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Ontology of Collaborative Supply Chain for Quality Management

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***Abstract*—**In the highly competitive and rapidly changing global marketplace, independent organizations and enterprises often come together and form a temporary alignment of virtual enterprise in a supply chain to better provide products or service. As firms adopt the systems approach implicit in supply chain management, they must manage the quality from both internal process control and external control of supplier quality and customer requirements. How to incorporate quality management of upstream and downstream supply chain partners into their own quality management system has recently received a great deal of attention from both academic and practice. This paper investigate the collaborative feature and the entities' relationship in a supply chain, and presents an ontology of collaborative supply chain from an approach of aligning service-oriented framework with service-dominant logic. This perspective facilitates the segregation of material flow management from manufacturing capability management, which provides a foundation for the coordination and integration of the business process to measure, analyze, and continually improve the quality of products, services, and process. Further, this approach characterizes the different interests of supply chain partners, providing an innovative approach to analyze the collaborative features of supply chain. Furthermore, this ontology is the foundation to develop quality management system which internalizes the quality management in upstream and downstream supply chain partners and manages the quality in supply chain systematically.

***Keywords*—**Ontology, supply chain quality management, service-oriented architecture, service-dominant logic.

I. INTRODUCTION

NOWADAYS business organizations are facing with an economic environment in which quickly responses should be made to rapid changing customer requirements and the market environment. This need for flexibility has brought independent enterprises come together and forms a temporary alignment of virtual enterprise in a supply chain to provide products or service more flexibly and effectively. As these enterprises come from various geographical locations, and belong to the organizations with different interests, the coordination and integration of business processes involving all these independent enterprises becomes important to improve product quality and service quality to satisfy customer.

The systematic view of supply chain to performance improvement and quality management has been advised more and more in both scholarly work and practice recently. Robinson and Malhotra [1] took a review at the literature of quality management and supply chain management, arguing that quality practice must advance from traditional firm centric and product-based mindsets to an inter-organizational supply chain orientation involving customers, suppliers, and other partners. Foster Jr. [2] shared the position and defined supply chain quality management as a systems-based approach to performance improvement that leverages opportunities created by upstream and downstream linkages with suppliers and customers. They both agree that satisfying customer can only take place when product quality, service, and value are coupled at every node in the supply chain. The quality management functions and activities should be taken beyond enterprise boundaries leverage the competition capability in a supply chain level instead of a firm level.

2008 tainted milk scandal also reveals the importance of quality management from a supply chain perspective. In that event, some suppliers for Sanlu, a well-known Chinese dairy manufacture, diluted milk for profits and added melamine to dupe an inspection for determining protein content, affecting some 294,000 infants and killing six [3]. It was once a pride of the Sanlu that the over 1,000 intra-organization quality tests [4], now becomes a satire for the ignorance of inter-organizational quality management. Chinese consumers and dairy industry have paid a prize, from which the government and producers should learn a lesson and leverage the quality management along the collaborative supply chain.

The coordination and integration of business process along the supply chain is a complicated task because of the different interests the supply chain partners have. Information technology for coordination and communication is a major success factor in forming the virtual organizations to integrate the supply chain [5]. However, there's little research reports or explores the successful information systems building for quality management in collaborative supply chain, more specifically for the quality management including both internal process control and external control of upstream and downstream quality initiatives. This lack can be attributed to the shortage of information systems infrastructure model synthesizing the

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collaborative feature of supply chain into quality management activities. In this paper, we propose an ontology of collaborative supply chain from a perspective of aligning service-oriented framework with service-dominant logic. In this ontology, the collaborative features are investigated along with the entities and relationships along the supply chain.

The rest of this paper is arranged as follows. In the second section, we introduce the ontology building approach, from which the collaborative features along supply chain can be modeled more clearly than traditional perspective. In section 3, we present the ontology. We use a case to demonstrate our model in section 4. And we conclude with contributions in the last section.

II. Ontology Building for Quality Management from A Service Orientation Perspective

In this section, the ontology building approach from a service orientation perspective with the approach of aligning service-oriented framework with service-dominant logic will be introduced with the comparison with traditional ontology building approach.

The word "ontology", taken from Philosophy where it means a systematic explanation of being, has been applied in computer science and information science and become a relevant word for knowledge engineering. Ontology refers to the shared understanding of some domain of interest which can be used as a unifying framework to represent selected phenomena. An ontology necessarily entails or embodies some sort of world view with respect to a given domain. The world view, referred as a conceptualization, is often conceived as a set of concepts (e.g. entities, attributes, and processes), their definitions and their inter-relationships [6].

The ontology building approach used in this research is adopted from [7], which is a modeling approach of aligning service-oriented framework with service-dominant logic. As researchers suggest that ITs alone have not produce sustainable performance advantages [8], but that firms have gained advantages by strategic planning –alignment between IT strategy and business strategy [9]. To bridge service computing and service management [10, 11, 12], Yan et al. [7] propose a modeling approach aligning service-oriented framework with service-dominant logic.

Figure 1 shows the essential strategy alignment of service dominant logic and service oriented Framework and the infrastructure alignment of collaborative infrastructure with service oriented architecture. The foundational proposition of Service-Dominant (S-D) Logic is that organizations are fundamentally concerned with exchange of service – the applications of competences (knowledge and skills) [13]. The business strategy grounded on S-D logic has shifted from thinking about value in terms of operand resources – usually tangible static resources that require some action to make them valuable – to operant resources – usually intangible, dynamic resources that are capable of creating value.

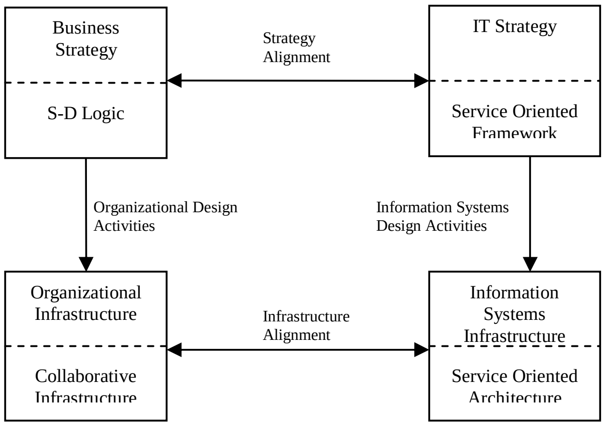

Fig. 1 Strategy alignment and infrastructure alignment

This modeling approach has several advantages to the quality management in collaborative supply chain comparing with traditional modeling perspectives. First, the modeling of operant resource separates the application of manufacturing capability – the cause of quality -- from products – the carrier of quality. This separation facilitates the detection of product defects and the inspection of defects' reason. The firms can focus on the improvement of their manufacturing skills and knowledge, shifting from products as unit of analysis. Second, the customer is modeled as an operant resource, making the consumer a co-producer that expresses quality requirement and supervises the improvement of product quality. Customer orientation, which is one of the foundations of quality management, is expressed by this modeling approach. Third, the modeling of interaction and co-creation of value with supply chain partners encapsulates the collaborative nature and system-based view of supply chain. The modeling approach characterizes the supply chain entities with different motivations or interests of 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 elements for the coordination and integration of the supply chain. Furthermore, the modeling of quality management from a service orientation perspective provides an instrument to analyze and improve the service quality, which covers a broader range to be evaluated than traditional manufactured quality.

III. Ontology of Collaborative Supply Chain

A. Concepts organization

The ontology of collaborative supply chain has been designed to model the foundations for quality management, which has been captured in four key based classes: Role Class, Goal Class, Operant Resource Class, and Operand Resource Class.

Role Class models an entity in the supply chain that has strategic goals and intentionality, representing a physical, social or software agent. For example, several roles, such as supplier, manufacturer, retailer, and consumer, are played in the collaborative supply chain

Goal Class represents roles' strategic interests. One role may

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rely on another role to fulfill its goal. For example, manufacturer relies on suppliers for good raw material supply while relying on consumer to get money. The goal class is an important element to characterize the collaborative feature of supply chain.

Operant Resource Class refers to the resources that can act on or in concert with other resources to create value. For example, the manufacturing skill can be classified as operant resource. Operant resources are employed to act on operand resources or other operant resources.

Operand Resource Class are defined as resources on which an operation or act is performed to produce an effect. For example, because production is carried out on goods transforming from raw material to final product, the goods at different production stages, including raw material and final product, can be classified as operand resource.

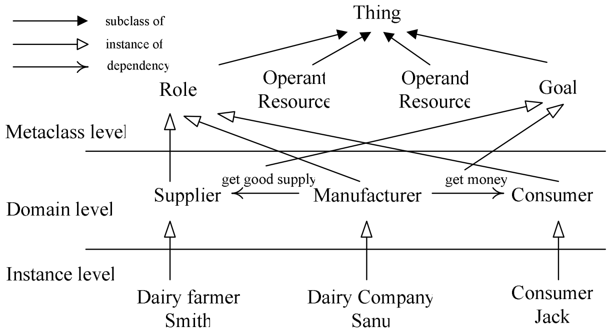

Fig. 2. A partial schema

The ontology of collaborative supply chain is produced in three levels: Metaclass level, Domain level, and Instance level. A portion of semantic schema is shown in Fig.2. Real world instances are represented as entities in instance level. For example, a dairy farmer named Smith, a dairy company named Sanu, and a consumer named Jack. The entities at the instance level correspond to the instances of domain classes, while the domain classes inherit the attributes from metaclass level classes.

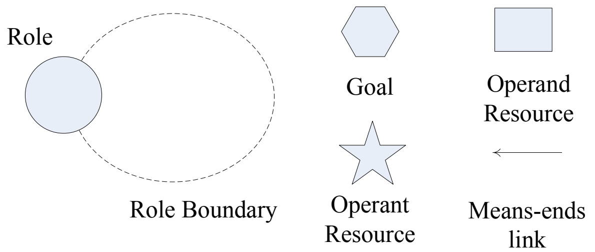

Fig. 3. Legend

It was with the complexity of Fig.2 in mind that many link and domain classes cannot be represented completeness. To better represent the relationship between the four classes, we develop several icons to represent each class as shown in Fig.3. In next section, we will introduce the application of these icons to develop a more complete ontology.

B. *Modeling activities*

Various modeling activities with graphic descriptions contribute to the ontology building of collaborative supply chain, including:

1) Role modeling. The role modeling consists of identifying and analyzing both roles of the supply chain partners and the information system's role. For example, Fig.4 shows the role modeling of manufacturer and consumer.

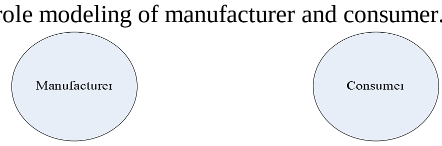

Fig. 4. Role modeling

2) Goal modeling. Goal modeling rests on the analysis of each role's goals. Here we adapt the goal analysis and modeling techniques from i* [14] and Tropos [15], using the means-ends analyze approach to decompose each goal into sub-goals which can be fulfilled by the manipulation of operant resource. In other words, goals are composed by several sub-goals which can be fulfilled by some service. Fig.5 shows examples of decomposing manufacturer's goal and consumer's goal.

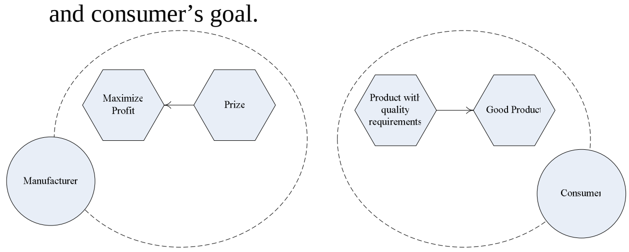

Fig. 5. Goal modeling

3) Operant Resource Modeling. The operant resource modeling consists of identifying and analyzing the operant resource of each role. As shown in Fig. 6, each role may have one or more than one operant resources, which can be characterized by a 5-tuple <I, O, C, S, E>. I and O represent the data elements (operand resources or other operant resources) accepted by the service during invocation and made available after the invocation of this operation, respectively. C is the set of conditions (including available of operand resources or other operant resources) that should be true for this operation to be invoked. P is the documents description of the operant resource's status, states, operation procedures, or other explicit description about the operant resource. E is the effect of this operation, in other words, the fulfillment of a goal.

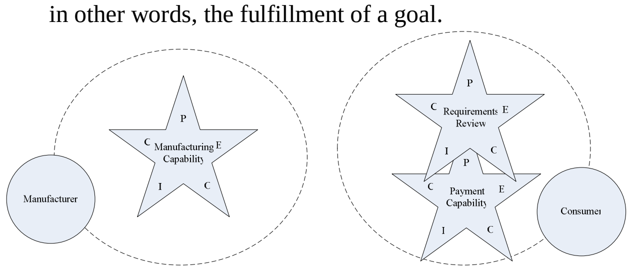

Fig. 6. Operant resource modeling

4) Service exchange modeling. From a service orientation perspective, the application of operant resources – service, is the basis for all exchange. Service is exchanged for service. The role will exchange his service to other roles for

other roles' service to fulfill his goal. To illustrate for an example, as shown in Fig. 7, the manufacturer offers his service – the application of manufacturing capability to fulfill consumer's goal – good product with quality requirements, while the consumer offers his service – the application of payment capability to fulfill manufacturer's goal – Profit with a specific prize. The exchange of service may be not limited on one-to-one relationships. For the above example, the manufacturer may also have other goals such as improve his product, which can be partially fulfilled by consumers' capability of quality requirement review. And also, the goal's fulfillment may not rely on other role's operant resource. For example, the manufacturer's goal maximize profit may be partly fulfilled by its own operant resource – the applications of new manufacturing skills to reduce the production costs.

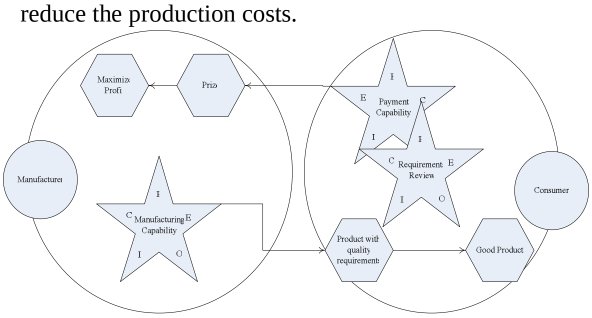

Fig. 7. Service exchange

5) Operand resource modeling. Operand resource modeling consists of identifying and analyzing operand resource of each role. Operand resources are those resources that are data or material that are explicit documented or tangible, and associated with at least one operant resource. Fig. 8 shows examples of operand resources such as raw material, final product, manufacturing plants, and operation procedure.

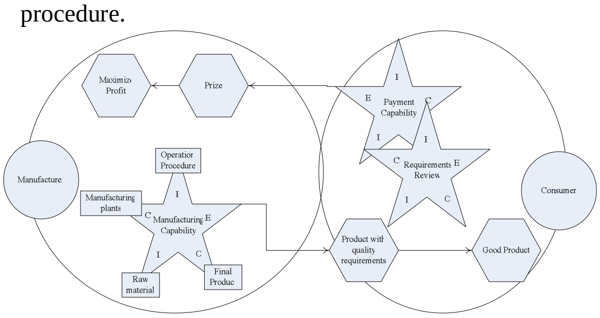

Fig. 8. Operand resource modeling

C. *Conceptual model of collaborative supply chain*

To keep it simple and clear, let's assume there're three roles in a supply chain in dairy industry: a raw milk supplier named Smith, a dairy firm named Sanu, and a consumer named Jack.

Smith, Sanu, and Jack are real world instance represented as entities in instance level, corresponding three roles in the domain class level: Raw milk supplier, Dairy firm, and Consumer. We model some of their goals, such as get payment (shorten as "Payment"), maximize their profit (shorten as "Profit"), get good supply (shorten as "GetS"), buy a good product (shorten as "Product"), a clear recognize of quality requirement of good product (shorten as "QR"). Some of their operant resources are also modeled, such as raw milk supply capability ("Supply"), milk powder production capability ("Produce"), product evaluating capability ("Evaluate"), and payment capability ("Pay").

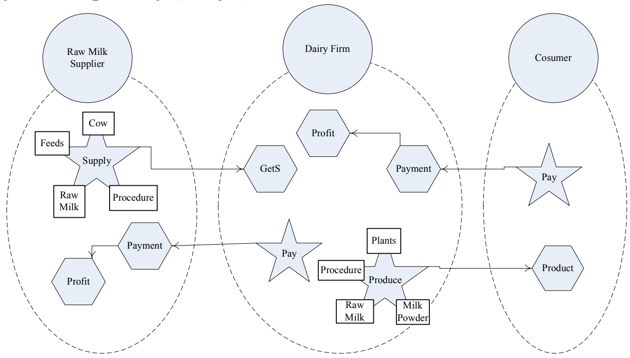

Fig. 9. A partial conceptual model

There are also several operand resources. For example, the supplier has cows and a procedure to milk the cows. Feeds are needed to nourish the cows, and the raw milk is the output of the milking service. Also, dairy firm has manufacturing plants, a procedure of the production, raw milk as the input, and milk powder as the output. Fig. 9 shows a partial conceptual model of the collaborative supply chain, which is sufficient to demonstrate the ontologies of collaborative supply chain.

IV. Case Studies

In this section, we will use several cases from quality management scenarios to demonstrate the ontology is built and facilitates quality management in collaborative supply chain.

A. *Product tracing for quality management*

Traceability or product tracing has been a hot topic of quality management within supply chain especially food supply chain where information of product quality is asymmetry [16] [17] [18]. Our ontology supports the product tracking and tracing by the representation of material flow as operand resources.

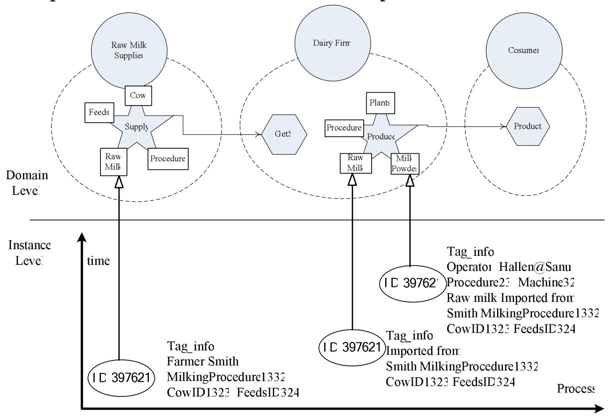

Fig. 10. Product tracking and tracing

As shown in Fig. 10, a specific product as an instance entity corresponds to different domain class with the evolving of time and producing process. The product will be assigned a specific

ID tag to different the product from others. With the support of traceable technology such as RFID, the product can be featured with different information in different process stages. From this information tag, a product can be tracked and traced with information of its suppliers, producing procedures, inspector, and plants.

B. Product inspection and plant inspection

In the collaborative supply chain, the inspection of supplies and inspection of supplier facilities are suggested to complements each other [19]. An information system is needed to identify and record the manufacturing plants and its associated products that have been processed.

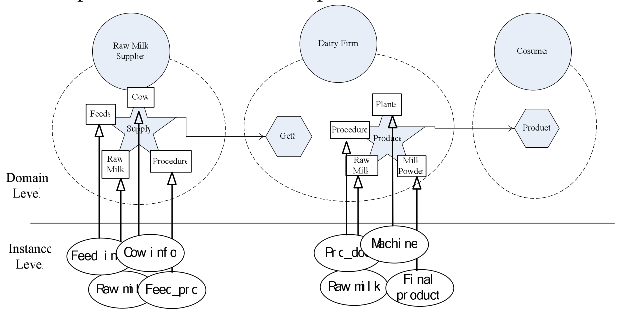

Fig. 11. Product and plant inspection

As shown in Fig. 11, the real world instance of plants and products are modeled as operand resources classes in the domain class level. The inspection of plants and products can be regarded as the inspection of operand resources which are associated with operant resource. Operant resource is the fundamental unit of exchange, which is the determinative element of quality. However, the operant resource is intangible [13]. We can evaluate the operant resource by inspecting its associated operand resource. Because the operand resources are all categorized with its associated operant resource, the product inspection and plant inspection become more targeting for specific operant resources.

C. Customer orientation

Customer orientation is an essential element for a firm to manage quality and sustain competitive advantage [20]. Traditional modeling approaches regard the customer only as a recipient of goods, while our modeling approach regard the customer as a co-producer, acting as a role in charge of several operant resources. For example, the customer has the intangible ability to review the product and evaluate the quality. Their comments on product quality are important resources for improving the product quality.

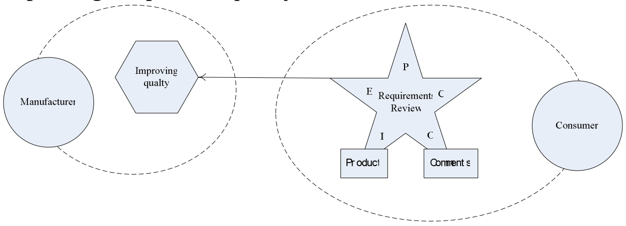

Fig. 11. Customer orientation

For an illustration, Fig.11 models the customer's capability to review the product and comments on new quality requirements as an operant resource. In the service exchanging process, the manufacturer may exchange its manufacturing ability with consumer's payment capability, as well as requirement review capability.

D. Prevention of Quality Deception

In the collaborative supply chain, because of information asymmetry on product quality, moral hazard phenomena exist [21]. Supply chain partners may do quality deception to evade the quality inspection to maximize their profit [22] [23]. Our modeling approach provides an instrument to model the different goals of supply chain partners, including the motivations of quality deception. This approach is a foundation to the prevention of quality deception.

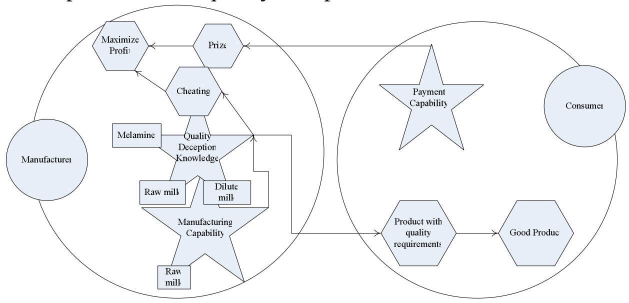

Fig. 12. Quality deception

For example, the manufacturer may have the knowledge of quality deception, such as the melamine knowledge. We model this knowledge as an intangible operant resource which needs melamine and raw milk as operand resources, and the dilute milk with lower quality is the output operand resource. Because the deception knowledge may fulfill the goal of cheating, and cheating is a sub-goal to achieve the goal of maximizing benefit, the manufacturer may do a quality deception in addition to ordinary production.

V. CONCLUSIONS

In this paper, we develop the ontology of collaborative supply chain in a service orientation perspective. This perspective aligns service-oriented framework with service-dominant logic, which facilitates the segregation of material flow management from manufacturing capability management. This ontology provides an instrument provides a foundation for the coordination and integration of the business process to measure, analyze, and continually improve the quality of products, services, and process. Further, this approach characterizes the different interests of supply chain partners, providing an innovative approach to analyze the collaborative features of supply chain. Furthermore, this ontology is the foundation to develop quality management system which internalizes the quality management in upstream and downstream supply chain partners and manages the quality in supply chain systematically.

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