Expert Systems with Applications 37 (2010) 2222–2231

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Ontology of collaborative manufacturing: Alignment of service-oriented framework with service-dominant logic

Jiaqi Yan [a,b,*], Kang Ye [a,b], Huaiqing Wang [b], Zhongsheng Hua [a]

[a] School of Management, University of Science and Technology of China, Hefei, Anhui, China
[b] Department of Information Systems, City University of Hong Kong, Kowloon, Hong Kong, China

ARTICLE INFO

Keywords:
Collaborative manufacturing
Service orientation
Service-dominant logic
Ontology

ABSTRACT

The transformation from a goods-based economy to a services-based economy suggests that firms need to redirect the production and marketing strategy that they have adopted for manufactured goods. A fundamental shift in worldview from goods-dominant (G-D) logic to service-dominant (S-D) logic has been proposed to match the analogous shift in the economy. At the same time, service computing is one of the new information technology (IT) paradigms that is transforming the way corporations organize their information resources. Because of the differences and relationships between service computing and service management, the different role of service computing technologies and service-oriented management logic deserves attentions.

In this paper, we first discuss the relationship between service-oriented architecture and service-dominant logic based on strategic alignment model. Then, we propose an ontology of service-oriented collaborative manufacturing to organize the concepts and knowledge on a fit between service-oriented architecture and service-dominant logic. This ontology provides an understanding of the collaborative manufacturing domain from a service orientation perspective, which is important for successful Business-IT alignment. Furthermore, this ontology will increase the level of automation in service discovery, invocation, composition and interoperation. A case study based on a customized bicycle buying scenario is used to provide a preliminary validation and design evaluation of this ontology. The case study shows the improvement and benefit of our approach, which can lead to promising new business opportunities.

1. Introduction

Over the past several decades, we have witnessed a transformation from an industrial economy to a service economy. The service industry now account for 55% of economic activity in the US,[1] and numerous initiatives for transforming firms from a goods orientation to a service orientation can be found in both business-to-business (e.g. IBM, GE) and business-to-consumer enterprises (e.g. Lowe's, Kodak, Apple) and in some cases entire industries (e.g. Software-as-a-service) (Vargo & Lusch, 2008). It has been calculated that between 30% and 70% of added value in a typical manufacturing company can be attributed to the service component (Machuca, Conzalez-Zamora, & Aguilar-Escobar, 2007).

The growth in services suggests that firms need to redirect the production and marketing strategies that they have adopted for manufactured goods by adjusting them for the distinguishing characteristics of services. A fundamental shift in worldview has been proposed to match the analogous shift in the economy: the shift from Goods-Dominant (G-D) logic to Service-Dominant (S-D) logic (Spohrer, 2008; Vargo & Lusch, 2004, 2008). The most critical distinction between G-D logic and S-D logic is found in the conceptualization of service. In S-D logic, service is defined as the application of competencies (knowledge and skills) for the benefit of another party. It represents a shift 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. Whereas G-D logic sees services as units of output, S-D logic sees service as a process during which something is done for another party. The locus of value creation, then, moves from the "producer" to a collaborative process of co-creation between parties (Vargo & Lusch, 2008).

While the recent marketing literature has emphasized the service-centered view of marketing, service computing is one of the new IT paradigms that is transforming the way corporations organize their information resources. Service computing refers to an emerging area of computing science and engineering that includes a collection of techniques such as service-oriented architectures (SOA), Web services, and associated computational techniques

* Corresponding author. Address: School of Management, University of Science and Technology of China, Hefei, Anhui, China.
E-mail address: jqyan@ustc.edu (J. Yan).

[1] US Census Bureau. http://www.census.gov/.

0957-4174/$ - see front matter
doi:10.1016/j.eswa.2009.07.051

such as security, service choreography and orchestration, and service composition (Zhao et al., 2008). These service computing techniques are developed to facilitate information integration, enable business process automation, and increase the agility of enterprise information architectures. As a representative method of service computing, SOA can be defined as the loose coupling of services, which communicate with each other. It is an information system framework design for linking computational resources on demand to achieve the desired results for service consumers.

In demystifying concepts of ''service'' in service research (Zhao, 2007), we find the differences and relationships between service computing and service management. A ''service'' in a business sense is defined as provider-client interaction that creates and captures value (Services Science: A New Academic Discipline, 2004). Within IT, a service is defined as a self-contained distributed component with a published interface that supports interoperability, is discoverable, and is dynamically bound (Crawford, 2005). The fact that enterprise adopts service computing techniques, such as a firm with SOA architecture, does not mean its production and marketing strategy has transformed to S-D logic. On the contrary, although ''service'' in the computing sense differs from service concepts in the business sense, service orientation embraced by both the business and IT communities presents an unprecedented new opportunity for alignment (Chen, 2008; Zhao, 2007, 2008). S-D logic implies that ''producing'' should be transformed into ''resourcing''. Resourcing allows value creation through collaborative value creation, not only involving the provider and the beneficiary but all parties in a value-creation network. Fundamentally, this is at the heart of SOA (Lusch, Vargo, & Wessels, 2008; Spohrer, 2008;Vargo & Lusch, 2004). Adopting service computing techniques, therefore, facilitates the transformation from G-D logic to S-D logic. In other words, service computing techniques are a means to achieve the goal of service orientation in S-D logic.

Because of the inter-disciplinary nature of service research, attention is rarely paid to the different roles of service computing technologies and service-oriented management logic in the literature. In the service computing community, the goal of service orientation for marketing and production strategy is always ignored. More and more scholars have found this to be a serious problem and interests are emerging in how to bridge service computing and service management (Chen, 2008; Rai & Sambamurthy, 2006; Zhao, 2008; Zhao et al., 2008).

In this paper, we discuss the relationship between service-oriented architecture and service-dominant logic based on a strategic alignment model. We then propose an ontology of service-oriented collaborative manufacturing to organize the concepts and knowledge on a fit between service-oriented architecture and service-dominant logic. This ontology provides an understanding of the collaborative manufacturing domain from a service orientation perspective. In such a perspective, the operant resources rather than the operand resources have become the ingredients constituting the domain. Furthermore, this ontology will improve the customer-centered strategy and facilitate customized service discovery.

The paper is organized as follows. The next section will give an introduction to the related background. We will then discuss collaborative manufacturing based on the strategic alignment model, in which several building guidelines are given for building the ontology of collaborative manufacturing. In Section 3, an ontology for service-oriented collaborative manufacturing is proposed. We will give a preliminary validation and design evaluation of this ontology by a case study. In Section 5, implications and discussions are presented, leading finally to the conclusion.

2. Related work

2.1. Collaborative manufacturing within a service-oriented framework

Manufacturing systems are evolving towards a more agile environment in which quick responses can be made to rapidly changing customer requirements and the market environment. Increasing numbers of manufacturers today focus only on their core competencies, while depending on other firms to provide the complementary expertise and resources. In collaborative manufacturing, designated individuals and organizations, both internal to the manufacturing enterprise and extended to its suppliers, customers, and partners, work together for mutual gain.[2] The concept of virtual enterprise is defined to describe such a temporary alliance of independent organizations and enterprises that come together to share skills and resources to better provide a product or service (Camarinha-Matos & Afsarmanesh, 1999). The application of grid computing in collaborative manufacturing also brought a new manufacturing model – the Manufacturing Grid. The aim of the Manufacturing Grid is to effectively utilize resources distributed in heterogeneous systems and different places, through which users can obtain various manufacturing services as conveniently as obtaining information from the internet. The above approaches for collaborative manufacturing[3] have many common characteristics and are even complementary. Since the distributed and intelligent features of collaborative manufacturing, agent technology has been recognized as a promising paradigm for collaborative intelligent manufacturing systems. For the application of agent-based systems in intelligent manufacturing, readers could refer to (Shen, 2006) for thorough literature review.

The service-oriented computing paradigm is transforming traditional workflow management from a close and centralized control system into a worldwide dynamic business process. Service-oriented collaborative manufacturing has attracted several scholars' attentions. Wang, Shen, and Hao (2006) present an agent-based workflow model in which agent-based technology provides the workflow coordination at both inter-and intra-enterprise levels while Web service-based technology provides infrastructures for messaging, service description and workflow enactment. To better solve the product variety problem in mass customization, Yan (2008) propose a conceptual model of collaborative manufacturing. In this model, collaborative manufacturing is adopted to deal with the limitations in the traditional value chain and production paradigm in mass customization. To support networked manufacturing enterprises from external manufacturing, a promising service to use web-based manufacturing resources for product development is developed (Dong, 2008). Shen (2007) propose an agent-based service-oriented integration architecture to leverage manufacturing scheduling services on a network of virtual enterprises. Tso (1999) also provide a framework for the development of a collaborative service-support system, which is an object-based tool designed to provide a service to manufacturing firms within an enterprise information network. A flexible manufacturing service is also encapsulated to build a virtual fab in a highly specialized and uncertain environment, and a novel dynamic manufacturing service provision mechanism is designed to compose objects flexibly among various manufacturing services to allow flexible service composition (Su, Guo, & Chang, 2005). An agent-oriented dynamic trading mechanism and supply chain integration for the electronic marketplace is developed to support

[2] White Paper: Collaborative Manufacturing Explained from MESA Internal. http://www.mesa.org/, 2004.

[3] Holonic Manufacturing Systems (HMS) is also a highly distributed control paradigm. However, the HMS project addresses problems at a lower level, that is, intra-company, while this paper focuses on the collaboration of several companies.

the collaboration and reduce times-to-market and costs (Ghenniwa, Huhns, & Shen, 2005).

Reviewing the existing research on collaborative manufacturing, there is still a lack of analysis of the alignment of the collaborative manufacturing information infrastructure with business needs. That is, how to "orchestrate" the lower level IT infrastructure services to deliver the desired business-level customer services or to effect service innovation that increases a firm's performance (Chen, 2008).

2.2. Service-dominant logic

In their seminal article published in the Journal of Marketing, Vargo and Lusch (2004) called for the evolution of a service-dominant logic in marketing to replace the goods-dominant logic that has taken hold over the last two centuries. Vargo and Lusch define a service as "the application of specialized competences (skills and knowledge), through deed, processes, and performances for the benefit of another entity or the entity itself" (Vargo & Lusch, 2004). Grounded in a historical analysis of the evolution of marketing thought in economic and business literature, the authors suggest considering a service orientation as a fundamental philosophy or strategy of doing business. The service-dominant logic implies that marketing is a continuous series of social and economic processes that is largely focused on operant resources with which the firm is constantly striving to make better value propositions than its competitors. It has also been pointed out that this "new logic" can be found in such diverse academic fields as information technology (e.g. service-oriented architecture), human resources (e.g. organizations as learning systems), marketing (e.g. service and relationship marketing, network theory), the theory of the firm (e.g. resource-based theories), and so on, as well as in practice (Spohrer, 2008).

The S-D logic quickly sparked a lively debate among scholars: for example, in the 2006 compendium by Lusch and Vargo on S-D logic; in *The transition from product to service in business markets*, a special issue of Industrial Marketing Management 37 (2008); in the special issue titled *On the service-dominant logic of marketing: insights from The Otago Forum* in Marketing Theory (2006), and Bolton (2004). Of course, S-D logic does not remain unchallenged, and the academic debate about its evolution and impact is far from being closed.

2.3. Ontology

The word "ontology" is taken from Philosophy, where it means a systematic explanation of being. During the last decade, the word ontology became a relevant word for the Knowledge Engineering community. 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 (Uschold & Gruninger, 1996).

The research of ontology has attracted a great deal of interest and has been applied in conceptual modeling, knowledge engineering, semantic web, and so on. In conceptual modeling, ontology research has been used as a tool to better understand the domain (Wand & Weber, 2002; Weber, 2003); for example, virtual markets have been conceptually modeled via an ontological approach (Wang, 1997). By creating rich ontologies, this method provides a comprehensive framework for analysis, design, and investment decisions involving future virtual market information systems. Ontology is also an effective instrument for supporting the knowledge management. Ku, Wensley, and Kao (2008) use an ontology-based approach to analyze complex knowledge management issues in the context of the integrated circuit industry, which helps managers deal with the problems relating to communication, knowledge sharing and management issues occurring in joint venture projects. For knowledge integration during product lifecycle activities, Chen et al. use ontology to capture the product lifecycle knowledge, and develop a novel mechanism for integrating ontology-based product lifecycle knowledge to effectively integrate the heterogeneous product knowledge which is distributed among different enterprises during a product lifecycle (Chen, Chen, & Chu, 2009). Wang et al. use ontology to understand the knowledge about news in financial instrument markets and in building trading models on news in the financial instrument markets (Wang, 2008). On the basis of the ontology, it helps to build trading models based on news in the financial instrument markets, and facilitate design and development in this domain. Ontology web language is a popular modeling language, which, for example, could be used to model the product configuration knowledge (Yang et al., 2009). Furthermore, ontology could be used to support agent-based systems or web service, such as ontology-supported website models (Yang, 2008), which will increase the level of automation in service discovery, invocation, composition and interoperation.

3. The fit of service-oriented architecture and service-dominant logic for Collaborative manufacturing

Researchers suggest that ITs alone have not produced sustainable performance advantages, but that firms have gained advantages by strategic planning-IT integration (Powell & Dent-Micallef, 1997). Prior research reported that the alignment between IT strategy and business strategy is critical for enhanced results in many types of organizations (Chan, 1997), and has been a top concern for Chief Information Officers (CIOs) for the past two decades (Tallon, 2003).

In 1993, the Strategic Alignment Model (SAM) was introduced to establish a conceptual framework stressing strategic fit and functional integration between elements in the business and IT domains in an organization (Henderson & Venkatraman, 1993). The effective transition of strategy into infrastructure requires considering the information system design to create an effective information system infrastructure, as well as organizational design to create an effective organizational infrastructure. We contend that effective information system building for collaborative manufacturing

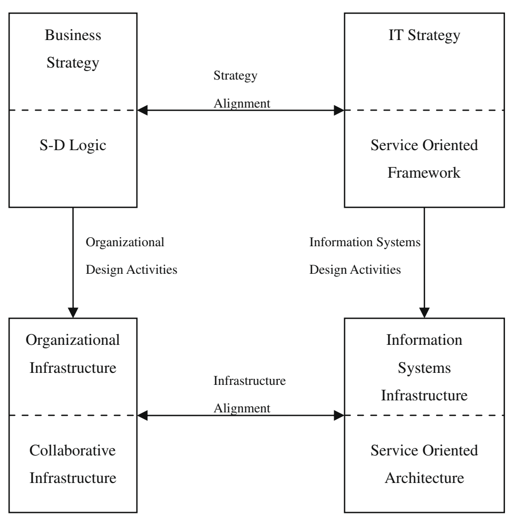

Fig. 1. Strategy alignment and infrastructure alignment.

should incorporate institutional analysis from organization studies. Fig. 1 shows the essential alignments between S-D logic and service-oriented framework and between collaborative infrastructure and Service-Oriented Architecture (SOA), which is adapted from prior studies (Hevner, 2004; Henderson & Venkatraman, 1993). Based on the strategic alignment model, we will analyze the collaborative manufacturing infrastructure and its corresponding information systems infrastructure by aligning IT strategy with S-D logic, and propose several design guidelines for an ontology of service-oriented collaborative manufacturing.

As defined in S-D logic (Vargo & Lusch, 2004, 2008), "service" – the application of operant resources – is the fundamental basis of exchange. The specialized skills and knowledge are the fundamental source of an enterprise's competitive advantages. The comparative ability to cause desired change drives competition. Enterprises can offer their applied resources for value creation and collaboratively (interactively) create value following acceptance of value propositions, but cannot create and/or deliver value independently. Therefore, the intangible, dynamic, operant resources (Madhavaram & Hunt, 2008) – manufacturing capability in manufacturing enterprise and distribution capability in transportation enterprise–should be the focus for encapsulated service. Variants of manufacturing capabilities coexist as respective core competitive capabilities of each enterprise. The polymorphism property of capabilities leads to differentiated and customized service.

Guideline 1: Manufacturing capability and distribution capability should be modeled as operant resources, which are fundamental units for service exchange. Variants of these capabilities coexist as the core competitive capability of each enterprise.

In S-D logic, the customer is not just the recipient of goods, but always a co-creator of value. Interactivity, integration, customization, and co-creation are the hallmarks of a service center view (Lusch et al., 2008; Vargo & Lusch, 2004). Because a service-centered view is participatory and dynamic, service provision is maximized through an iterative learning process on the part of both the enterprise and the consumer. Therefore, in collaborative manufacturing, the customer should be modeled as an operant resource, which is an active participant in relational exchanges and coproduction. It is the customer who integrates resources to create value (a value that is uniquely determined by the customer).

Guideline 2: The customer should be modeled as an operant resource, which is an active participant in relational exchanges and coproduction.

Jim Spohrer et al. emphasized the important role of the operant general contractor, which makes proposals, agreements, and value judgments (Spohrer, 2008). The general contractor function may be a separate service system or may operate as a committee of contractors – but without such an operant resource, there is no service system. Therefore, in collaborative manufacturing, the general contractor should be modeled as an operant resource which acts on behalf of the customer to make the proposal, agreement, and value judgments, but the customer may not need to know details of the constituent contractors.

Guideline 3: A general contractor should be modeled as an operant resource to make the proposal, agreement, and value judgments.

In S-D logic, goods (both durable and non-durable) derive their value through use – the service they provide (Vargo & Lusch, 2004). Thus, tangible products can be viewed as embodied knowledge or activities. Wheels, pulleys, internal combustion engines, and integrated chips are all examples of encapsulated knowledge, which informs matter and in turn becomes the distribution channel for skill application (i.e. services). Therefore, in collaborative manufacturing, goods (raw manufacturing material, prototypes) are distribution mechanism for service provision.

Guideline 4: Goods are a distribution mechanism for service provision.

The above analysis offers a new perspective, or we can say "world view", to understand the collaborative manufacturing domain. This is the fundamental for our ontology. In S-D logic, the supply chain is reconceptualized as a network of service systems, each representing distinct (mostly operant) resources. In this context, these service systems consist of manufacturing services, distribution services, and customers. Here, to keep our ontology simple and clear, we simplify the expression of distribution service, which is similar and could be derived as manufacturing service. In the next section, we will introduce the ontology of collaborative manufacturing for bicycle production.

4. Ontology for collaborative manufacturing

4.1. Concepts organization

The ontology of collaborative manufacturing has been designed to model the foundation for collaborative manufacturing applications, which have been captured in four key based classes: Consumer Class, Product Broker Class, Manufacturing Service Class, and Distribution Service Class. A portion of semantic schema of collaborative manufacturing for customized production is shown in Fig. 1. The subset of the overall collaborative manufacturing schema is sufficient to demonstrate the ontology. Because of the complexity of this Figure, many links, such as Is_a, Instance_of, Object_property and Dataype_property, have been omitted.

The ontology which represents the collaborative manufacturing for customized production is produced in three levels: Top Level, Domain Level, and Instance Level. The entities at the instance level correspond to the instances of domain classes, while the domain classes inherit the attributes from top level classes. For example, the object property of finalGoodDelivery (omitted in Fig. 2) at the instance level is an instance of a domain level object property "delivery final product", which in turn inherits from the top level object property.

Web Ontology Language (OWL)[4] could be used to model collaborative manufacturing from this schema. The main advantages of OWL, which has become a widely used ontology language for the semantic web, are efficient reasoning support, sufficient expressive power, and convenient expression.

In the OWL DL definition, the subClassOf keyword shows the inheritance hierarchies of domain concepts. Table 1 shows an example of OWL definition of the class Manufacturing_Service_Class.

A property defines a directed relationship from a resource to a resource or literal. OWL distinguishes two types of properties: (1) an "object property" linking a resource to a resource, and (2) a "datatype property" linking a resource to a literal. Tables 2 and 3 show the examples of the OWL DL definitions of object property and datatype property.

For instance, the datatype property of a manufacturing service class consists of a serviceDescription, a stateDescription and an operationDescription. The serviceDescription describes the general information about the service type, while the stateDescription defines the internal state maintained by the manufacturing service. The operationDescription is a 4-tuple $\langle I, O, P, E \rangle$ (adapted from Kumar, Neogi, & Ram, 2006), I and O represent the data elements accepted by the service during invocation and made available after the invocation of this operation, respectively. P is the set of conditions that should be true for this operation to be invoked. E is a set

[4] OWL Web Ontology Language Reference, Available on line as http://www.w3.org/TR/owl-ref/.

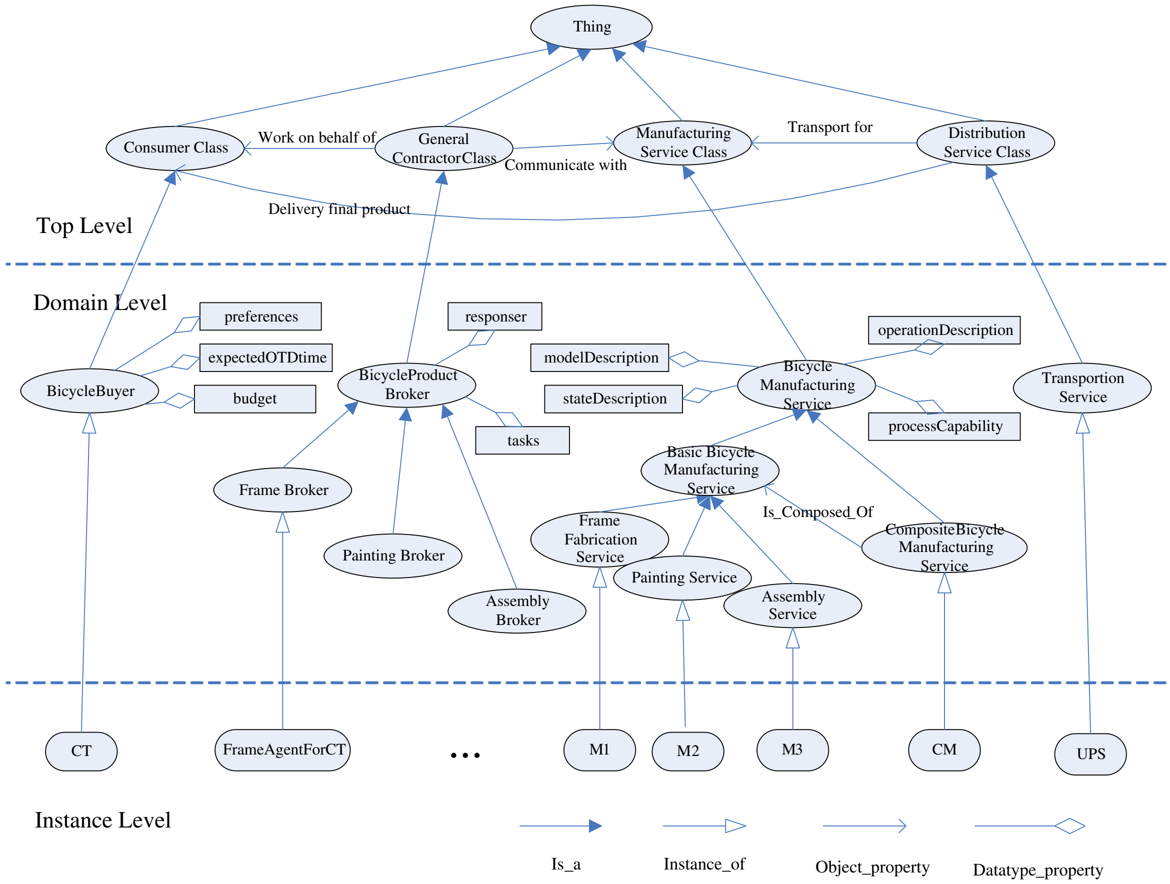

Fig. 2. A partial schema.

Table 1
The OWL DL definition of class Manufacturing_Service_Class.

```
<“http://www.semanticweb.org/ontologies/2008/1/Ontology1203231410743.owl#Manufacturing_Service_Class”>
    <owl:Class rdf:about=“#Manufacturing_Service_Class”>
    <rdfs:subClassOf rdf:resource=“&owl;Thing”/>
    <owl:disjointWith rdf:resource=“#Distribution_Service_Class”/>
    <owl:disjointWith rdf:resource=“#Consumer_Class”/>
</owl:Class>
```

Table 2
The OWL DL definition of ObjectProperty communicate_with.

```
<!–http://www.semanticweb.org/ontologies/2008/1/Ontology1203231410743.owl#communicate_with–>
    <owl:ObjectProperty rdf:about=“#communicate_with”>
    <rdfs:range rdf:resource=“#Manufacturing_Service_Class”/>
    <rdfs:domain rdf:resource=“#Product_Broker_Class”/>
</owl:ObjectProperty>
```

Table 3
The OWL DL definition of DatatypeProperty state_description.

```
<!–http://www.semanticweb.org/ontologies/2008/1/Ontology1203231410743.owl#state_description–>
    <owl:DatatypeProperty rdf:about=“#state_description”>
    <rdfs:domain rdf:resource=“#Manufacturing_Service_Class”/>
    <rdfs:range rdf:resource=“&xsd;string”/>
</owl:DatatypeProperty>
```

of expressions that become true after the invocation of this operation. For the painting service in the scenario, the ⟨I, O, P, E⟩ in simplified form would be ⟨Frame, ColoredFrame, ColorTypeAvailable, AssemblyServiceAssigned⟩. The datatype property and object property of class have the features of inheritance and polymorphism, which we will further discuss in the next section.

4.2. Manufacturing service customization

The characteristics of inheritance and polymorphism in the ontology can be used to provide differentiated and customized manufacturing services to different clients. As manufacturers focus on their core competencies, the manufacturing services they provide would evolve to incorporate changing requirements. Interface inheritance can be effectively applied to enable different clients of the same service to experience different behaviors. More specifically and formally, the customized manufacturing service can be defined as follows:

- Given a basic Manufacturing Service MS_{basic} and the customized Manufacturing Service $MS_{customized}$, $MS_{customized}$ may add new properties to the set of properties inherited from MS_{basic}. For instance, there are new properties of processCability, shapeProcessingCapability, productionCapability, sizeProcessingCapability in the Frame Fabrication Service.
- $SD_{customized} \supset SD_{basic}$, where $SD_i = stateDescription(MS_i)$, the customized service can maintain additional state elements (such as the specific machine working state), apart from the state inherited from the base service.
- The IOPEs of each operation Description are obtained as follows:
  - $I_{customized} \supset I_{basic}$, the customized service can accept additional input elements, apart from the input elements inherited from the basic service.
  - $O_{customized} \supset O_{basic}$, the customized service can make more outputs available than its basic service.
  - $P_{customized} \rightarrow P_{basic}$, the precondition of basic service could be more general than those of the customized service. There may be more preconditions should be satisfied to offer customized service.
  - $(E_{customized} \nleftarrow E_{basic}) \wedge (E_{customized} \nrightarrow E_{basic})$, the effects of the basic service and the effects of the customized service are independent. This is because the customized service may behave completely differently than the basic service.

4.3. Manufacturing service composition

Collaborative manufacturing is achieved by manufacturing service composition. In Fig. 3, the class of Composite_Bicycle_Manufacturing_Service has an ObjectProperty of "is_composed_of" to the class of "Basic_Bicycle_Manufacturing_Service", which demonstrates the service composition. In the former scenario, given a set of Manufacturing Services, M1, M2, M3, ..., Mn, a composite manufacturing service CM can be defined using the following axioms:

- The state of a composite manufacturing service is a union of the state maintained by its component services. $SD_{CM} = SD_1 \cup SD_2 \cup \ldots \cup SD_n$, where SD_{CM} = stateDescription (CM) and SD_i = stateDescription (MS_i).

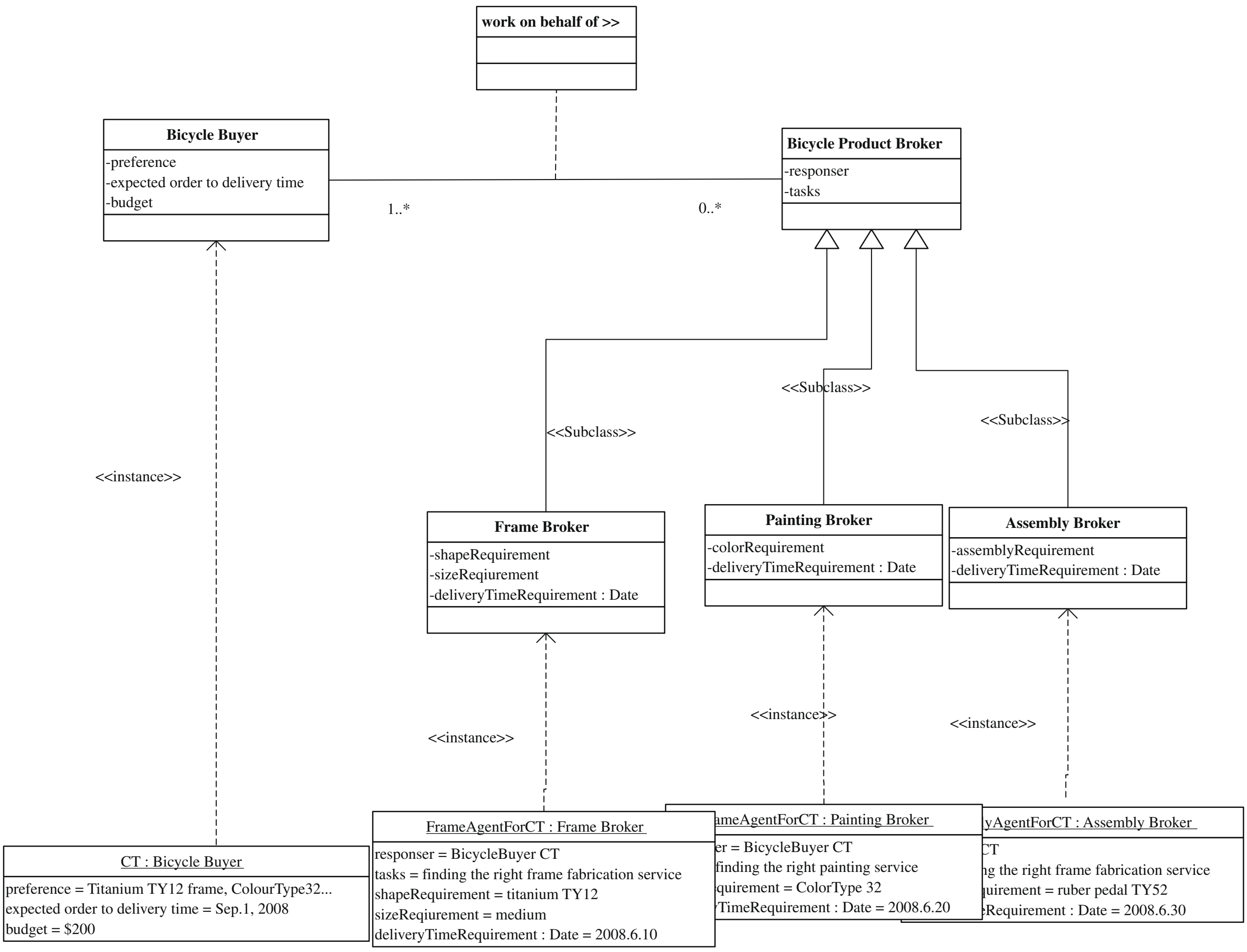

Fig. 3. Service proposal.

- The operationDescription OD_{CM} of the composite manufacturing service is composed from those operationsDescription OD_i of Mi, $i = 1, 2, 3$. The workflow is $OD_{CM} = OD_p \oplus OD_q \oplus OD_r$, where " $\oplus$" stands for composition.
- $\langle$I, O, P, E$\rangle$ of OD_{CM} are composed as below:
  - $I_{CM} = \{e | e \in I_j \wedge e \notin O_k, j, k = p, q, r\}$, where $(I_j \in OD_j) \wedge (O_k \in OD_j) \wedge (k \prec j)$. This means that the set of input elements of OD_{CM} consists of input elements of all the operations involved minus those which occur as output elements of a preceding operation in the workflow.
  - $O_{CM} = \{e | e \in O_j \wedge e \notin I_k, j, k = p, q, r\}$, where $(O_j \in OD_j) \wedge (I_k \in OD_j) \wedge (j \prec k)$. This means that the set of output elements of ODCM consists of output elements that become available through all the operations involved minus those which occur as input elements of a preceding operation.
  - $P_{CM} = \{t | (t \in P_j) \wedge (\neg \exists s, (s \rightarrow t) \wedge (s \in E_k)), j, k = p, q, r\}$, where $(P_j \in OD_j) \wedge (E_k \in OD_k) \wedge (k \prec j)$. This means the set of preconditions of OD_{CM} consists of all the preconditions of the operations involved minus those which get satisfied by effects of a preceding operation involved.
  - $E_{CM} = \{t | (t \in E_j) \wedge (\neg \exists s, (s = \neg t)), j, k = p, q, r\}$. This means the set of effects of OD_{CM} consists of all the effects of operations involved after canceling out those that negate each other.

5. Case study

In this section, we will evaluate our ontology-based on the Interact-Service-Propose-Agree-Realize (ISPAR) model of service systems interaction episodes (Spohrer, 2008).

5.1. Customized bicycle buying scenario

Let us suppose a customer ("CT") is interested in acquiring a customized bicycle. In collaborative manufacturing, each producer focuses on their core competence, so as to minimize their production costs and market mediating costs. The major components are the manufacturing service grid, web services, and the product broker. The manufacturing service grid is composed of manufacturers all over the world which focus on their core manufacturing competence and offer special manufacturing services. Information on manufacturing services is encapsulated in the grid web services, with a well-defined interface using WSDL, a standardized messaging protocol such as SOAP, and a service address that a requester can use to access the service. The web services can be accessed and invoked programmatically by software agents. The product broker is such a software agent that can help consumers customize their product and find the corresponding manufacturing services.

Based on the ISPAR model, we have the scenario and transaction illustrated below.

5.1.1. Stage 1: Proposal

The customer "CT" wants his customized bicycle, so he asks for help from the product broker. With its domain knowledge, the product broker tells CT the three generic production tasks which bicycle production requires: frame fabrication, frame painting, and bicycle assembly – these tasks must be performed in this order. Frame fabrication consists of cutting and welding tubes into unfinished frames. Frame painting consists of adding color to frames and applying decals and a final clear finish. In assembly, components such as wheels, tires, suspension, and drive trains are attached to the finished frame. Firms need not collocate operations.

The consumers could add additional production tasks to meet his individual needs. In this scenario, we assume that CT accepts the three production tasks and does not need any additional production tasks. After the product development verification, the product broker separates into three sub-brokers: frame broker, painting broker and assembly broker. All three sub-brokers are responsible to the bicycle production broker, and propose a value co-creation interaction to the corresponding manufacturing

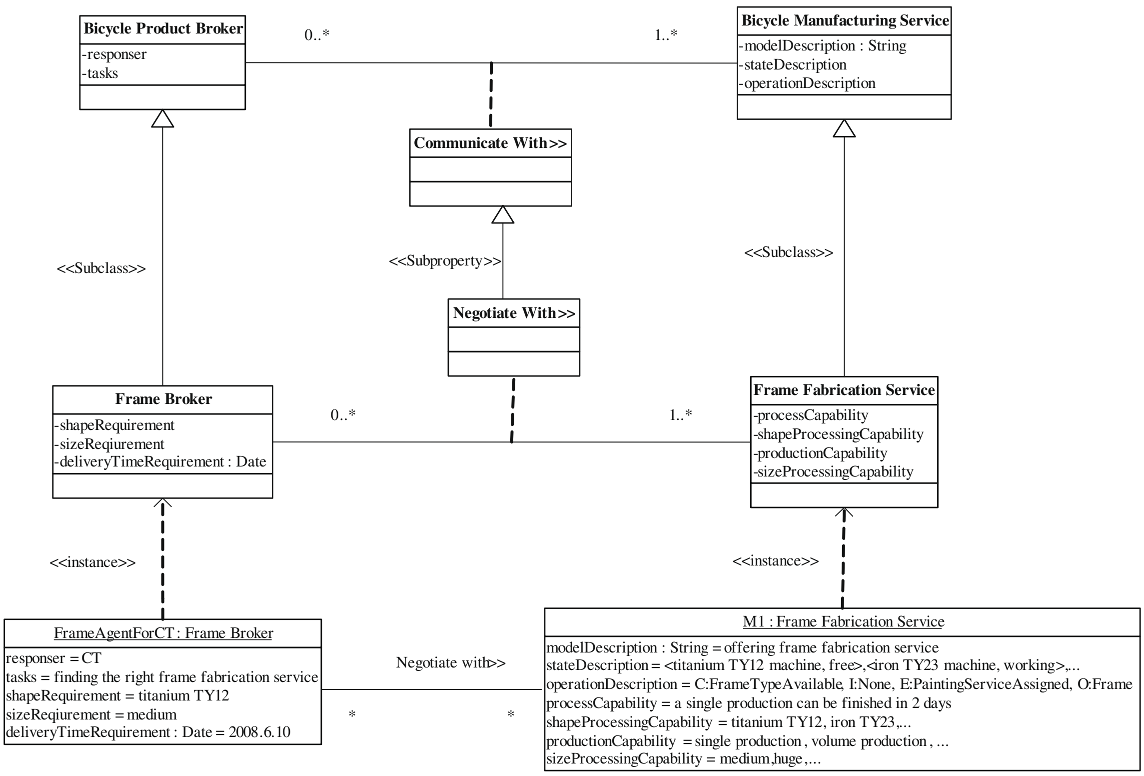

Fig. 4. Service agreement.

services. Fig. 3, which is from a part of the ontology in Fig. 2, expresses the service proposing stage in UML.

5.1.2. Stage 2: Agreement

Searching and finding the corresponding manufacturing services in the Manufacturing Grid services, the product broker will offer a set of available manufacturing services for frame fabrication, painting and assembly. CT could either choose the services himself according to his preferences or delegate the product broker to choose the preferred services by the agent's negotiation.

As we can see in Fig. 4, FrameAgentForCT acts on behalf of customer CT, communicates and negotiates with the Frame Fabrication Service. The inheritance and polymorphism in the ontology provide a differentiated and customized manufacturing service, such as M1 can produce titanium TY 12, iron TY23, etc. These kinds of frame may be produced by M1 alone, which is the core competitive competence of M1. The Frame Agent and Frame Fabrication Service M1 reach an agreement on frame shape, frame size, delivery time, and so forth.

5.1.3. Stage 3: Realization

After the completion of the manufacturing services verification, M1, M2, M3 will carry out their manufacturing services in order. The physical distribution network (such as UPS) will be responsible for the transportation among M1, M2 and M3. After the production, the finished customized bicycle will be shipped to CT.

As shown in Fig. 5, the composite bicycle manufacturing service CM is realized by the collaborative production of M1, M2, and M3. The stateDescription, IOPEs operationDescription of CM could also be derived. Of course, distribution service is also an important ingredient, but here we omit the expression of this part to keep the model simple and clear.

5.2. Discussion and implications

Perhaps the most notable distinction of collaborative manufacturing between traditional G-D logic and S-D logic can be seen in the conceptualization of "manufacturing". In S-D logic, manufacturing is defined as the application of manufacturing skills and knowledge for the benefit of another party. It represents a shift 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 resource that are capable of creating value.

Table 4 provides a comparison of ontologies between G-D and S-D perspectives. As we can see, the ontology from the S-D perspective focuses more on the intangible, dynamic resource – manufacturing skills and knowledge. The changes in the roles of producers, customers, and goods provide the following benefits:

- Producers can focus on their core competencies. By efficiently producing its core product, the producer could reduce both the production cost and the response time. Manufacturing skills and knowledge are the fundamental source of an enterprise's competitive advantages. This is in line with competitive advantage theories.

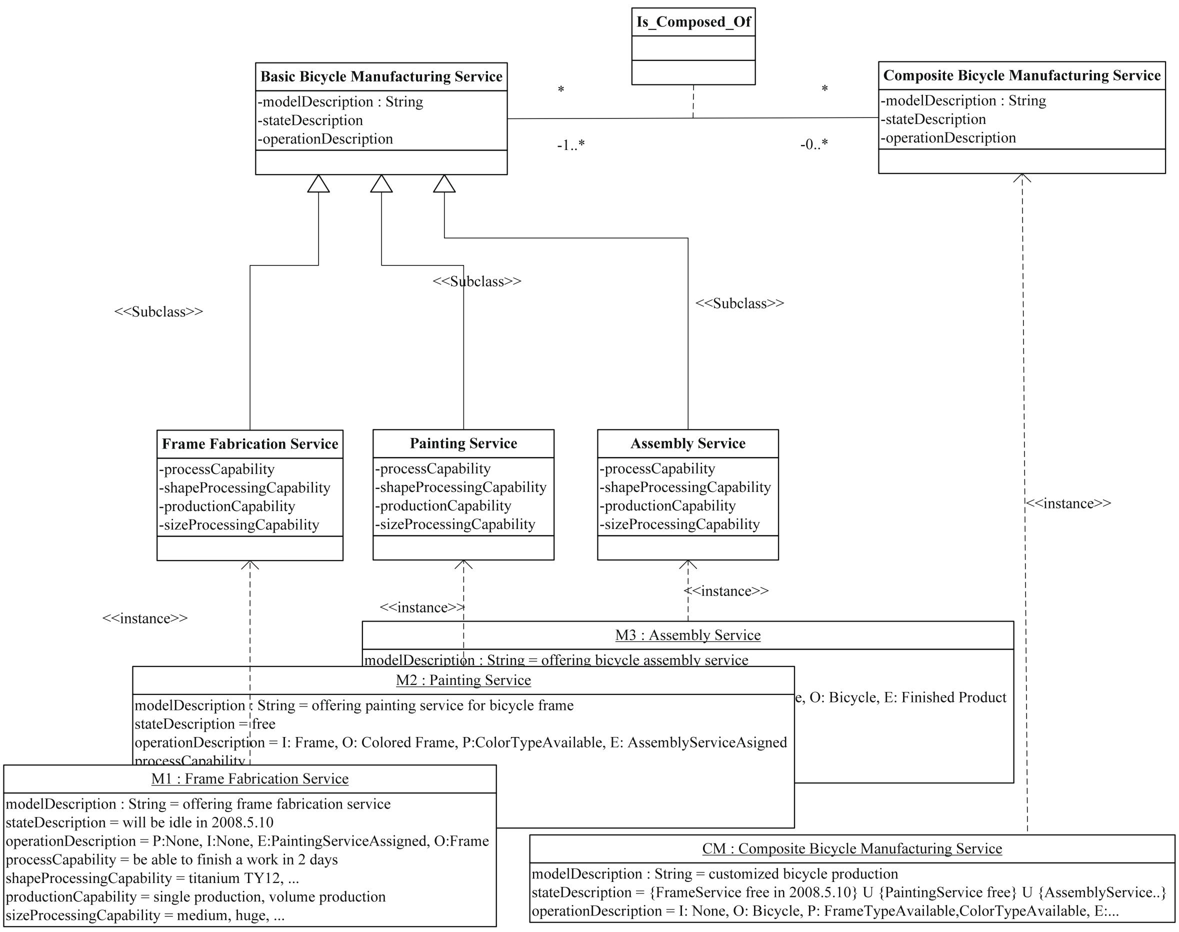

Fig. 5. Service realization.

Table 4
Comparison from two perspectives.

	Ontology from G-D perspective	Ontology from S-D perspective
Role of Producers	The producers are the value creator of goods; Products are the fundamental source of the enterprise's competitive advantage	Focus on their core competencies; Manufacturing skills and knowledge are the fundamental source of the enterprise's competitive advantage; The enterprise cannot deliver value, but only offer value propositions
Role of Consumers	The customer is the recipient of goods; The customer is an operand resource	The customer is a co-producer of service; The customer is primarily an operant resource, only functioning occasionally as an operand resource
Role of Goods	Goods are operand resources and end products	Goods are transmitters of operant resources (embedded knowledge); They are intermediate "products" that are used by other operant resources (customers) as appliances in value-creation processes

- Consumers, as innovators, achieve greater freedom to "design" their product. More product variety could be produced by collaborative manufacturing, and customers could even design their products by adding new production tasks. This approach would benefit the system actualization of mass customization and customers as innovators (von Hippel & Katz, 2002).
- Goods become a distribution mechanism for service provision. Tangible products can be viewed as embodied knowledge or activities. Through collaborative production using this knowledge and skills, which are the competitive competencies of each enterprise, the product variety problem in mass customization could be better resolved (Yan, 2008).

6. Conclusion

Business/IT alignment is critical for the successful implementation of information systems, and has been a top concern for CIOs. Previous researches have highlighted the importance of shared domain knowledge for alignment (i.e. top managers' knowledge of IT, IT managers' knowledge of business) (Burn & Szeto, 2000; Kearns & Sabherwal, 2006). However, because of the wide disparity of definitions and poor shared domain knowledge in the service engineering domain, the business-IT alignment for service-based systems exists as a challenge in the service industry. This paper presents an ontology from the alignment of Service-Oriented Framework with S-D logic, which provides an understanding of the collaborative manufacturing domain from a service orientation perspective. This is the major contribution of the ontology – it serves as a guide for understanding the shared domain knowledge-based on business-IT alignment.

By creating a rich and precise ontology model of collaborative manufacturing, our work provides a solid framework for IT/IS practice. The development of this ontology provides the basis for formal study of the Business-IT alignment for service orientation. The application of our ontology can lead to better understanding of the concepts, and pinpoint the likely cause of confusion. Furthermore, combining the work on the semantic web and service grid computing, this ontology will increase the level of automation in service discovery, invocation, composition and interoperation.

One potential limitation of this study is related to the fact that the business-IT alignment has multi-layer approaches, while our study focuses on the alignment via information systems architecture. However, we believe that such work will provide a solid foundation for future work on the alignment via governance or communication, such as solving the problems of collaborative scheduling and forecasting, and the secure and coordinated exchange of information contained in the collaborative manufacturing process.

Acknowledgement

This research is supported by City University of Hong Kong Strategic Grant (Grant Number 7002244), PRC's International Cooperative Research Project (Grant Number 2006DFA73180), and grants from National Natural Science Foundation of China (Grant Numbers 70725001 and 70821001).

References

Bolton, R. N. (2004). Invited commentaries on evolving to a new dominant logic for marketing. *Journal of Marketing, 20*(1), 73–79.
Burn, J. M., & Szeto, C. (2000). A comparison of the views of business and IT management on success factors for strategic alignment. *Information and Management, 37*(4), 197–216.
Camarinha-Matos, L. M., & Afsarmanesh, H. (1999). *Infrastructure for virtual enterprise*. Norwell, MA: Kluwer Academic Publisher.
Chan, Y. E. et al. (1997). Business strategic orientation, information systems strategic orientation, and strategic alignment. *Information Systems Research, 8*(2), 125–150.
Chen, H.-M. (2008). Towards service engineering: service orientation and Business-IT alignment. In *41st annual Hawaii international conference on system sciences (HICSS2008)*.
Chen, Y.-J., Chen, Y.-M., & Chu, H.-C. (2009). Development of a mechanism for ontology-based product lifecycle knowledge integration. *Expert Systems with Applications, 36*(2), 2759–2779.
Crawford, C. et al. (2005). Toward an on demand service-oriented architecture. *IBM Systems Journal, 44*(1), 81–107.
Dong, B. et al. (2008). Web service-oriented manufacturing resource applications for networked product development. *Advanced Engineering Informatics, 22*(3), 282–295.
Ghenniwa, H., Huhns, M. N., & Shen, W. (2005). eMarketplaces for enterprise and cross enterprise integration. *Data and Knowledge Engineering, 52*(1), 33–59.
Henderson, J. C., & Venkatraman, N. (1993). Strategic alignment: Leveraging information technology for transforming organizations. *IBM Systems Journal, 32*(1), 4.
Hevner, A. R. et al. (2004). Design science in information systems research. *MIS Quarterly, 28*(1), 75–105.
Kearns, G. S., & Sabherwal, R. (2006). Strategic alignment between business and information technology: A knowledge-based view of behaviors, outcome, and consequences. *Journal of Management Information Systems, 23*(3), 129–162.
Kumar, A., Neogi, A., & Ram, D. J. (2006). An OO based Semantic Model for Service Oriented Computing. In *IEEE international conference on services computing (SCC'06)* (pp. 85–93).
Ku, K.-C., Wensley, A., & Kao, H.-P. (2008). Ontology-based knowledge management for joint venture projects. *Expert Systems with Applications, 35*(1–2), 187–197.
Lusch, R. F., Vargo, S. L., & Wessels, G. (2008). Toward a conceptual foundation for service science: Contributions from service-dominant logic. *IBM Systems Journal, 47*(1), 5–14.
Machuca, J., Conzalez-Zamora, M., & Aguilar-Escobar, V. (2007). Service operations management research. *Journal of Operations Management, 25*(3), 585–603.
Madhavaram, S., & Hunt, S. D. (2008). The service-dominant logic and a hierarchy of operant resources: Developing masterful operant resources and implications for marketing strategy. *Journal of the Academy of Marketing Science, 36*(1), 67–82.
Powell, T. C., & Dent-Micallef, A. (1997). Information technology as competitive advantage: The role of human, business, and technology resources. *Strategic Management Journal, 18*(5), 375–405.
Rai, A., & Sambamurthy, V. (2006). Editorial notes – the growth of interest in service management: Opportunities for information systems scholoars. *Information Systems Research, 17*(4), 327–331.
Services Science: A New Academic discipline. In *IBM Research Report*, 2004.
Shen, W. et al. (2006). Applications of agent-based systems in intelligent manufacturing: An updated review. *Advanced Engineering Informatics, 20*(4), 415–431.
Shen, W. et al. (2007). An agent-based service-oriented integration architecture for collaborative intelligent manufacturing. *Robotics and Computer-Integrated Manufacturing, 23*(3), 315–325.
Spohrer, J. et al. (2008). The service system is the basic abstraction of service science. In *Hawaii international conference on system sciences*.
Su, Y.-H., Guo, R.-S., & Chang, S.-C. (2005). Virtual fab: An enabling framework and dynamic manufacturing service provision mechanism. *Information and Management, 42*(2), 329–348.
Tallon, P. (2003). The alignment paradox. CIO Insight, 2003. November 15.

Tso, S. K. et al. (1999). A framework for developing an agent-based collaborative service-support system in a manufacturing information network. *Engineering Applications of Artificial Intelligence, 12*(1), 43–57.

Uschold, M., & Gruninger, M. (1996). Ontologies: Principles, methods and applications. *Knowledge Engineering Review, 11*(2), 93–136.

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a new dominant logic for marketing. *Journal of Marketing, 68*(1), 1–17.

Vargo, S. L., & Lusch, R. F. (2008). From goods to service(s): Divergences and convergences of logics. *Industrial Marketing Management, 37*(3), 254–259.

Vargo, S. L., & Lusch, R. F. (2008). Service-dominant logic: Continuing the evolution. *Journal of the Academy of Marketing Science, 36*(1), 1–10.

von Hippel, E., & Katz, R. (2002). Shifting innovation to user via toolkits. *Management Science, 48*(7), 821–833.

Wand, Y., & Weber, R. (2002). Research commentary: Information systems and conceptual modeling – a research agenda. *Information Systems Research, 13*(4), 363–376.

Wang, H. (1997). A conceptual model for virtual markets. *Information and Management, 32*(3), 147–161.

Wang, S. et al. (2008). An ontology for causal relationships between news and financial instruments. *Expert Systems with Applications, 35*(3), 569–580.

Wang, S., Shen, W., & Hao, Q. (2006). An agent-based Web service workflow model for inter-enterprise collaboration. *Expert Systems with Applications, 31*(4), 787–799.

Weber, R. (2003). Conceptual modelling and ontology: Possibilities and pitfalls. *Journal of Database Management, 14*(3), 1–20.

Yan, J. et al. (2008). Conceptual modeling of collaborative manufacturing for customized products: An ontological approach. In *Pacific Asia conference on information systems*. Suzhou, China.

Yang, S.-Y. (2008). An ontological website models-supported search agent for web services. *Expert Systems with Applications, 35*(4), 2056–2073.

Yang, D. et al. (2009). Product configuration knowledge modeling using ontology web language. *Expert Systems with Applications, 36*(3), 4399–4411.

Zhao, J. L., Tanniru, M., & Zhang, L. J. (2007). Services computing as the foundation of enterprise agility: Overview of recent advances and introduction to the special issue. *Industrial Systems Frontiers, 9*(1), 1–8.

Zhao, J. L. (2008). Impact of service-centric computing on business and education. In *Communications of the AIS* (pp. 295–310).

Zhao, J. L. et al. (2008). ICIS 2007 panel report: Bridging service computing and service management: How MIS contributes to service orientation. In *Communications of the AIS* (pp. 295–310).