On Domain Modeling of the Service System with its Application to Enterprise Information Systems

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Abstract

Information systems are a kind of service systems and they are throughout every element of a modern industrial and business system, much like blood in our body. Types of information systems are heterogeneous because of extreme uncertainty in changes in modern industrial and business systems. To effectively manage information systems, modeling of the work domain (or domain) of information systems is necessary. In this paper, a domain modeling framework for the service system is proposed and its application to the enterprise information system is outlined. The framework is defined based on application of a general domain modeling tool called FCBPSS. The FCBPSS is based on a set of core concepts, namely: function, context, behavior, principle, state and structure and system decomposition. Different from many other applications of FCBPSS in systems engineering, the FCBPSS is applied to both the infrastructure and substance systems, which is novel and effective to modeling of service systems including enterprise information systems. It is to be noted that domain modeling of systems (e.g., enterprise information systems) is a key to integration of heterogeneous systems and to coping with unanticipated situations facing to systems.

Key words: Service system, function-behavior-structure, enterprise information system, domain modeling, system decomposition.

1. Introduction

The concept of the service system emerges from a point of view of service economy. According to our previous work [Wang et al. 2013b], a system can broadly be classified into three categories: agricultural systems, manufacturing systems and service systems, which are further relevant to agricultural economy, manufacturing economy and service economy. An information system are a kind of service system, which is known to play more and more important roles in modern manufacturing systems and agricultural systems [Niu et al. 2013, Wang et al. 2005, Xu et al. 2008],.

Modeling of ontology or domain of service systems including information systems is an essential step to more effectively manage information systems across different firms. There are two major roles for a domain model: a common language for different humans to communicate with each other about a domain (service in general and enterprise information systems in particular) and a tool to allow the computer system to understand the semantics of a domain. As such, a domain model will facilitate both distributed human-centered decision making and computer-assisted decision making. A unified approach to domain modeling is still absent in the service and service system or general work system. A justification of this observation will be provided in the next section (Section 2) of this paper.

The objective of this paper is to propose a framework for domain modeling for the service system and to demonstrate how this general framework can be applied to enterprise information systems which are a kind of the service system [Duan and Xu 2012, Wang et al. 2013b]¸. It is noted that our focus in this paper is on the framework of modeling instead of a concrete model of service systems or enterprise information systems. That said; our work presented in this paper will only provide a set of modeling building blocks tailored to the service system such as enterprise information systems. It is expected that with this framework, a generic service system domain model can be established, followed by specialized service system domain models such as enterprise information systems. To achieve this objective is to apply a general domain modeling tool called FCBPSS, which was developed by Lin and Zhang [2004, 2005] upon a careful analysis of various similar modeling tools which are only based on three concepts: function, structure, and behavior.

This paper is further organized as follows. In section 2, a literature review on two topics: definition of service system and domain modeling of service system are presented. In Section 3, the definition of the service system we proposed elsewhere [Wang et al. 2013b] along with a discussion of several basic concepts is outlined. This discussion lays a foundation for domain modeling, as the domain of a work is based on the definition of the work. In Section 4, the FCBPSS framework is briefly described. In Section 5, the framework for domain modeling for the service system using the FCBPSS is proposed. In Section 6, the effectiveness and usefulness of the model are discussed. In Section 7, a hypothetical example of enterprise information is presented to illustrate how the framework can be used for application for specialized service systems such as enterprise information systems. At last, the conclusion of the paper is given in Section 8.

2 Literature review

2.1 Service System Definition

The “service system” has been given different definitions from a different point of view in literature [Sampson and Froehle 2006, Pinhanez 2009, Alter 2003, 2008, Spohrer et al. 2007, IfM & IBM 2008, Stanicek and Winkler 2010, Xing et al. 2013]. According to our previous work [Wang et al. 2013b], the definitions could be classified into three categories. The first category [Sampson and Froehle 2006, Pinhanez 2009] views the human-in-the loop as the key feature in a service system. The second category [Alter 2003, 2008] considers that the service system and manufacturing system has the same structure but is capable of producing either a product or service. The third category [Spohrer et al. 2007, IfM & IBM 2008, Stanicek and Winkler 2010] views the service system as a complementary component of economic exchange.

Beside the definitions above, there are also definitions of the service system from a point of view of the nature of various services. For instance, Lusch and Vargo [2006] defined that service may refer to a kind of action, performance, or promise that is exchanged for value. Krishnamurthy [2007] outlined four features of a service as: (1) intangible, (2) consumed at the time it is produced, (3) provision of value-adding in different forms, and most importantly, (4) co-production. Regarding the last feature, Tien and Berg [2003] explained that co-production means that the consumer and provider are communicating constantly, reevaluating the need of the customer and the manner in which the customer is being satisfied.

The above definitions have some difficulties to distinguish a service system from other systems, such as agricultural systems, manufacturing systems, and product systems. For instance, in the agricultural system, humans and technologies are also included. Modern agricultural systems are highly automated similar to manufacturing systems. Emphasis on technology, people, and organization for the manufacturing system can be dated back to the 1990s [Zhang et al. 1997]. Further, the first and second features of service as described by Krishnamurthy [2007] cannot include the transportation system as a service system, which passes goods from place A to place B. The nature of co-production is the customer participation in businesses, which is not only for service systems but also for manufacturing systems [Li et al., 2004]. Various service systems, such as enterprise information system [Xu 2011, Wang et al. 2010a, Niu et al. 2013, Zhou et al. 2012], transportation system [Wang et al. 2010b, Wang et al. 2013c, Yuan et al. 2010, Feng and Xu 1996] and health care service systems [Li and Benton 1996, Li et al. 2008, Li et al. 2012, Yin et al. 2012, Shan et al. 2013, Xu 1994, Pang et al. 2013],] have been examined from an engineering perspective; especially, the enterprise information system has been shown its important strategic impact on the industrial development.

In short, the above definitions of the service system including enterprise information system has not been satisfactory for providing the service system an identity with which the service system can distinguish itself from the agricultural system, manufacturing system, and product system. This has affected the domain modeling, as a correct domain modeling must be based on a correct understanding of the domain in question. Section 3 will present a definition of the service system, which can give the service system an identity.

2.2 Domain Modeling of Service System

Modeling of the service system is known as an important topic for service system design due to ever increased complexity of the modern service system. A systematic modeling of information systems requires domain modeling first. Domain modeling is considered to be similar to ontology modeling or conceptual modeling in this paper, and they further depend on the definition of the domain of an application – service systems in this case. There are only a few studies in literature on domain modeling in the context of service systems. Besides, they are based on the definitions of the service system, which we believe are problematic; see subsequent discussions.

Stanicek and Winkler [2010] proposed a conceptual model for the service system. The imitations of their model are: (1) the model is based on an extension of the service system definition proposed by Spohrer et al. [2007], which has difficulty in providing an identity of the service system [Wang et al. 2013b], and (2) the model is much focused on the service delivery not much on the constituent elements of the service system. The proposed framework in the present paper will be shown to overcome these shortcomings. Nevertheless, the proposed framework has a connection with the model of Stanicek and Winkler [2007] in that the proposed framework represents the whole generalization/specialization lattice of conceptual modeling of the service system, while Stanicek and Winkler’s model is at a certain level of this lattice.

Dinh and Thi [2010] presented a conceptual framework for service modeling in a network of service system and used simplified UML (Unified Modeling Language) for the meta-model in the framework. Their work was also based on the service system definition proposed by Spohrer et al. [2007], which, however, involves some conflict. The service system definition of Spohrer et al. [2007] has a very general scope and views that individuals, families, firms, nations, and economies are all instances of the service system; however, the framework proposed by Dinh and Thi [2007] considered service system into a narrow scope which views network as a higher level of service system. Further, UML is a tool which is based on object-oriented (OO) paradigm. The OO modeling approach is restricted in its expression power to real world phenomena and activities, as it flats them into a framework which has only two levels: object and its method or end and means.

In general, as far as the domain modeling tools are concerned, the current tools employed for domain modeling in the context of service systems are at most based on the OO paradigm. These tools are not natural in modeling of rich real world semantics in service systems. Specifically, they are poor at capturing the domain semantics in why, how, where and when the means achieves the end; the modeling approach based on the method in OO is just too general to capture these semantics. The FCBPSS to be introduced in Section 4 can capture these semantics.

3. A unified definition of service system and enterprise information systems

In our previous work [Wang et al. 2013b], we defined service and service system as follows. "A **service** is a function that is achieved by an interaction between a human and an entity under a protocol. A **service system** or organization or firm consists of three subsystems: (i) an infrastructure, (ii) a substance, and (iii) a management to meet demands of humans or consumers. The infrastructure is of network, and substance ‘flows’ over the infrastructure. The management plays the roles such as coordinating, leading, planning and controlling, which are applied to both the infrastructure and substance systems [Wang et al. 2013b]." The following remarks are drawn from [Wang et al. 2013b].

Remark 1: The new definition covers both the structural and functional aspects of a service system as well as the aspect of operation management.

Remark 2: The service system as we defined is structurally generic and functionally general.

Remark 3: The substance can have four generic types: material, human or animal, energy, data or signal [Fang et al. 2013, Tan et al. 2012, Tan et al. 2013, Xu et al. 2012, Viriyasitavat et al. 2012]. Data further makes sense for information or knowledge depending on a service's receiver on his purpose [Shi et al. 2011].

Remark 4: A resource is a physical or cognitive entity with limited availability and accessibility that needs to be consumed to obtain a benefit from it.

Remark 5: The sense of a service lies in that a human's status or state is changed to meet his or her need by operation of a system.

Remark 6: The structural aspect of a service system puts emphasis on a network.

Remark 7: A protocol is an agreement or constraint between service providers and service demanders.

An enterprise information system is used for integrating and extending business processes across the boundaries of business functions at both the intra-organizational and inter-organizational levels [Xu 2011]. An enterprise information system is a kind of the service system in that it meets the definition of the service system. First, the enterprise information system has the infrastructure system such as various computers, network systems and terminals with relevant software systems. Second, the information which describes the semantics of a particular enterprise flows over the infrastructure system. Third, both the infrastructure system and information operate under a certain protocol, and the operation is further enhanced by the management system.

4. The FCBPSS framework for domain modeling

The FCBPSS framework is a methodology as well as tool to develop a conceptual or domain model of the dynamic system proposed by Lin and Zhang based on the FBS framework [Lin and Zhang 2004, 2005].

The FBS framework was initially developed for increasing the intelligence of computer program systems for fault diagnosis and reasoning [Kuipers 1984, De Kleer 1984]. The knowledge representation along this direction is called Function-Behavior-State (FBS) model. Pioneer studies on this model in the engineering design community refer to the work by Ulrich and Seering [1988]. Umeda et al. [1990] provided a more comprehensive description of the basic concepts of function, behavior, and state of machines and the application of the FBS model in the areas such as computer aided design, simulation, and diagnosis. Umeda and Tomiyama [1995] further developed a modeling scheme of the FBS. Umeda et al. [2005] employed the FBS modeling scheme to the product upgrade design. Kruchen [2005] proposed the FBS framework into the software engineering to direct the software design activities in large system engineering projects.

The FCBPSS framework modified and extended the Function-Behavior-State (FBS) framework to have more layers of concepts. The FCBPSS framework has a set of key concepts, including: (1) structure, (2) state, (3) behavior, (4) principle, (5) function, (6) context, (7) relationship among concepts (1)–(6), and (8) system decomposition. Figure 1 shows these concepts and their relations. The definitions of these concepts are referred to reference [Lin and Zhang 2004, 2005].

The next section will present a domain modeling framework for service systems, which is illustrated by an enterprise information system.

5. FCBPSS models of the IS and SS

5.1 System decomposition

As stated in the definition, the service system has three subsystems: the infrastructure system (IS), substance system (SS) and management system (MS). MS is a body of decision in its nature [Qi et al. 2006]; in particular, the MS is designed and implemented based on its managed objects: the IS and SS. In the FCBPSS model, we shall focus on the IS and SS. In the following, we shall present these models. The relationships between MS and its managed objects (IS and SS) are further explained in Section 7 by an example.

As a typical service system, an enterprise information system can be viewed as having three subsystems: the infrastructure system (IS), the substance system (SS) and management system (MS); in particular they are related to each other by the constraint that the SS depends on the IS or the SS must "flow" within the IS and both IS and SS are under the management of MS. The flow of SS follows certain constraints which could be called "information flow rules". These rules are derived from particular enterprise information systems and/or general rules for database management systems (e.g., "no null value for the primary key" rule in relational database systems). The dynamics of the enterprise information system is determined by the flow of SS under the constraints of these rules.

5.2 Structures of the IS and SS

5.2.1 Structure of the IS

The structure of the IS refers to a network of components including both the physical entity and human. In the case of enterprise information system, the structure of IS is a network composed of various components; in particular, there are three typical components, namely hardware systems, software systems and human experts who provide technological supports for the system. This network can be further represented by the graph formalism to facilitate the modeling. We define node for components and arc for links among the components. Suppose a particular IS has M nodes and N directed arcs. The IS of a service system can be represented as a graph denoted by G and $G=(N,A)$, as shown in Fig. 2. It is noted that we can use different graphs to represent the IS of a service system, such as directed graph, undirected graph, weighted graph and non-weighted graph, or mixture of them. Which one is employed depends on the nature of a particular service system and a particular purpose to examine the system.

5.2.2 Structure of the SS

The structure of SS refers to different types of substances, the connections among different types of substance and the distribution of different types of substance, as shown in Fig. 3. In the enterprise information system, as mentioned above, the substance refers to enterprise information flows in the enterprise information system. In particular, in one enterprise information system, the substance may be classified into different types depending on their different properties or attributes. For example, the substance of a particular enterprise information system may include different types of information flows, such as financial information, production material information, and production process information and so on.

At a particular time, the substance of an information system stays on a particular node or arc of the infrastructure system. Therefore, the distribution state of the substance is also considered in the representation of the structure of the SS. Again, different substances have different features. For example, the information of the enterprise information system moves very fast in the connection line. We usually view the information stays on a particular node, namely a terminal or storage and ignore the transmission time when modeling. Therefore, we can only use the distribution state of substance on the nodes to represent the structure of SS for the enterprise information system. Take another typical service system, a water supply system, as an example. The substance, water, has different features. The transmission time of water in the arcs may or may not be ignored, depending on the modeling accuracy. In the latter case, we must use the distribution of water on the node and arc to represent the structure of the water supply system.

5.3 Behaviors and states of the IS and SS

5.3.1 Behavior and state of the IS

Entities in the IS are perceived by a set of properties, and these properties are called states in the FCBPSS framework. In the IS of an enterprise information system, states thus refer to the properties of the hardware systems, software systems and human experts. For example, a data storage system may have the following states: available memory space, readability, writability and so on. The behavior of the IS is the causal relationship among its state variables. In the IS of an enterprise information system, the behavior of a component, say storage, may refer to the change of the available memory space, or readability or writability.

5.3.2 Behavior and state of the SS

The states of the SS refer to the properties of the substance flow on the IS. In an enterprise information system, the states of the SS, may refer to the amount of information on nodes and the rate of the information flow on edges. The behavior of the SS is the causal relation among its state variables. In the SS of an enterprise information system, behavior may refer to the change of amounts of information on nodes and rates of information flows on edges.

5.4 Principles of the IS and SS

5.4.1 Principle of the IS

The principle of the IS governs the behavior of components in IS. In an enterprise information system, as mentioned above, one of the behaviors of a particular storage component may refer to the change of the available memory space. However, such a behavior must obey the a principle that the available memory space changes within a range between predefined minimum bound and maximum bound. An enterprise information system is built upon a particular computer network system, the principles of IS include the protocols and controls of different components in IS, which decompose the whole IS into seven layers in logic, namely application layer, presentation layer, session layer, transport layer, network layer, data link layer and physical layer.

5.4.2 Principle of the SS

The principles of SS govern the behaviors of SS. In the SS of an enterprise information system, the principles refer to the flow protocols that govern the different types of information flows over the IS.

5.5 Functions and contexts of the IS and SS

The function is defined as a purpose in the mind of human users and can be realized by the system (structure) owing to certain behaviors existing in the structure. For a service system, the services provided by the system, are the functions of the system in the FCBPSS domain. The function of the whole service system is performed by the functions of the IS and SS, which are coupled together. The context is the particular environment where the particular system operates or works or makes sense. Considering its particular features, a service system has two different contexts: (1) normal context, and (2) abnormal context, as shown in Fig. 4.

A. The normal context is the regular environment where a service system works. In this context, all components of the system are in its normal states and the function of the service system is described as regular function.

B. The abnormal context refers to the special circumstance where a service works. For example, in a particular emergency situation, a part of the enterprise information system breaks down. In this context, the other healthy part of the enterprise information system usually needs to meet a larger demand than the normal situation.

We call the function of a service system under an abnormal context as transient function.

Next, the functions and contexts of IS and SS are discussed respectively.

5.5.1 Function and context of the IS

As discussed above, the functions of IS are explained in the normal context and abnormal context, respectively.

A. Normal context. In the normal context, IS of a service system has regular functions which provide regular infrastructure services to the SS. The regular function means that different components of IS work in a stable state. The regular function can be measured by the average ability of the IS to provide a stable situation for the SS. For example, the IS of an enterprise information system provides information infrastructures for different information flows in a system. In a normal situation, the IS has an average ability to support the flow of SS and further to provide information services to the enterprise.

B. Abnormal context. In the abnormal context, the IS of a service system has transient functions which provide special infrastructures to the SS. In this context, the IS usually can not work in a normal manner due to the partially damage or largely increased demand function, as shown in Fig. 5. When a large-scale athletic meeting is held in a place, the wireless communication demand will increase to a huge amount. Therefore, the wireless communication system needs to meet this demand. We call the wireless communication system in this case having a transient function. Another typical example is the transportation system that needs to evacuate a large number of people from one place to another in an emergency situation. Regarding an enterprise information system, when parts of the system break down due to online attack (for example), the other un-damaged parts of the system need to meet the demand of the enterprise operation. Since the transient function of IS is to meet a special demand, it can be measured by the maximum ability of the IS to provide to the SS in an abnormal situation. To perform the maximum function, the IS may need optimal recovery solution.

5.5.2 Function and Context of the SS

A. Normal context. The service of the whole service system provided to the customers is exhibited as the flow of the SS flowing on the IS. Therefore, in the normal context, SS of a service system has regular function which provides general services to the customers of the whole service system. The regular function means different components of SS works in a stable state. The regular function can be measured by the average ability of the IS to provide for the SS in a stable situation. For example, the SS of an enterprise information system provides information services to an enterprise. This regular function can be measured by the average ability of information service provided by the SS to the enterprise.

B. Abnormal context. In the abnormal context, SS of a service system has transient function which provides special services to the customers. As discussed before, in this context, the IS usually cannot work in a normal manner due to partially damage or largely increased demand. The transient function of SS can be measured in terms of meeting a transient demand from customers in a particular abnormal situation.

6. Effectiveness and usefulness of the model

The FCBPSS approach and its application have been shown useful in the context of various applications [30]. For the service system, the effectiveness and usefulness of the proposed domain model in this paper are explained as follows.

6.1 Effectiveness of the model

The proposed model is effective; in particular, it could play the two roles stated in Section 1. First, it is used as a common language for different human entities to communicate with each other about service systems. It is easy for people to have a thorough understanding on a particular service system with the propose model. Second, the proposed framework could be further converted by a particular computer language, which allows the computer system to understand the semantics of a particular service system.

6.2 Usefulness of the model

First, it is useful to understanding of the service system and clarifying a particular research idea. The domain model documents the key concepts, and the domain-vocabulary of the service system. The domain model provides a structural view of the system that can be effectively used to verify and validate the understanding of the problem domain among various groups of humans. It is especially helpful as a communication tool and a focusing point to understand the system; in particular, it is helpful to clarify a particular research idea. For example, when we undertake integrated design and control for a networked service system, it will be easy to understand the research idea with the proposed domain model.

Second, it is useful to design of the service system. The system decomposition and the key concepts in the domain model give the presentation of design notion, which is the basis of the design process of the service system. In the design process, the structure of the system becomes a part of variables in math model. The domain model provides a support to define these variables; in particular, when the topology of the system changes, the domain model provides a source of knowledge for re-defining the variables.

Third, it is useful to management of the service system. The management of the system usually involves the structure and behavior of the system. For example, in the resilience management of the service system, the structure and behavior of the system are necessary to be considered for creating different recovery solutions.

Fourth, it is useful to measure the properties of the service system. The key concepts in the domain model are the basis of measurement of different properties of the service system. Again take the resilience property as an example. The definitions of normal context and the abnormal context, with the corresponding regular function and transient function, not only distinguish the property domain, but also indicate a potential way to measure the resilience property of the service system from different contexts.

7. Application to enterprise information system

In this section, we will use an enterprise information system to explain the effectiveness and usefulness of this domain model in the area of design, planning and control of a service system; in particular, an integrated approach (based on the proposed domain model) to function recovery of an enterprise information system in an emergency situation will be introduced.

Based on the FCBPSS model, the relationships of the three subsystems and the detailed management strategies of the enterprise information system can be described in Fig. 6. The management of the IS of enterprise information system refers to management of the design activity of the IS, which determines the configuration of a IS at the physical level, including the information of hardware systems, software systems and human experts. The management of the SS refers to planning of information flow patterns, which determines protocols of information flow. Upon the design and planning activities, there is another activity namely control which works on both the IS and SS and their corresponding management units. The control strategy may works on the design strategy and planning strategy and makes the latter two strategies coupled with each other as integrated design and planning strategy. The control activity may work on the IS and SS and enable the two subsystems to have some further responding ability to the output of the whole enterprise information system.

The foregoing three activities are usually undertaken separately in a sequence, i.e., design first, followed by planning and finally control. A strategy to understand these activities in an integrated manner will further improve the performance of a service system. With the FCBPSS framework, it has been found that the relationship among these activities can be captured explicitly (Fig. 6). On a general note, in artificial intelligence technique, the explicit representation of the domain information is an essential step to make the computer system intelligent. This is because the domain information is the deepest knowledge about the system. The architecture of a management (including design) system by having two layers of models (i.e., a domain model layer and a decision-making model layer) provides a guarantee for the system to be able to cope with unanticipated events [Lin and Zhang 2004].

The integrated management approach is especially useful in the abnormal context. In the situation where the enterprise information system is partially damaged, to meet the enterprise operation demand, the design, planning and control may turn out to be rather integrated. For example, when some hardware components of the enterprise information system are damaged, we need to consider whether the "maximum" capacity of the remaining enterprise information system is still satisfied to the demand of the enterprise operation. If not, we then have to replace or repair some or even all the damaged components or reconfigure the network structure, which is the design of the IS. It may also be possible that through re-planning of the information flows, the demand is satisfied. The control activity may also need to apply to provide for example more resources into the perhaps reconfigured IS or to the perhaps replanned SS to meet the demand of the system. It may be further the case that the three management activities are performed at the same time, i.e., an integrated approach, as described in Fig. 6.

8. Conclusions

In this paper, we proposed a framework for domain modeling for the service system including enterprise information systems. The novelty of the proposed domain modeling framework for the service system has been contributed by the unified definition of the service system and the domain modeling tool FCBPSS.The validity of the unified definition comes from the fact that a service system under this definition can well distinguish it from the other systems such as manufacturing systems, agricultural systems, and product systems. The FCBPSS framework is a semantic or natural tool to model the domain of a system. In comparison with the related method of Umeda and Tomiyama [1995], the FCBPSS framework includes a complete set of concepts underlying a system, being able to capture the semantics of why, how, where, and when the means achieves the end. The FCBPSS framework thus goes beyond the OO paradigm in modeling information and knowledge.

An integrated design, planning and control strategy for enterprise information systems in the abnormal context was presented to show the effectiveness and usefulness of the proposed domain model. This is on its own a contribution to the area of research on management of enterprise information systems for resilience [Zhang and Lin 2010, Zhang and van Luttervelt 2011, Wang et al. 2013a].

The future work should be directed to developing more examples to demonstrate the promise of the domain model in design and management of industrial informatics systems, e.g., enterprise information systems, signal planning and scheduling systems at the machine or component level.

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References

1. Alter, S. (2003). "18 Reasons Why IT-Reliant Work Systems Should Replace the IT Artifact as the Core Subject Matter of the IS Field," Communications of the Association for Information Systems (12:23), pp. 365-394.
2. Alter, S., (2008). Service system innovation. In IFIP International Federation for Information Processing, Volume 267, Information Technology in the Service Economy: Challenges and Possibilities for the 21st Century, eds. Barrett, M., Davidson, E., Middleton, C., and DeGross, J. (Boston: Springer), pp. 61-80.
3. Bullinger H.J., Fahnrick K.P. and Meiren T. (2003) Service engineering—methodical development of new service products. Int J Prod Econ 85:275–287.
4. De Kleer, J. (1984). How circuits work. Artificial Intelligence, Vol. 24, pp: 205-280.

5. Dinh T. L. and Thi T. T. P. (2010). A conceptual framework for service modeling in a network of service systems, in *Exploring services science*, LNBIP, J-H. Morin, J. Ralyte and M. Snene, Eds, Springer, NY, 2010, pp. 192-206.
6. Duan, L.and Xu L. D. (2012). Business Intelligence for Enterprise Systems: a Survey. IEEE Transactions on Industrial Informatics, 8(3), 679-687.
7. Duzi, M. (2001), "Logical Foundations of Conceptual Modelling", habilitation work, Ostrava, available at: http://www.cs.vsb.cz/duzi/HABILvsb.zip
8. Fang, S., et al. 2013. An Integrated Approach to Snowmelt Flood Forecasting in Water Resource Management. IEEE Transactions on Industrial Informatics, in press Digital Object Identifier: 10.1109/TII.2013.2257807
9. Feng, S. and Xu L. D. (1996). A Hybrid Knowledge-based System for Urban Development. Expert Systems With Applications, 10,157-163.
10. Glushko R.J. and Tabas L. (2009). Designing service systems by bridging the "front stage" and "back stage". Inf Syst E-bus Manage, 7: 407-427.
11. Karni R. and Kaner M (2006). An engineering tool for the conceptual design of service systems, In Advances in Service Innovations, edited by Spath and Fahnrich. Springer. NY, 66-83.
12. Kruchten, P. (2005). Casting software design in the function-behavior-structure framework. IEEE Software,Vol. 22(2), pp: 52 – 58.
13. Krishnamurthy A.(2007) From Just in Time Manufacturing to On-Demand Services, Integrated Series In Information Systems, 1, Volume 16, Service Enterprise Integration, eds by Hsu C. Pages 1-37, Springer.

14. Kuipers, B. (1984). Commonsense Reasoning about causality: deriving behavior from structure. Artificial Intelligence, Vol. 24, pp. 169-203.

15. Levitt T. (1972). Production-line approach to services. Harv Bus Rev 50 (Sep. to Oct.): 41-52.

16. Li, J.X., (2004). An internet-based configuration design system using constraint-based programming techniques. M. Sc. thesis. University of Saskatchewan, Canada.

17. Li L. and Benton WC. (1996). Performance measurement criteria in health care organizations: review and future research directions. European Journal of Operational Research, 93, 449-468.

18. Li, L., Ge R., Zhou S. and Valerdi R. (2012). Guest editorial integrated healthcare information systems. IEEE Transactions on Information Technology in Biomedicine, 16(4), 515-518.

19. Li L., Xu L., Jeng H. A., Naik D., Allen T. and Frontini M. (2008). Creation of Environmental Health Information System for Public Health Service: A Pilot Study. Information Systems Frontiers, 10(5), 531-543.

20. Lin Y. and Zhang W.J. (2004). Towards a novel interface design framework: function-behavior-state paradigm. International journal of human-computer studies, 2004, 61(3): 259-297.

21. Lin, Y., and Zhang, W. J. (2005). A function-behavior-state approach to designing human-machine interface for nuclear power plant operators. IEEE Transactions on Nuclear Science, Vol. 52(1), pp: 430-439.

22. Lusch R.F. and Vargo S.L. (2006). The service-dominant logic of marketing: dialog, debate, and directions. Editors, Sharpe M.E., Armonk, NY.

23. Maglio PP, Kreulen J, Srinivasan S, Spohrer J (2006) Service systems, service scientists, SSME, and innovation. Commun ACM, 49(7):81–85.

24. Manderbaum A. (1998). Service engineering: modelling, analysis and inference of stochastic service networks. Israel institute of technology, Haifa.

25. Mills PK and Moberg DJ (1982). Perspectives on the technology of service operations. Acad Manage Rev 7(3): 467-478.

26. Niu, N., Xu L. D., Cheng J. and Niu Z. (2013). Analysis of Architecturally Significant Requirements for Enterprise Systems. IEEE Systems Journal, in press Digital Object Identifier: 10.1109/JSYST.2013.2249892

27. Niu N. Xu L. D. and Bi Z. (2013). Enterprise Information Systems Architecture-Analysis and Evaluation. IEEE Transactions on Industrial Informatics, in press Digital Object Identifier: 10.1109/TII.2013.2238948

28. Norman D.A. (1986). Cognitive engineering. In Norman D.A. and Draper S.W. (Eds.) User centered system design: new perspectives on human-computer interaction. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

29. Pang, Z., Zheng L., Tian J., Kao-walter S., Dubrova E. and Chen Q. (2013). Design of a terminal solution for integration of in-home health care devices and services towards the Internet-of-Things. Enterprise Information Systems, in press DOI:10.1080/17517575.2013.776118

30. Pinhanez C. (2009). “HUMANS INSIDE” AS THE KEY CHARACTERISTIC

OF SERVICE SYSTEMS. Proc. of QUIS'11, Wolfsburg, Germany. June 2009.

31. Qi, J., Xu L. Shu H. and Li H. (2006). Knowledge Management in OSS--an Enterprise Information System for the Telecommunications Industry. Systems Research and Behavioral Science, 23(2), 177-190.

32. Rigby D. and Cáceres D. (2001). Organic farming and the sustainability of agricultural systems. Agricultural systems, 68(1): 21-40.

33. Sampson, S. E., (2001). Understanding Service Businesses, John Wiley & Sons.

34. Sampson, S.E. and Froehle C.M. (2006). Foundations and implications of a proposed unified services theory. Production and operations management, 15(2): 329-343.

35. Shan S., Xin T., Wang L., Li Y. and Li L. (2013). Indentifying influential factors of knowledge sharing in emergency events: a virtual community perspective. Systems Research and Behavioral Science in press DOI: 10.1002/sres.2181

36. Shi, X., Li L. X., Yang L., Li Z. and Choi J Y. (2011). Information flow in reverse logistics: an industrial information integration study. Information Technology and Management, 13(4), 217-232.

37. Smith J.S. (2003). Survey on the use of simulation for manufacturing system design and operation. Journal of manufacturing systems, 22(2): 157-171.

38. Spohrer J, Maglio P.P, Bailey J, and Gruhl (2007). Steps toward a science of service system, Computer, 40(1):71-77.

39. Stanicek Z. and Winkler M. (2010). Service Systems through the Prism of Conceptual Modeling, Service Science, 2(1/2): 112-125.

40. Tan, W., Li L., Xu W., Yang F., Jiang C., Yang L. and Choi J. (2012). A Role-oriented service system architecture for enterprise process collaboration. Computers & Operations Research, 39(8), 1893-1900.

41. Tan W., Xu W, Yang F., Xu L. and Jiang C.(2013). A Framework for Service Enterprise Workflow Simulation with Multi-Agents Cooperation. Enterprise Information Systems, in press, DOI:10.1080/17517575.2012.660503

42. Tien J.M. and Berg D. (2003), A case for service systems engineering. Journal of systems science and system engineering, 12(1): 13-38.

43. Umeda, Y., Kondoh, S., Shimomura, Y., and Tomiyama, T. (2005). Development of design methodology for upgradable products based on function–behavior–state modeling. Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Vol. 19(03), pp: 161-182.

44. Umeda, Y., Takeda, H., Tomiyama, T., and Yoshikawa, H. (1990). Function, behaviour, and structure. In Applications of Artificial Intelligence in Engineering, V, (Gero, J.S.,Ed.), Computational Mechanics Publications and Springer-Verlag, pp: 177-193.

45. Umeda, Y., and Tomiyama, T. (1995). FBS modeling: Modeling scheme of function for conceptual design. Workshop on Qualitative Reasoning, pp: 271–278.

46. Ulrich, K. T., and Seering, W. P. (1988). Function sharing in mechanical design. The Seventh National Conference on Artificial Intelligence, Vol. 1, pp: 342-370.

47. Vargo, S. L. and Lusch, R. F., (2004). "Evolving to a New Dominant Logic for Marketing", Journal of Marketing, 68 1-17.

48. Viriyasitavat, W., Xu L. D. and Martin, A. (2012). SWSpec, Service Workflow Requirements Specification Language: The Formal Requirements Specification in Service Workflow Environments. IEEE Transactions on Industrial Informatics, 8(3), 631-638.

49. Wand Y. and Weber R (2002). Research commentary- information systems and conceptual modeling-a research agenda, Information systems research, 13(4): 363-376.

50. Wang, C., Xu L. Liu X. and Qin X. (2005). ERP Research, Development and Implementation in China: An Overview. International Journal of Production Research, 43(18), 3915-3932.

51. Wang, F., et al., 2013. A systems framework of security management in enterprise systems. Systems Research and Behavioral Science, in press, DOI: 10.1002/sres.2184

52. Wang J.W., F. Gao and W.H. IP. (2010a) Measurement of Resilience and its Application to Enterprise Information Systems, Enterprise information systems, 4(2): 215-223.

53. Wang J. W., Ip W H and Zhang W J (2010b). An integrated Road Construction and Resource planning approach to the evacuation of victims from single source to multiple destinations, IEEE transactions on intelligent transportation systems, 11(2): 277-289.

54. Wang J. W., Ip W. H., Muddada R. R., Huang J. L., and Zhang W. J. (2013a), On Petri Net Implementation of Proactive Resilient Holistic Supply Chain

Networks, International Journal of Advanced Manufacturing Technology, DOI:10.1007/s00170-013-5022-x.

55. Wang, J. W., Wang H. F., Furuta K., Zhang, W.J. and Ip W.H. (2013b). On a unified definition of the service system: what is its identity? IEEE Systems Journal, in press.

56. Wang J. W., Wang H. F., Zhang W J, Ip W.H. and Furuta K (2013c), Evacuation Planning Based on the Contraflow technique with Consideration of Evacuation Priorities and Traffic Setup Time, IEEE transactions on intelligent transportation systems, 14(1): 480-485.

57. Xing Y., Li L., Bi Z., Wilamowska-Korsak M. and Zhang L. (2013) Operations research (OR) in service industries: a comprehensive review. Systems Research and Behavioral Science in press DOI: 10.1002/sres.2185

58. Xu, L. D. (1994). Developing a Case-based Knowledge System for AIDS Prevention. Expert Systems, 11(4): 237-244.

59. Xu, L. D. (2007). Editorial: Inaugural Issue. Enterprise Information Systems, 1(1), 1-2.

60. Xu L. D.(2011) Enterprise systems: state-of-the-art and future trend, IEEE transactions on industrial informatics, 2011, 7(4): 630-640.

61. Xu L. D., Liang N. and Gao Q. (2008). An Integrated Approach for Agricultural Ecosystem Management. IEEE Transactions on SMC Part C, 38(4), 590-599.

62. Xu, L., Viriyasitavat, W., Ruchikachorn, P. and Martin, A. (2012). Using Propositional Logic for Requirements Verification of Service Workflow. IEEE Transactions on Industrial Informatics, 8(3), 639-646.

63. Yin, Y. H., Fan Y. J. and Xu L. D. (2012). EMG and EPP-Integrated Human-machine Interface between the Paralyzed and Rehabilitation Exoskeleton. IEEE Transactions on Information Technology in Biomedicine, 16(4), 542-549.

64. Yuan, R., Li Z., Guan X. and Xu L. (2010). An SVM-based Machine Learning Method for Accurate Internet Traffic Classification. Information Systems Frontiers, 12(2), 149-156.

65. Zhang, W.J., Lin Y. (2010). Principles of Design of Resilient Systems and its Application to Enterprise Information Systems. Enterprise Information Systems, 4(2): 99-110.

66. Zhang W.J., Liu X., Van Luttervelt C.A., (1997). On the Proposal of a New Theory, Methodology and Computer Aid for Virtual Enterprises Manufacturing Systems Design - in Relation to Partner Factories Selection, Proceedings of Int. Conf. of World Manufacturing Congress' 97 (ISBN: 3-906454-08-8), New Zealand, 61-66.

67. Zhang W. J. and van Luttervelt C. A. (2011).Toward a resilient manufacturing system," CIPP Annuals-Manufacturing Technology, 60: 469-472.

68. Zhou, Z., Valerdi R. and Zhou S. (2012). Guest editorial special section on enterprise systems. IEEE Transactions on Industrial Informatics, 8(3), 630.

Figure captions page

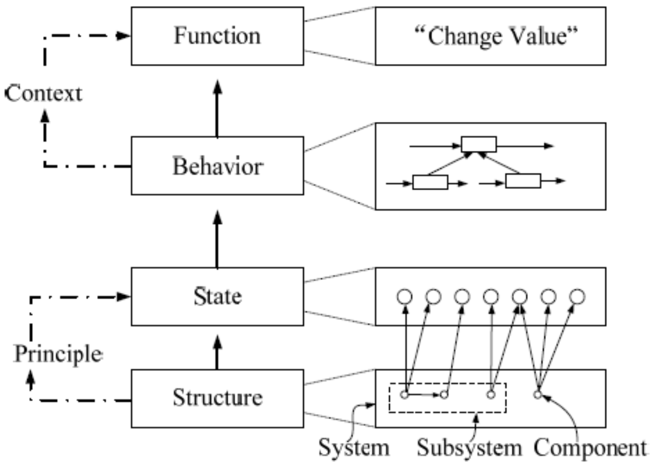

Figure 1. Architecture of FCBPSS framework

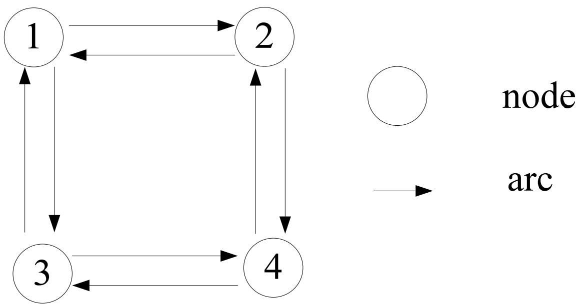

Figure 2 Structure of an IS

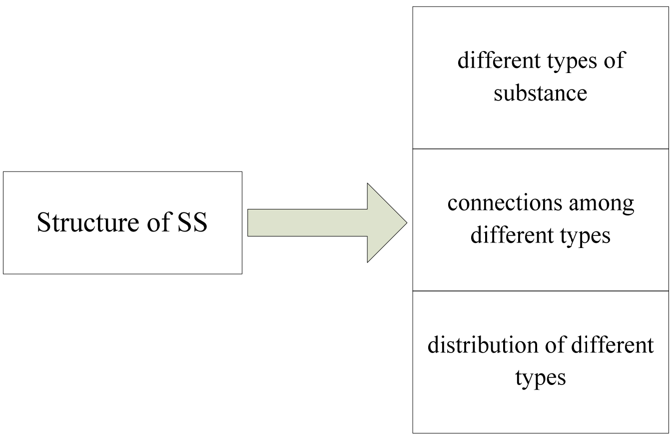

Figure 3 Structure of SS

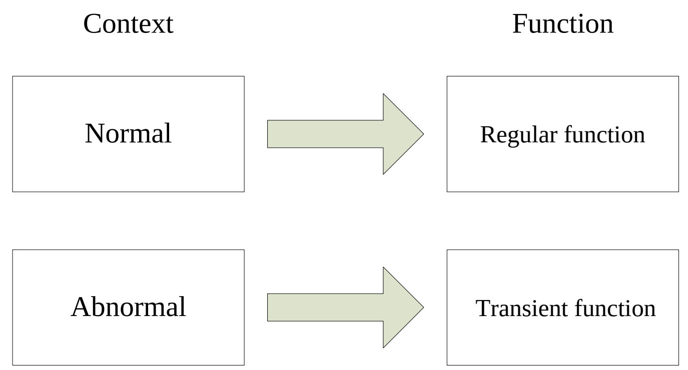

Figure 4 Contexts and function of a service system

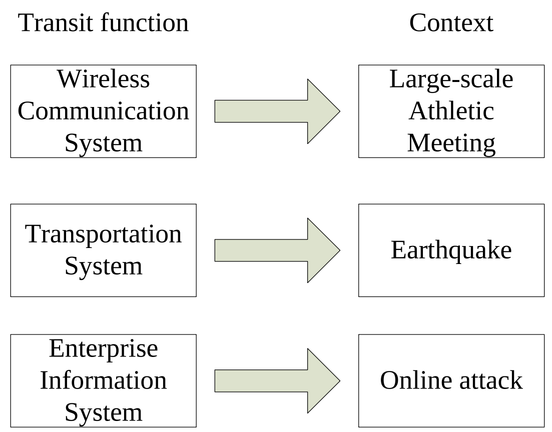

Figure 5 Examples of abnormal context

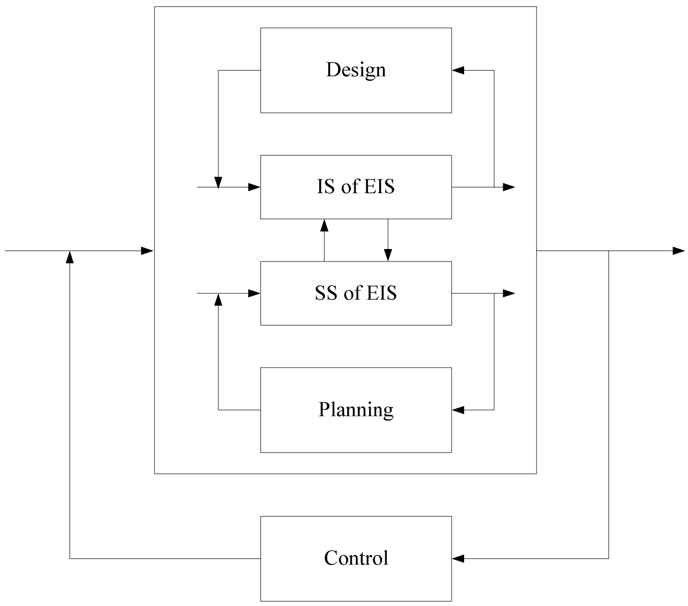

Figure 6 Relationships of IS, SS and MS