing operant resources and operand resources.Blockchain-enabled SCQIS should be modeled as entities providing services to fulfill SCQM goals. Entities provide their service in exchange for other entities' service to fulfill their goals.*

Guideline 2: *Service is the application of operant resources to fulfill an achievable goal. Supply chain entities' skills and knowledge, such as suppliers' supply, manufacturers' production and inspection, and consumers' product review, should be modeled as operant resources.Blockchain-enabled SCQIS includes several operant resources, such as distributed ledger and inspection service.*

Guideline 3: *Operant resources are associated with several operand resources. Goods and production materials, such as inputs and outputs in a manufacturing process, procedure specifications, plants and conditions, should be modeled as operand resources. Operand resources can be recorded in a distributed ledger to track and trace the application of operant resources.*

Guideline 4: *The exchange goals can be packaged into smart contracts. The fulfillment of decomposed goals can be used to measure service quality.*

Figure 2: Design guidelines according to the service-dominant view.

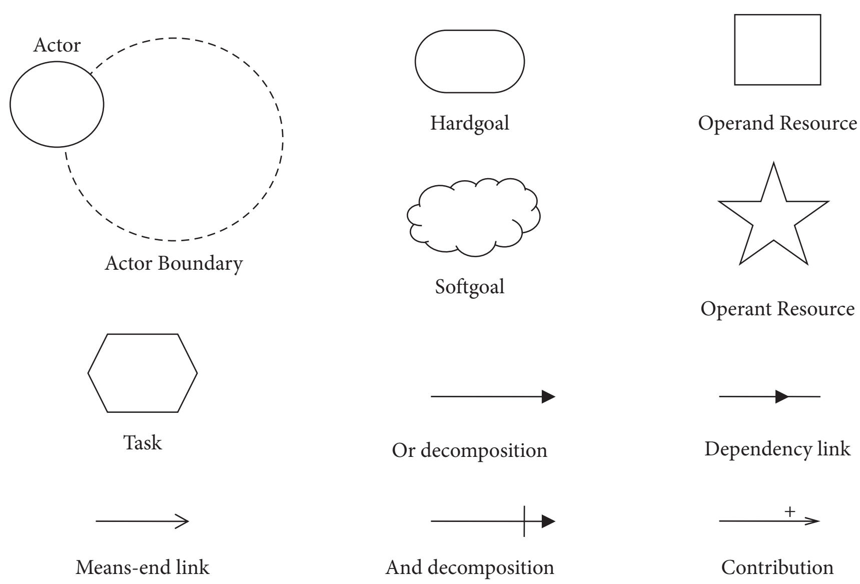

Figure 3: Legend for knowledge-level modeling language.

(1) Actor models a service provider that has strategic goals, possesses resources, and intentionally acts within the service setting. An actor can be a physical, social, or software agent that provides a type of service. In our dairy supply chain example, the actors may include supplier, manufacturer, retailer, consumer, and blockchain-enabled SCQIS.

(2) Goal represents an actor's strategic interests. One actor may rely on another actor to fulfill its goal. For example, a manufacturer relies on suppliers for a good raw material supply. Goal is classified into two categories: hard goal and soft goal. The hard goals can be checked through verification techniques. Soft goals have no clear-cut criteria to check whether they are satisfied or not.

(3) Resources represent the belongings an actor possesses. Resources are further classified into operant resources and operand resources. Operant resources can act on or in concert with other resources to create value, such as manufacturing skills. Operand

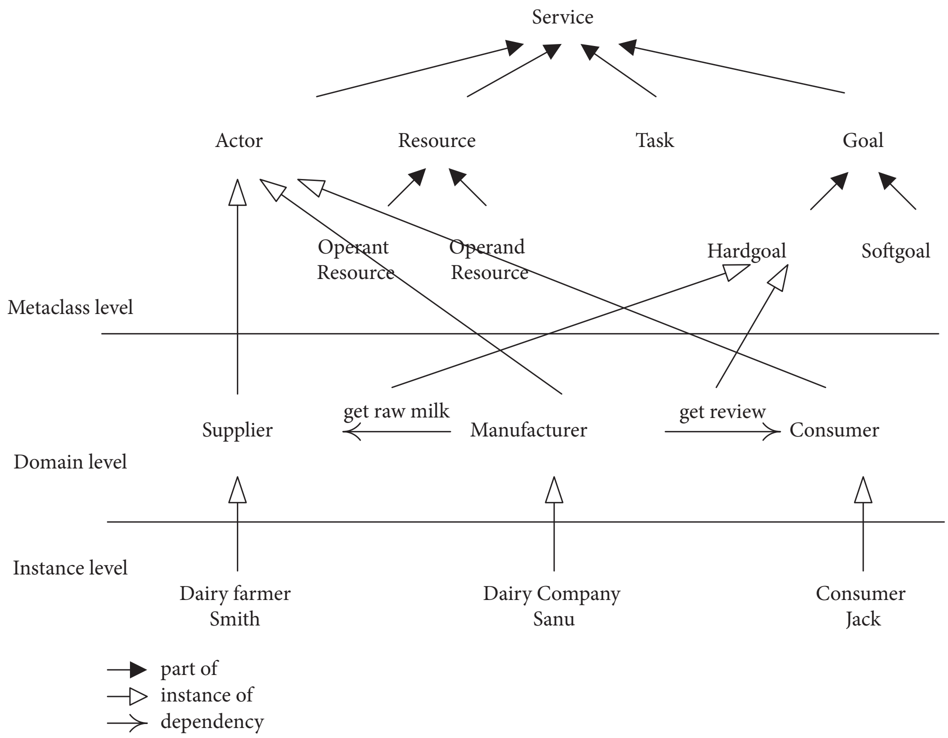

Figure 4: A simplified ontology for SCQM.

resources are resources on which an operation or act is performed to produce an effect, such as goods at different production stages, including the raw material and final product.

(4) Task is an activity that needs to be performed by the actor. The execution of a task can be a means to satisfy a hard goal. A task may be carried out under some constraints. In supply chains, the payment, production, and delivery activities can be modeled as a task. A task may be decomposed into subtasks.

The relationships between the service components consist of traditional association relationships and strategic relationships. Traditional relationships include the Is-part-of association, Is-A association, and AND-OR decomposition. The strategic relationships are specifically adopted from i^* modeling [56], as follows:

(1) Contribution relationship describes how one goal (soft goal or hard goal) contributes to the achievement of another goal. Contributions can be either negative or positive. A positive (negative) contribution means that a goal is helpful (harmful) to the achievement of another goal.

(2) Means-ends relationship shows how the goal (i.e., end) can be fulfilled by the series of tasks (i.e., means) through the manipulation of resources. A goal may be satisfied in several possible ways (means).

(3) Dependency relationship, between two actors, or actors and goals, indicates that one actor depends on the other in order to attain some hard goal. The former actor is called the depender, while the latter is called the dependee.

(4) Configuration relationship, between an operant resource and operand resources, represents how an operant resource is configured by some operand resources as inputs, outputs, procedure, and constraints.

To further explain the service components and their relationships defined in our visual language, we illustrate them in Figure 5. As shown in Figure 5, actors play a central role in our modeling framework. The goal and its subclasses, soft goal and hard goal, are desired by actors. Actors are connected to each other through the dependency relationship, which is a quaternary relationship involving depender, dependee, and dependum (i.e., a hard goal). Actors process the resources to conduct the tasks. Goals (of the actors) can be analyzed to clarify their related decomposition, contribution, and means-ends relations. Contribution is a ternary relationship between an actor and two goals, which identifies that one goal can contribute positively or negatively towards the fulfillment of another goal. Means-ends relation is a ternary relationship defined among an operant resource (the constraints), a goal (the end), and tasks (the means),

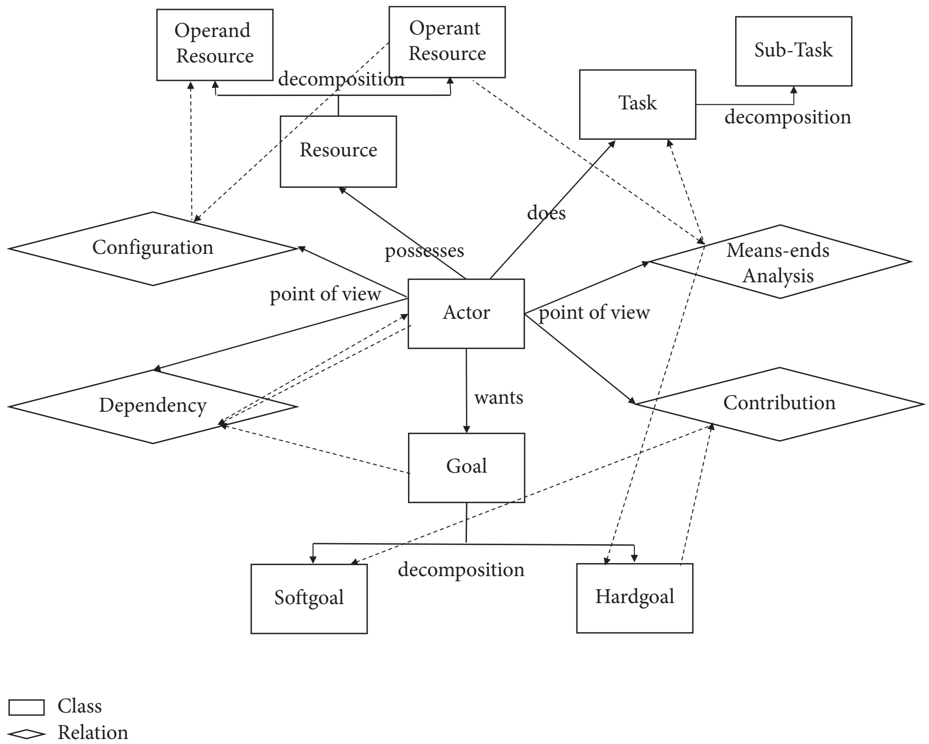

Figure 5: Relationships between the service components.

showing that the actors can conduct tasks with some resources to attain the goal. Configuration is a ternary relationship between an actor, an operant resource, and some operand resources, showing that the operand resources needed to apply a specific operant resource.

4.3. Conceptual Modeling for Blockchain-Enabled SCQIS. With the defined service model, we are able to conceptually model the facts and relationships between service providers in a blockchain-enabled supply chain. The major procedures using our proposed service modeling for knowledge-level modeling contain four steps: (1) actor and goal modeling, (2) service and resource modeling, (3) goal and resource dependence modeling, and (4) blockchain-enabled SCQIS modeling.

First, one needs to identify all the entities participating in SCQM as actors and elaborate each actor's goals. Figure 6 shows examples of a manufacturer and its corresponding goals, in which the dashed circle shows the boundary of each actor. As we can see, the general purpose (soft goal) of manufacturers is to get a qualified supply, which can be decomposed into two soft goals: "trust in the production process" and "trust in the quality inspection."

Definition 1. Actor

An actor is a 5-tuple $< a\_id, G, S, R, T>$, in which a_id is the unique identifier of the service provider, $G = \{g|g$ is a goal in the scenario$\}$, $S = \{s|s$ is a service in the scenario$\}$, $R = \{r|r$ is a resource in the scenario$\}$, and $T = \{t|t$ is a task in the scenario$\}$.

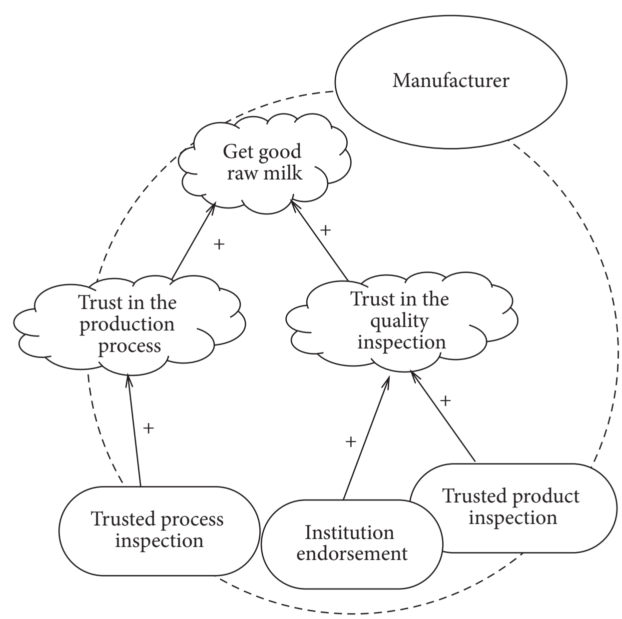

Figure 6: Actors and goals.

According to references [56–58], blockchain-enabled SCQIS can be modeled as a set of actors possessing various goals to fulfill. As the goals for blockchain-enabled SCQIS are ambiguous, we only model the supply chain enterprises in this first step. Blockchain-enabled SCQIS will be modeled after the goal exchange phase.

In the goal modeling phrase, we need to detail the decomposition and contribution relationships among goals. Figure 7 further illustrates such analysis, in which the soft

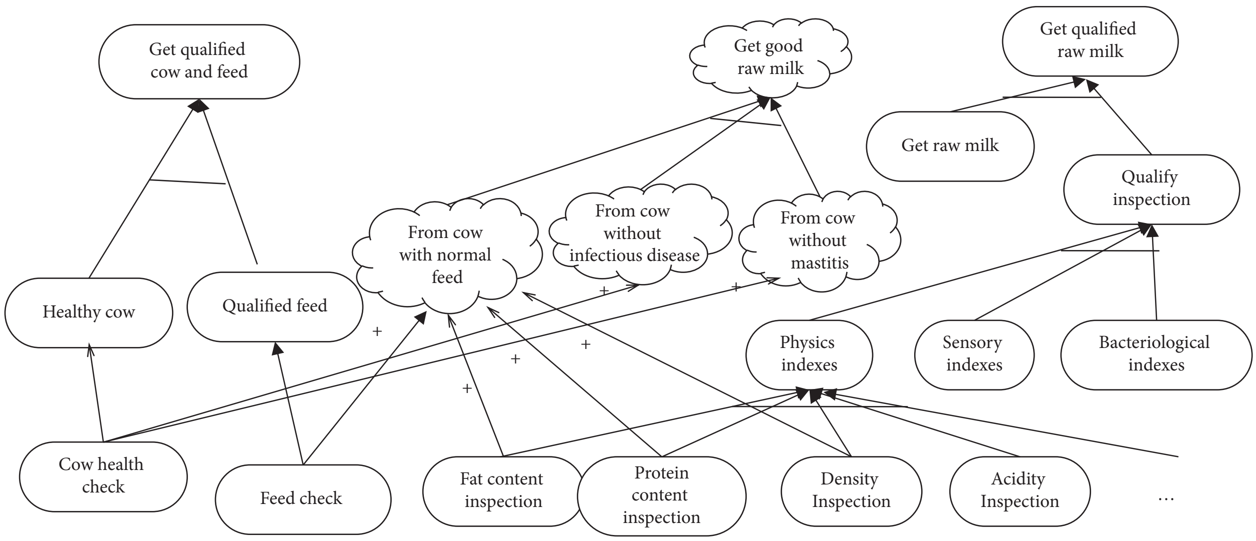

Figure 7: An example of goal modeling.

goal of "get good raw milk" is decomposed to the AND-OR soft goals "from cow with good feed," "from cow without infectious disease," and "from cow without mastitis." The soft goals can be further transformed to explicit and achievable goals (hard goal). In Figure 7, the soft goal "from cow with good feed" can be attributed to the contribution of the hard goals "fat inspection," "protein inspection," and "density inspection." The hard goals of "cow health check" and "feed check" can contribute to the soft goal of "get good raw milk." As such, the hard goal of $g1$ "quality inspection" can be decomposed into $g2$ "physics indexes," $g3$ "sensory indexes," and $g4$ "bacteriological indexes." Such an AND composition of hard goal $g1$ can be represented as a constraint $c1(c1\colon g1 \Rightarrow g2 \wedge g3)$ meaning that if g1 exists, then both $g2$ and $g3$ exist. Here, "$c1$" is the unique identifier of this constraint.

Second, in service and resource modeling, we need to depict the resources possessed by each entity, including operant resources and their related operand resources. A service is the application of an operant resource, while operand resources are explicitly documented or tangible and need to be associated with at least one operant resource. Figure 8 shows an example of the operant resource (a service of raw milk supply) associated with four operand resources (milking procedure, cows, feed, and raw milk).

Definition 2. Service

A service is a 5-tuple $s = <I, O, C, P, T>$. I and O represent the input and output elements (operand resources or other operant resources) accepted by a particular operation and made available after the operation, respectively. C is the set of conditions (including the availability of operand resources or other operant resources) to invoke the operation. P is the description of the operant resource's status, state, operation procedures, or other explicit features. T is the set of tasks carried out to provide the service.

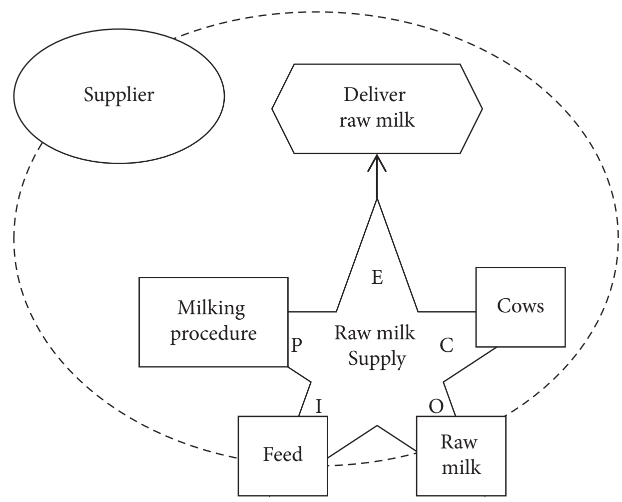

Figure 8: Resource modeling.

After identifying an actor's resources, we are able to model the individual actor's goal exchange and fulfillment. From a service perspective, multiple actors in a supply chain will exchange services to fulfill those goals. As some goals cannot be fulfilled by the actor, we need to connect different actors' goals through service exchange modeling. As we can see in Figure 9, the service of raw milk supply can fulfill the goal of "get raw milk," which should be a manufacturer's goal. In our framework, we allow actors to exchange hard goals fulfilled by others. Figure 9 shows an example in which the manufacturer exchanges her hard goal "get raw milk" for the supplier's hard goal "get paid." The exchange of goals may not be limited to one-to-one relationships. In this step, we began to define entities of blockchain-enabled SCQIS to fulfill the goals from the manufacturer and the supplier. As an example, in Figure 9, the inspection service is defined to fulfill the hard goals of "get cow health check" and "get protein inspection," and the distributed ledger is defined to "get consensus on cow data."

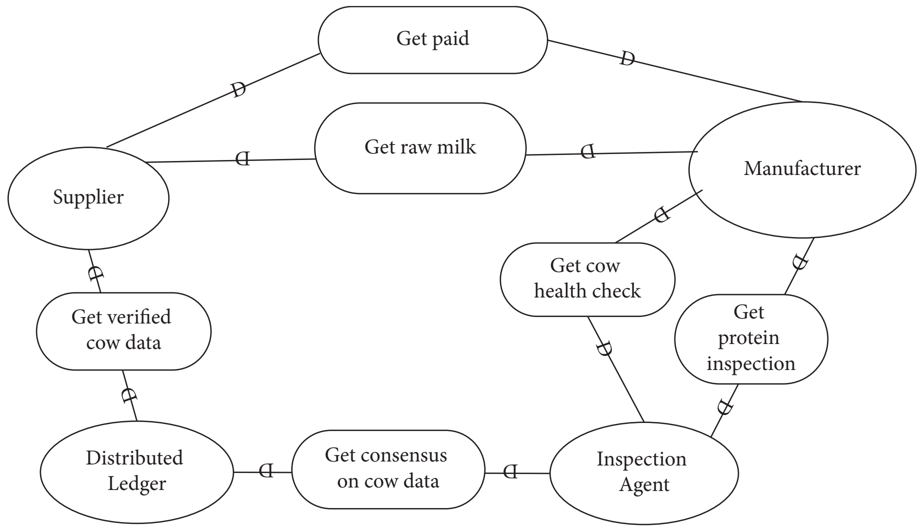

Figure 9: Service exchange modeling.

Up to this point, we need to identify tasks to satisfy the hard goal through the application of blockchain-enabled SCQIS. Now, we can use blockchain-enabled SCQIS to get a full conceptual model to depict the requirements and dependencies of supply chain partners with blockchain-enabled SCQIS. Figure 10 shows a part of conceptual modeling of the distributed ledger and inspection service. For instance, the distributed ledger offers consensus service to get consensus on cow data. Specifically, the consensus service takes cow data from the supplier and verification data from other nodes as inputs, and then, using its consensus algorithm (e.g., PBFT) as the processing procedure and peers' endorsement as constraints, the service will offer mutual agreement on cow data as outputs. It is worth noticing that an actor may offer several services in parallel. For example, the inspection agent can offer different services for different inspection requirements, including protein content inspection and fat content inspection. In Figure 10, we show an example of the Kjeldahl method to provide protein content inspection. It takes raw milk samples as inputs and shows nitrogen percentage as outputs, including a processing procedure of digestion, distillation, and titration. The Kjeldahl method measures nitrogen as a proxy of protein in milk, fulfilling the goal of "get protein inspection."

5. Case Study on Modeling a Blockchain-Enabled SCQIS

To illustrate the feasibility of applying our proposed approach, we use it to build a prototype for a dairy supply chain. We develop a conceptual model for the regular product tracing and quality inspection process in the supply chain, which is partially shown in Figure 11. In this figure, we identify that the quality of the milk is related to the milk production process, that is, cows and the feeding process. Previous literature suggested that the inspection of supplies and the inspection of supplier facilities complement each other [19]. Thus, the quality inspection system needs to identify and record both types of information for decision-making. So when building the quality inspection system, examining the raw milk supply service from the raw milk supplier focuses on the intangible operant resource of "supply" capability, associated with tangible operand resources I as feed, P as milking procedure, C as cows, and O as raw milk.

To ensure the quality of the final product, the dairy product manufacturer needs to check the quality of shipped raw milk. The quality inspection includes various examination indexes such as protein content, fat content, and density, all of which are evaluated by testing methods decided by testing policy. With different levels of inspection technologies and capabilities, the raw milk suppliers could have different potential deception intentions to manipulate the product and dupe some examination attributes. For example, adding melamine can dupe the Kjeldahl method for protein content detection. However, it is not feasible for the dairy product manufacturer (i.e., the buyer) to apply every inspection technology to eliminate the deception due to cost. So the manufacturer needs to decide its testing policy that can discourage a supplier's deception while keeping cost manageable. We build a blockchain-enabled SCQIS to facilitate the manufacturer's decision.

The designed blockchain-enabled SCQIS has enabled a flexible inspection in SCQM. As shown in Figure 12, services are captured by the proposed service modeling framework. The effect of flexible inspection is achieved by the service of contract execution, which depends on a service composition of data collection, data recording, data consensus, and quality inspection. A supply contract between the manufacturer and the supplier defines the flexible testing policy to be executed depending on the data stored in the distributed ledger. For instance, when the distributed ledger gets a record of cow data that indicates it is an unhealthy cow, a protein inspection will be carried out. To reach mutual agreement on such data of an unhealthy cow, the distributed ledger service provider provides a service of data recording via peer-to-peer recording in permitted nodes and a service

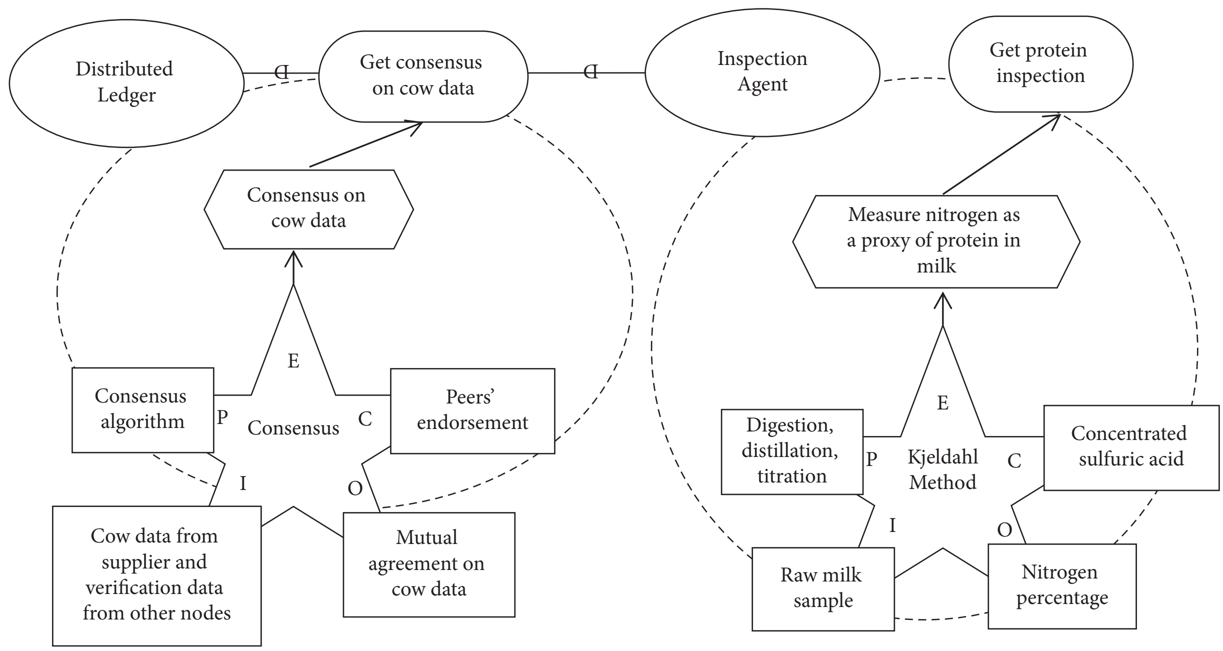

Figure 10: Blockchain-enabled SCQIS modeling.

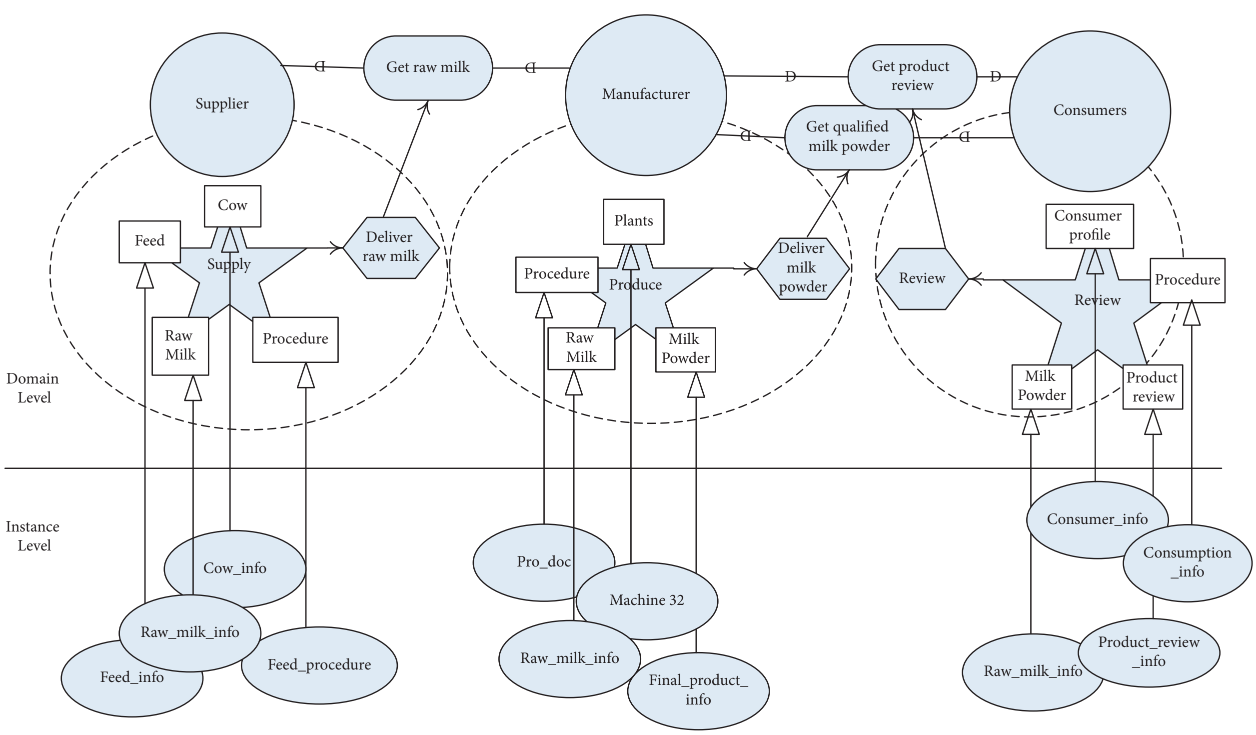

Figure 11: Product and process inspection.

of data consensus by the peer endorsements. The service of data recording, in turn, receives data from the IoT data collecting service.

6. Discussion

6.1. Transforming BOSM into BPMN. As business process models are important for information systems design, we discuss how to transform the proposed model into business process models in this section. Transforming to business process models can help to quickly develop the business process of SCQIS applications and provide a lens through which we can examine the practical significance and feasibility of the proposed model.

First, in the BOSM, participants, tasks, and other elements can be mapped to BPMN. The participants defined in the supply chain, including suppliers, manufacturers, and consumers, can be mapped into actors (represented as pools)

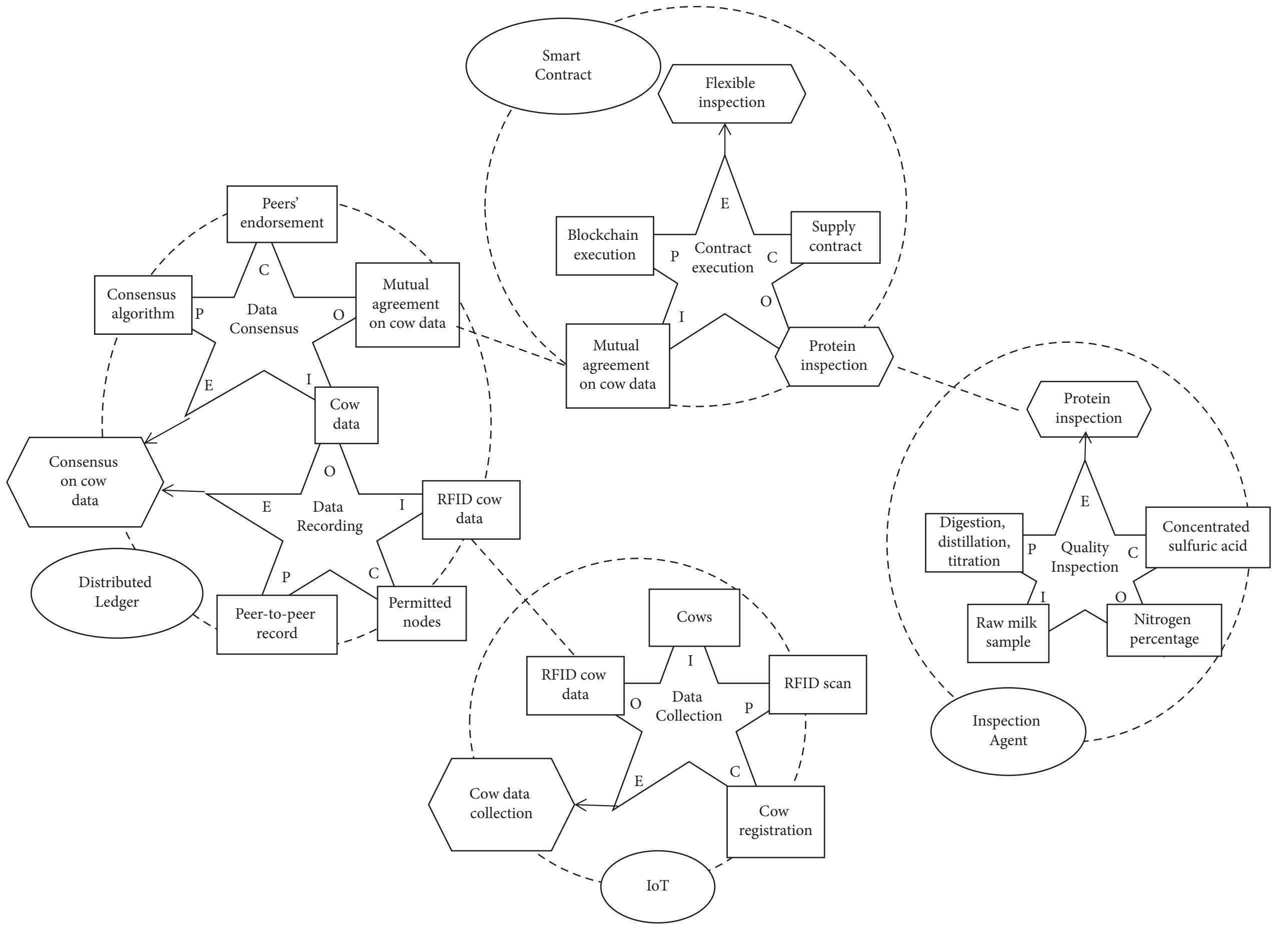

Figure 12: Services in a blockchain-enabled SCQIS.

in the BPMN diagram. However, the pools in BPMN will not automatically become participants, and they all are needed to be verified in the blockchain before they can become nodes in it. Then the behaviors in the BOSM can be mapped into tasks in the BPMN, such as feeding cows and producing milk. All these behaviors will be migrated to a blockchain platform through a consensus mechanism, and relevant information will be shared by all nodes. In addition, the quality inspection in the BOSM can be mapped into a gateway in the BPMN; only qualified products can enter the next round of the supply chain.

In Figure 13, we transform the service of dairy product supply in the BOSM to a BPMN model. As we can see from this BPMN model, all behaviors of the supplier are recorded and uploaded to a blockchain, including cow information, feeding information, production information, and transportation information. When the raw milk is delivered to the manufacturer, the manufacturer can obtain all the information of the raw milk production process from the blockchain. In addition to the inspection of raw milk products themselves, other operand resources can be inspected. This method can not only better detect product problems but also effectively discover the causes of product problems.

In the proposed BOSM approach, we also regard the experiences and opinions of consumers as important. As shown in Figure 14, transforming to the BPMN model shows that after a consumer buys a product, he can get all the product information through the blockchain, ensuring that the finally obtained information on dairy products is authentic and reliable. In addition, consumers can upload their feedback on products to the supply chain for manufacturers' reference, which will enable manufacturers to improve their products and services.

6.2. Comparing Blockchain-Enabled SCQIS with Traditional SCQIS. By transforming from BOSM to BPMN to illustrate the business processes of blockchain-enabled SCQIS, we can find the differences between blockchain-enabled SCQIS and traditional SCQIS in terms of business process implementation. Traditional SCQIS builds an internal information tracing system according to requirements of a central enterprise, mostly with traditional tracing technologies such as bar code, two-dimensional code, or radio frequency identification (RFID), and uploads the tracing data into enterprise data systems [59]. Each enterprise along supply chains has its own database. In blockchain-enabled SCQIS, all enterprises jointly use blockchain as a platform for data sharing and update process data in supply chains in real time through other collaborative technologies such as the Internet of Things, leading to collaboration among enterprises.

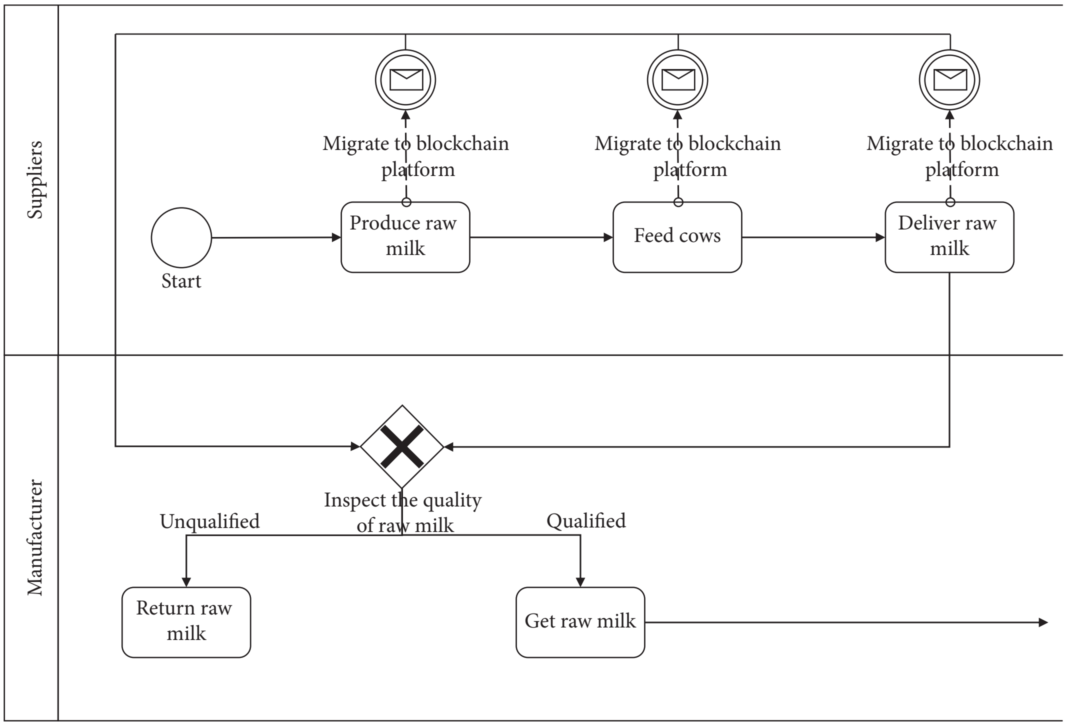

Figure 13: Dairy supply business process model.

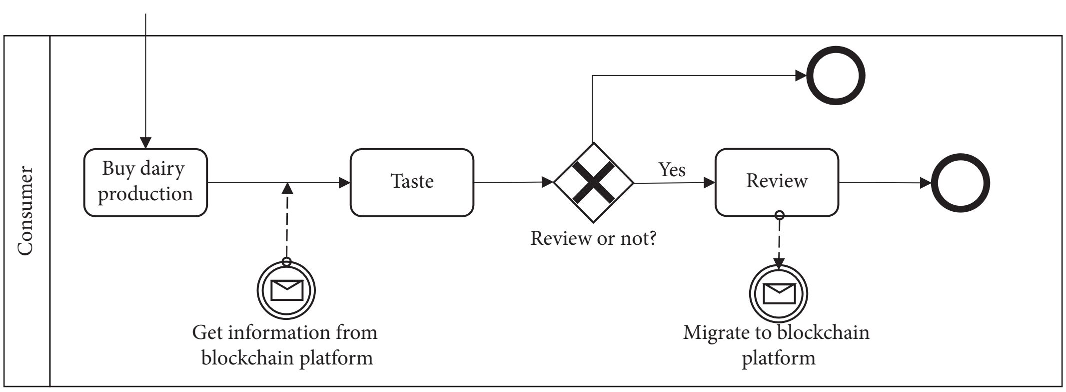

Figure 14: Consumers in the business process model.

Blockchain-enabled SCQIS can effectively improve the traceability of SCQIS and provide better visibility and higher efficiency by creating records in the supply chain grids [60]. Taking dairy supply chains as an example, the interests and needs of participants in the supply chain are different, and some participants may modify their process data privately, resulting in data tempering problems in supply chain management. For example, raw milk suppliers may modify the production time of raw milk in order to sell expired milk. In contrast, with the introduction of blockchain technology, the decentralization of data recording can improve trust-building among raw milk suppliers, dairy companies, and consumers, can minimize negative consequences of information asymmetry along supply chains, and can prevent improper behaviors of various stakeholders (such as falsifying product quality data). Therefore, blockchain can avoid the vulnerability of centralized nodes in establishing trust [61]. In addition, blockchain technology can bring certain security to SCQIS. According to a survey report [62], small organizations are often targeted by network attacks because of their size. Traditional SCQIS relies on communication and coordination at the same time, which may easily attract network attacks on the SCQIS, leading to a fragile situation [59]. For example, SCQIS may face the risk of counterfeit tag attacks and counterfeit product attacks. In contrast, with the introduction of blockchain technology, the blockchain-enabled SCQIS can have certain resistance capability in the face of such attacks [31].

Blockchain-enabled SCQIS has its limitations. Blockchain requires considerable computing power [63]. A blockchain-enabled SCQIS uses a lot of computer energy because it is necessary to keep all nodes updated from time to time to ensure the consensus of traceability. During the transaction process, every transaction needs to be signed by a cryptographic scheme, which will also bring high energy consumption. Without enough computing power, ordinary users may not be able to participate in the blockchain network, which further affects the application of blockchain in SCQIS. In addition, the integration of blockchain with existing systems may bring great challenges to actual business, as not all SCQIS can perfectly adapt to blockchain [64].

6.3. Comparing the BOSM Approach with Traditional Service-Oriented Modeling Approaches. The BOSM approach aims to model services in blockchain-enabled SCQIS, while traditional service-oriented modeling approaches do not take the context of supply chains and features of blockchain into consideration. In comparison with commonly used methods in service-oriented modeling approaches, such as UML [65], the proposed BOSM approach has advantages in the following aspects.

From a semantic perspective, BOSM distinguishes operant resources from operand resources, while traditional service-oriented modeling approaches, such as UML, do not possess such capabilities. Compared with UML, the BOSM method enables us to have a clearer representation of what the SCQIS offers and the conditions to achieve goals. In the knowledge-level modeling, we adopted the goal-oriented modeling technique to focus on the self-interest characteristics of supply chain participants and studied different behaviors under different knowledge and goals. This modeling method allows us to focus not only on the product itself but also on product manufacturing processes and the motivation of major participants, with better explanations for their behaviors.

From a grammar perspective, the BOSM approach reduces complexity of the modeling language, makes it easier for business users to understand, and can effectively reduce the cost of communication between business users to deal with specific business scenarios. In contrast, UML lacks grammatical elements, and its sentences are not coherent [66]. The BOSM approach provides a series of models and operations with graphical explanations, simplifies the modeling language at the knowledge level, and reduces business user's learning costs.

From an implementation perspective, in the process of UML modeling, there are repetitive and useless model elements in SCQM scenarios, which will cause ontology defects in the process of ontology building, including structural defects, structural redundancy, structural overload, and structural excess [46]. In the process of ontology construction, BOSM builds services on four kinds of concepts, that is, participants, goals, resources and tasks, and the relationship between concepts. This method ensures integrity and practicability in the process of ontology construction in SCQM scenarios.

7. Conclusion

SCQM faces several challenges due to the self-interested and distributed nature of supply chains, such as the information asymmetry that exists in the production process and the difficulty in quality measurement. Blockchain-enabled SCQIS holds the potential to alleviate such concerns for SCQM. However, the modeling techniques for developing blockchain-enabled SCQIS have not been fully investigated in literature. This research provides a novel service-oriented modeling framework to fill this gap.

Our proposed BOSM modeling approach enables us to model what the system does and how it does it from both a service management perspective and a service computing perspective. In the knowledge-level modeling process, we follow a service-dominant view and develop a visual language to capture the possible activities of partners. We conducted a case study and developed a prototype in the context of quality inspection in a dairy supply chain to illustrate how the proposed modeling approach is applied to real-world situations.

Our proposed modeling framework under the service-dominant view has several advantages as compared with other modeling perspectives. First, the modeling of operant resources separates the manufacturing process—the cause of quality—from products—the carrier of quality. This separation facilitates the detection of product defects and the inspection of the reason for these defects. Second, the modeling of services' interaction and cocreation of value with supply chain partners encapsulates the system-based view of the blockchain-enabled supply chain. The modeling approach characterizes the supply chain entities with different motivations or interests in acquiring the benefits of specialized competences of others. This perspective offers an instrument to analyze the different interests of supply chain partners as well as the competences they can offer, which is a key element for coordination in a supply chain.

Data Availability

This paper includes a case study in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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