Computational Thinking of Service Systems: Dynamics and Adaptiveness Modeling

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Service is broadly considered as an application of specialized knowledge, skill, and experience, performed for co-creation of respective values of both consumer and provider. Services are engineered and delivered through a heterogeneous *service system*. Compared to physical goods in manufacturing, resources, largely *people* (end users as the service consumer and employees as the service provider) - the main focus of a *service system*, cannot be held and are more complex to model and manage as *people* participating in service production and consumption have physiological and psychological issues, cognitive capability, and sociological constraints, etc. As the world becomes more complex and uncertain socially and economically, this research proposes a *computational thinking* approach to modeling of the dynamics and adaptiveness of a *service system*, aimed at fully leveraging today's ubiquitous digitalized information, computing capability and computational power so that the *service system* can be studied qualitatively and quantitatively. Ultimately, with this foundation we will successively and successfully develop the following mechanisms to implement and enhance *service systems*:

- A mechanism to timely capture end users' requirements, changes, expectation and satisfaction in a variety of technical, social, and cultural aspects;
- A mechanism to efficiently and cost-effectively provide employees right means and assistances to engineer services while promptly responding the changes;
- A mechanism to allow involved *people* consciously infuse as much intelligence as possible into all levels and aspects of decision-making to assure necessary system adaptiveness for smarter operations.

Key words: computational thinking; service system; modeling; dynamics; adaptiveness
History: Received Dec. 10, 2008; Received in revised form Feb. 16, 2009; Accepted Mar. 5, 2009; Online first publication Mar. 22, 2009

1. Introduction

Service is broadly considered as an application of specialized knowledge, skill, and experience, performed for co-creation of respective values of both consumer and provider (Lusch and Vargo 2006, Spohrer *et al* 2007, Qiu *et al* 2007). As the world is now all connected economically, technically, and socially, enterprises must aggregate products and services into customer solutions through implementing and executing integrated global value chains (i.e., globally integrated enterprises). Service indeed dominates the developed economy, resulting in today's business wave highlighted by customization, integration, intelligence, and globalization. This new wave seems to get more complicated and challenging, but it for sure entails end users better satisfaction and quality of life – the ultimate prosperity goal of human being (Palmisano 2008).

No matter what service is engineered and delivered, whether the need is fully met and the customer is completely satisfied relies on the efficient, effective and smart operations of its service-value delivery network, i.e. an integrated heterogeneous *service system*. It is well known that competitive systems are not at equilibrium as time goes; they are very dynamic and adaptive. A *service system* puts *people* (customers and employees) rather than physical goods in the center of its organizational structure and operations (Dietrich and Harrison 2006, Qiu *et al* 2007).

A service system essentially is a *social-technical* system, focusing on engineering and delivering services using all available means to realize respective values for both provider and consumer. It can simply be a software application, or a business unit within an organization, from a project team, business department, to a global division; it can be a firm, institution, governmental agency, town, city or nation; it can also be a composition of numerous collaboratively connected service systems within and/or across organizations. No matter what a service system is, small or large, individual or composed, and intra- or interconnected, it must radically consist of *people*, technologies, infrastructures, and processes of service management and engineering (Spohrer *et al* 2007). As the world is becoming better instrumented and interconnected, and more intelligent, a service system must be *people-centric*, information-driven, e-oriented, and satisfaction-focused; it should encourage and cultivate *people* to collaborate and innovate (Qiu *et al* 2007).

"Indeed, almost anything from people, object, to process, for any organization, large or small – can become digitally aware and networked." (Palmisano 2008) On one hand, the world becomes smaller, flatter, and smarter, which creates more opportunities and enormous promise; on the other hand, more challenges and issues appear in many aspects from business strategy, marketing, modeling, innovations, design, engineering, to operations and management in order for businesses to stay competitive in a globally integrated economy. Consequently, an enterprise has to rethink its operational and organizational structure by focusing on *people* (e.g., implementing a novel approach to overcoming social and cultural barriers to cultivate and enhance the cultures of co-production, collaboration, and innovations), so as to ensure the prompt and cost-effective production and delivery of competitive and satisfactory services for customers throughout its geographically dispersed while digitally integrated dynamic *service systems*.

It is well understood that, by end of the day the real value of a delivered service lies in its ability to satisfy customer's need, which is not simply and strictly shown in the technical characteristics of the service. According to Dietrich and Harrison (2006), there lacks sufficient modeling of service when service is in general compared to manufacturing due to the fact that service research is confronting more challenging issues. Compared to physical goods in manufacturing and supply chain systems, resources, largely *people* - the main focus of a *service system*, cannot be held and are more complex to model as *people* participating in service production and consumption have physiological and psychological issues, cognitive capability, and sociological constraints, etc.

As the world becomes more complex and uncertain socially and economically, *computational thinking* that fully leverages today's ubiquitous digitalized information, computing capability and computational power has evolved as an optimal way of solving problems, designing systems, and understanding human behavior. *Computational thinking* is qualitative and quantitative thinking in terms of abstractions, modeling, algorithms, and understanding the consequences of scale and adaptation, not only for reasons of efficiency and effectiveness but also for economic and social reasons (CMU 2009).

The competence or sustainable competitiveness of a *service system* largely depends on right principles and methods, and appropriate tools employed for conducting *quantitative*, *predictive*, and *social-technical* analytics at the point of need throughout the lifecycle of services. Using *computational thinking*, the developed approach shall enable us to explore, model, capture, and manage *systemic* behaviors, interactions, connections, complex relations, and interdependencies of *service systems*.

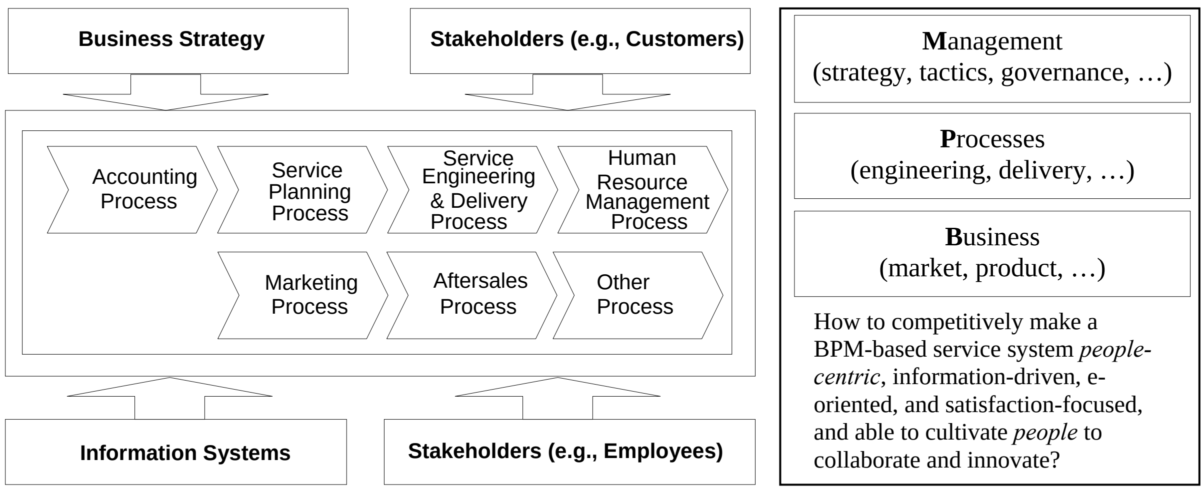
In this paper, given a *service system* with known service products, resources, and operations, we mainly explore a computational model of the operational dynamics and system adaptiveness of the *service system* by looking into its *systemic* operations, behaviors, and interactions. As a breakthrough in delivering a resolution to the *people-centric* enablement in a *service system*, end users (service consumers) and employees (service enablers) must be simultaneously taken into consideration throughout the lifecycle of services. The proposed computational approach should be able to model *people's* physiological and psychological issues, cognitive capability, and sociological constraints (to a certain extent at the very beginning). *People-centric* sensing is the fundamental enablement, providing all potentials of collecting human activities data throughout the lifecycle of services. More specifically, appropriate mechanisms should be developed 1) to timely capture end users' requirements, changes, expectation and satisfaction in a variety of technical, social, and cultural aspects; 2) to efficiently and cost-effectively provide employees right means and assistances to engineer services while promptly responding the changes; and 3) to allow involved *people* consciously infuse as much intelligence as possible into all levels and aspects of decision-making to assure necessary system adaptiveness from time to time.

The remaining paper elucidates such a model that we will eventually enable the delivery of those necessary resolutions. In Section 2, a *service system* is conceivably constructed based on the business process management (BPM) concept while being formularized using a structured workflow language and π-calculus. The new model called a (computational and configurable service system) C^2S^2 model mainly focuses on the future enablement of system configurability by taking into account human interactions and consequences. In Section 3, a brief discussion of metrics and methods to determine whether a given *service system* is operating on track (e.g., satisfaction level) will be provided, aimed at enabling *quantitative*, *predictive*, and *social-technical* analytics at the point of need throughout the lifecycle of services. In Section 4, a brief conclusion is given, and the future study of transformation mechanisms for reconfiguration, continuous and real-time optimization of a *service system* is also presented.

2. Modeling of a Configurable and Competitive Service System

BPM mainly focuses on managing changes to improve business processes. By embracing core principles of striving for collaboration, agility, innovation, and integration with state-of-the-art technology (Weske 2007, Qiu *et al.* 2008), BPM is considered as a holistic management and business process operation approach towards cutting-edge business competitiveness (Figure 1). BPM activities can largely be grouped into five categories from design, modeling, execution, monitoring, to optimization, aimed at ensuring the continuous process improvement on operation effectiveness and efficiency in order to stay competitive.

Figure 1 Business Process Management – a Process-driven Approach



(a) Organizational level model (b) Operational view

As the 21st-century becomes an information- and knowledge-based service-led economy, countless new products and services have been spawned, creating new opportunities that often change the very nature of businesses and organizations. Many world-class business organizations have been transforming themselves by taking the BPM approach for competitive advantages. However, there lacks a novel science that can govern and guide the transformation of a service organization (i.e. *service system*) to ensure that the organization will be 1) *people-centric*, information-driven, e-oriented, and satisfaction-focused, and 2) able to cultivate *people* to collaborate and innovate.

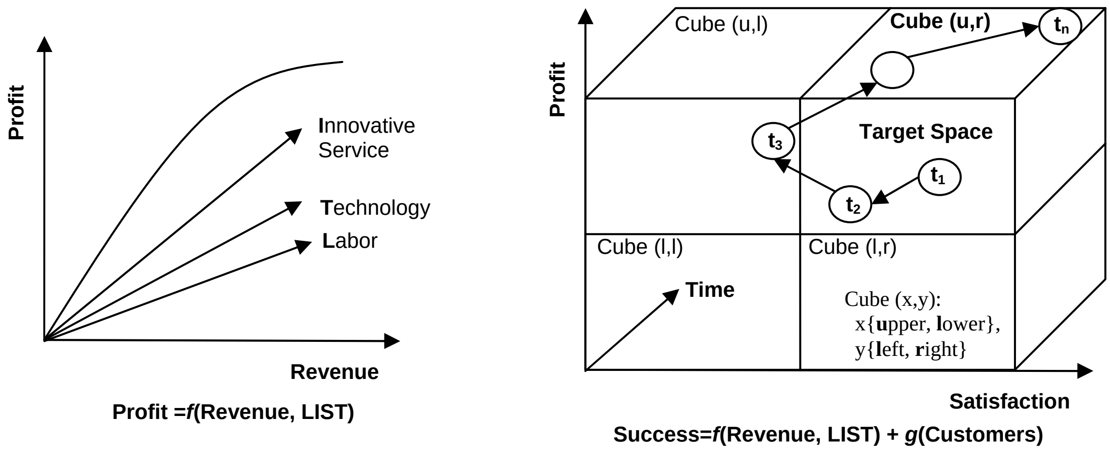
Note that a *service system* usually integrates different types of resources (capital, labor, technology, and innovation, etc.), realizing different scales of revenues and profits, and most importantly different competitiveness during a competition (Figure 2). Although it is common to use a profit equation to measure the competitiveness of a given *service system* at a given time, it might make more sense to measure its viability as the sustainable competitiveness of the *service system*. For instance, today's globally integrated economy is highlighted with dynamics and uncertainty, thus system viability might be calculated using a suite of performance factors and business environmental indicators collected during operations in a comprehensive and scientific manner.

More specifically, at a given time and market for a given service, the competitiveness of a *service system* might mainly rely on a combination of both profit and user satisfaction as shown in Figure 2 (b). To retain its competitive advantage, it is obvious that the *service system*'s trajectory should be well controlled as time goes. In other words, the system must navigate in its defined business target space during operations in order to outperform its competitors. Under different circumstances, the success might be measures using different or more dimensions of measurements, such as an equation of profit, satisfaction, and productivity. Due to a variety of uncertainties, the business goal at a given period might also require dynamic adjustment by navigating the system across different designated target spaces.

In the remaining section, a *service system* is conceivably constructed based on the BPM *process*-driven concept while being computationally formularized using an automaton-based structured workflow language and π-calculus.

The newly proposed C^2S^2 model mainly focuses on the enablement of system configurability by taking into account service system's characteristics (e.g., people-sensing, co-creation values, human interactions and consequences).

Figure 2 Service System Competitiveness



(a) Profit model (b) System trajectory model

2.1 The Systemic View of a Service System

The reality is that many aspects in the market are correlated in today's integrated global economy, so are the *service systems*. To better understand how a *service system* performs, it becomes clear that the levels and details of analyses should be broad enough and comprehensive enough to reveal all the necessary interactions, interdependencies, and relationships within the *service system*. The process-driven BPM approach appears as an appropriate choice as drilling down into specific processes and their nested sub-processes is which is needed to reveal the details.

However, as mentioned earlier, no matter where, why, when, who, what, and how, by end of the day the real value of a delivered service most likely lies in its ability to satisfy customer's need from a business competitiveness perspective. Extreme customer service helps businesses survive; BusinessWeek (2009) recently published a list showing that 25 companies get it right in a tough year. Thus the understanding of how process activities (or tasks) performed as individuals and a whole during the lifecycle of a service affects customer satisfaction becomes essential. The understanding is also a necessity for a *systemic* decision-making on how the *service system* should be transformed for improved customer satisfaction or a competitive advantage in a technically capable, financially available and justifiable, and socially amiable and adaptable manner. In other words, the *systemic* view of a *service system* capturing the issues mainly related to operations, integration, human behaviors, and globalization will play a key role in computationally modeling of the *service system*.

Very recently, Yet Another Workflow Language (YAWL) was developed to directly support all control flow patterns required in a workflow system (van der Aalst and ter Hofstede 2005). "Corporations are notorious for introducing technology without considering the human consequences." (Kanellos 2004) This is quite true for the existing workflow models and languages. In this paper, the set of symbols in YAWL is revised and expanded to better support BPM-based process flows (Weske 2007) incorporating human tasks and human interactions to meet the needs of this research. Figure 3 shows the revised set of symbols that will be used in the propose C^2S^2 model.

Figure 4 shows a typical example of a virtual project development system (VPDS) using the revised set of symbols (van der Aalst and ter Hofstede 2005, Weske 2007). This VPDS is composed of multiple teams working across geographic, political, cultural, and enterprise organizational boundaries, responsible for conducting research and development projects in a global high-tech bellwether service organization. One team takes a leadership, managing project development overall issues, such as customer contacts and requirement solicitation, service product design and architecture, work breakdown structure design, progress supervision, coordination among teams, and other managerial functions. Other teams are typically located in different regions or countries and focus on developing specific task components (i.e., part of projects, or sub-projects) based on their respective skill sets. By spanning institutional, geographical, and cultural boundaries, this VPDS as a typical *socio-technical service system* aims at leveraging the best-of-breed talents in an integrated and collaborative way for a competitive advantage in the integrated global marketplace.

Figure 3 Symbols Used in C^2S^2 Models, revised and adapted from YAWL (van der Aalst and ter Hofstede 2005)

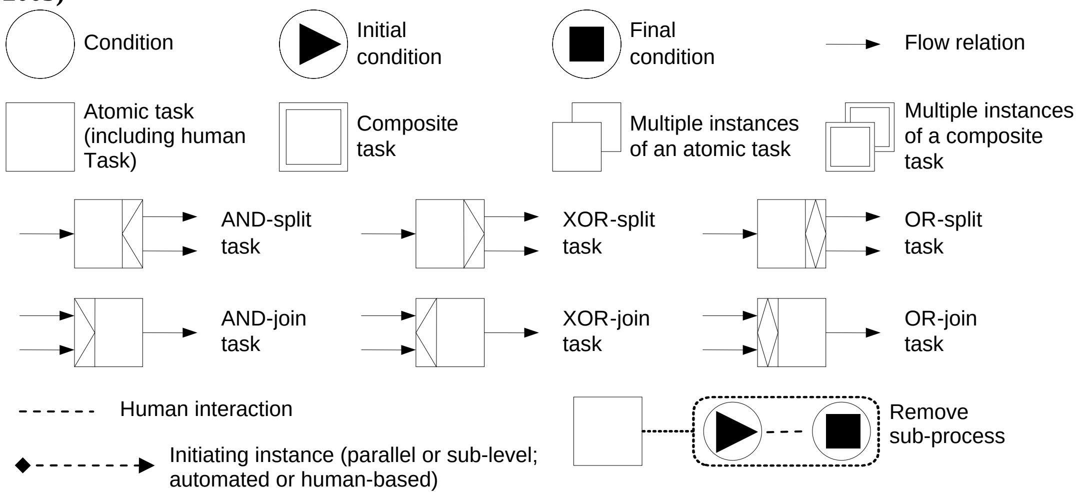
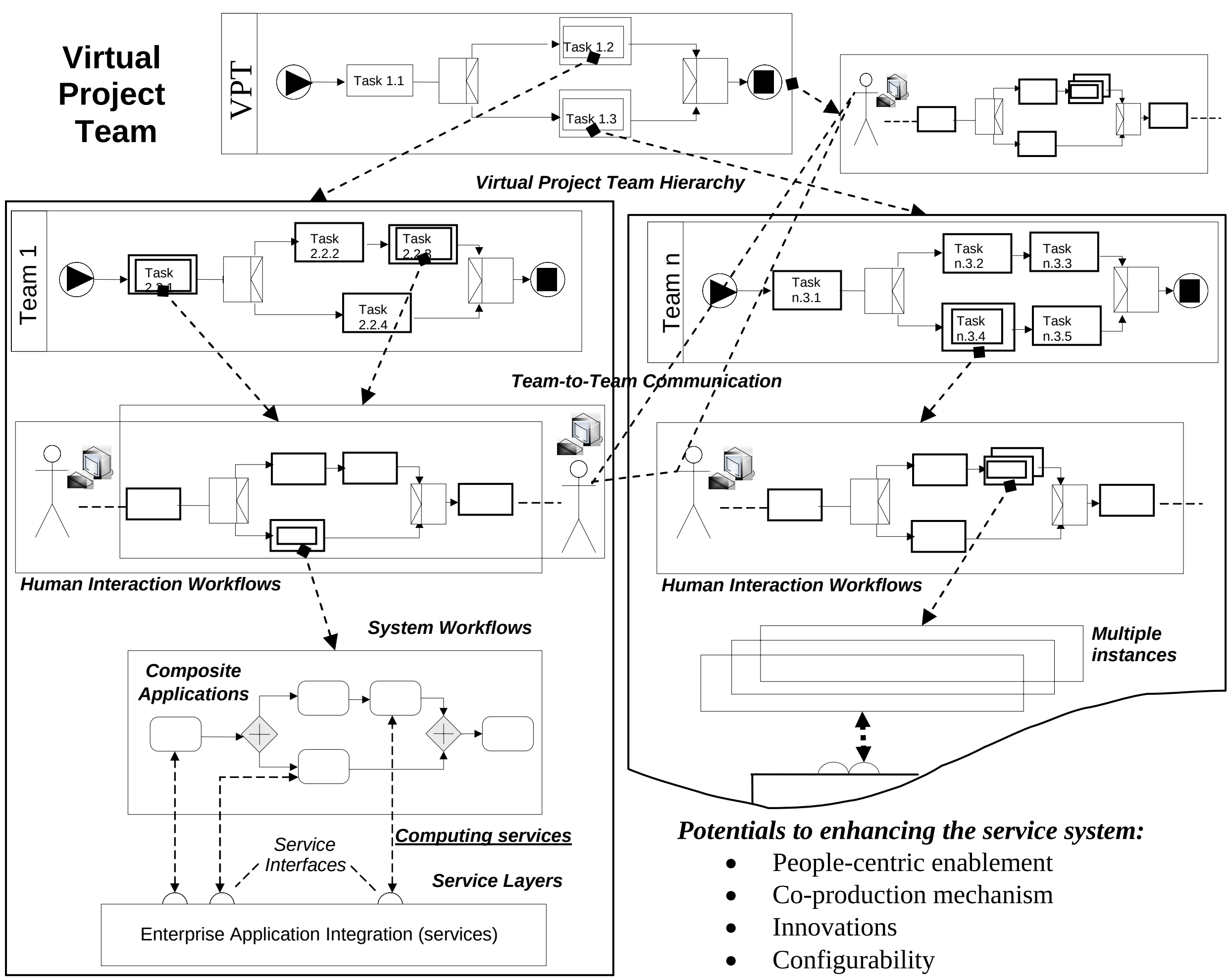


Figure 4 A Typical Global Project Development Service System



In general, the success of the VPDS operations largely depends on how *people* who are involved in the processes perform collectively, how they individually follow the identified best practice, how they collaborate with each other by leveraging the best-of-breed talents, and how the VPDS navigates when uncertainties occur from time to time. The following possible measurements collectively reflect how the VPDS is doing at the point of measure:

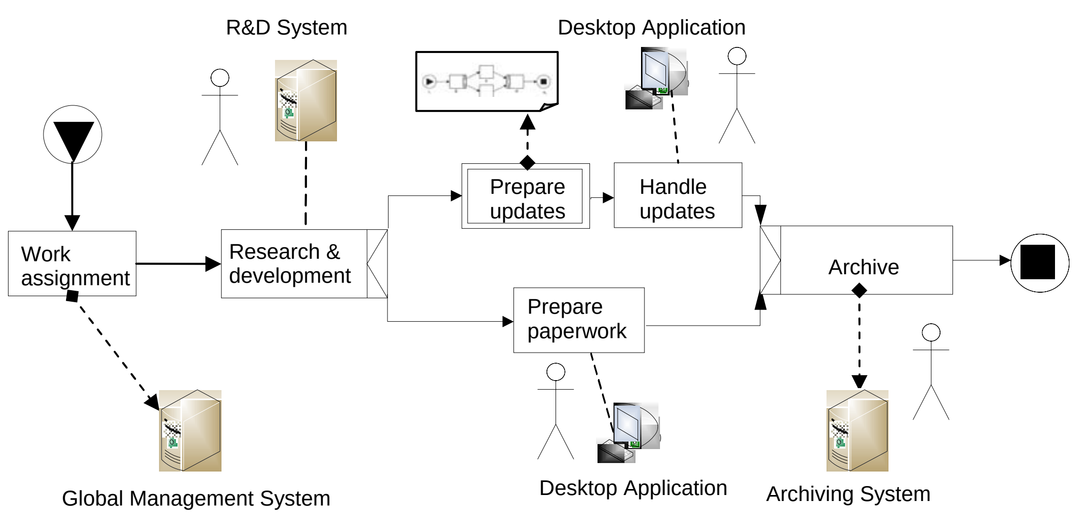
- Conflicts (indicated by culture issues, managerial styles, personalities, etc.);
- Communication effectiveness (indicated by language barrier, customs, infrastructures, meeting setting, etc.);
- Project matter (indicated by size, complexity, geographical locations, the number of teams and members, team competency, etc.);
- Project management (indicated by project management method, tools, cost, commitment, risk matrices and control, etc.);
- Project goal (indicated by targeted marketplace, timeframe, etc.); and service satisfaction (indicated by customer feedbacks, loyalty, etc.).

Given the complexity and uncertainties, the VPDS presumable superiority over centralized project development systems is not warranted if there are no a scientific method and a suite of tools to efficiently and cost-effectively manage its end-to-end operations. A computational model employed for capturing the operational dynamics and trajectory of the VPDS becomes the key to exploring its *systemic* operations, behaviors, and interactions. Being able to navigate in its target space at a given time, the VPDS would yield a more predictable, controllable, and sustainable service business.

2.2 The Dynamics of Processes in a Service System

Processes are the building blocks in a BPM *service system*. A process in a *service system* is a collection of related, ordered, structured activities or tasks, which is typically organized for producing a specific service to meet a particular need. When the service requires a divide-and-conquer approach by leveraging system resources (e.g., best-of-breed talents), the process can be recursively decomposed into sub-processes as shown in Figure 4. No matter how many process levels a *service system* has, each process should have its boundaries, inputs and outputs, dependencies, and communication channels clearly defined in the system hierarchy.

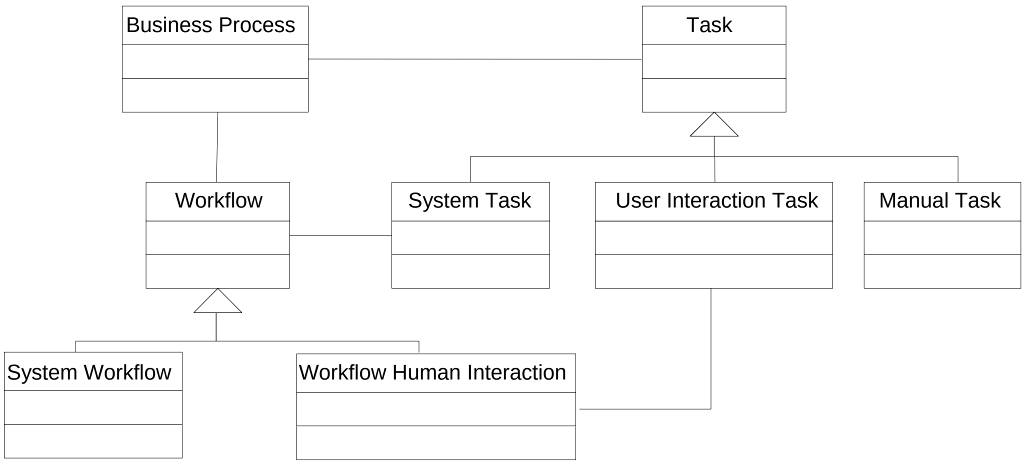
Figure 5 A Typical VPDS Process Flow, revised based on Weske (2007)



Dependent upon circumstances, levels of processes could take a hierarchical structure following the defined work breakdown structures so as to ensure that service work dependencies can be well controlled and managed. However, beyond communications facilitated by the top level process, personal communications among processes at all levels should be encouraged to leverage the culture of best-of-breed approach and cultivate *people* to innovate.

As a VPDS example seen in Figure 4, no matter how many projects or sub-projects are under research and development in a team, the team follows a given business (project development) process flow. The flow dynamics of a team in a VPDS can be schematically illustrated using a *systemic* process diagram (Figure 5). Each flow is essentially a logic sequence of different task operations and designated control patterns. For a task, it could be just a variety of activities performed at a given discrete time, by a given person(s). Using the Unified Modeling Language Figure 6 conceptually shows the relationships and dependencies among the entities in a given process.

Figure 6 Process Conceptual Entity Model , revised based on Weske (2007)



In the proposed C2S2 model, a *service system* process can be formally defined as a 7-tuple workflow net

$$S = (C, i, o, T, F, A, \pi) \,, \tag{1}$$

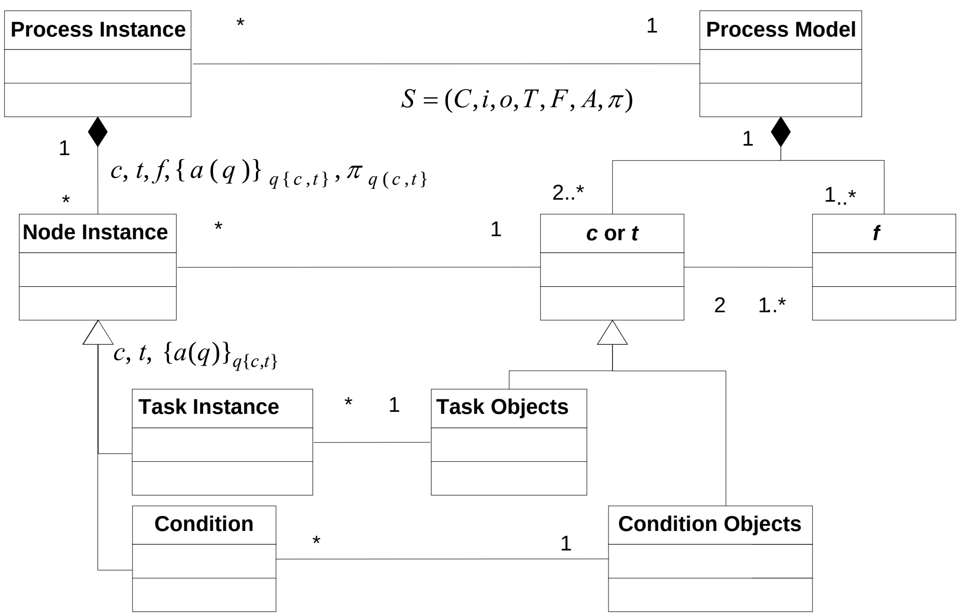
where

- C is a set of conditions;
- $i \in C$ is the initial condition ;
- $o \in C$ is the final condition ;
- T is a set of tasks, such that $C \cap T = 0$;
- $F \subseteq (C-\{o\} \text{x} T) \cup (T \text{x} C-\{i\}) \cup (T \text{x} T)$ is a flow function, such that every node in the defined graph $(C \cup T, F)$ is on a directed path from i to o;
- A is a family of finite sets of task-oriented attributes $\{A(q)\}_{q \in C \cup T}$, where $A(q) = \{split, join, rem, nofi, \Phi(q)\}$:
    - *split*: $t^{split} \in T \rightarrow \{And,\ Xor,\ Or,\ Null\}$, which specifies the split behavior of a task;
    - *join*: ${}^{join.}t \in T \rightarrow \{And,\ Xor,\ Or,\ Null\}$, which specifies the join behavior of a task;
    - *rem*: $t^{rem} \in T \nrightarrow \wp$ for $\wp \in 2^{S = (C, i, o, T, F, A, \pi)}$, which specifies the subset of the net that should be removed when the task is executed;
    - *nofi*: $t^{nofi} \in T \nrightarrow \mathrm{N} \times \mathrm{N}^{\inf} \times \mathrm{N}^{\inf} \times \{dynamic, static\}$ specifies the number of each task (min, max, threshold for continuation, and dynamic/static creation of instances);
    - $\Phi(q)$ for $q \in C \cup T$ and $\Phi(S) = \bigcup_{q \in C \cup T} \Phi(q)$ is the task hierarchy (e.g., a work breakdown structure) map function given at node q, where $\Phi(S)$ maps out all the tasks defined in the hierarchy.
- π is a set of collaborative communications defined using π-calculus. $\pi = \bigcup_{q \in C \cup T} \pi_q^{\Phi(q)}$, where $\pi_q^{\Phi(q)}$ for $q \in C \cup T$ is a collaborative communication with other concurrent processes by receiving and/or sending activity-related data through automated or manual channels: s, where $s = \bigcup_{q \in C \cup T} (s_q + \bar{s}_q)$. More specially,
    - $\pi_i^{\Phi(i)} = s_i(i^{\Phi(i)}).S$ indicates process S gets instantiated and initiated after receiving a service task;
    - $\pi_o^{\Phi(o)} = \bar{s}_o < o^{\Phi(o)} > .0$ indicates process S gets terminated and removed after sending out the outcomes of the completed service task;

- $\pi_q^{\Phi(q)} = \overline{s_q} < a^{\Phi(q)} > .S + s_q(a^{\Phi(q)}).S$ for $q \in (C-i-o) \cup T$ indicates receiving and/or sending activity-related data at node *q* through automated or manual channels during the operations of this instantiated process:
  - If $\overline{s_q}$ is a newly established channel at *q*, $\overline{s_q}$ is defined as $(\gamma \overline{s_q})$; if no channel is needed, then $\overline{s_q}$ is not defined, i.e., Λ (no sending channel).
  - If s_q is a newly established channel at *q*, s_q is defined as (γs_q) ; if no channel is needed, then s_q is not defined, i.e., Λ (no receiving channel).

Generally speaking, a process instance is instantiated from its predefined process model whenever there is a new service that is assigned as a new input (Figure 7). This instantiated process instance will be terminated or removed as soon as the service is completed or has an exception requiring a process removal. Data related to all the activities (tasks, communications, system behaviors, and so on and so forth; automated or manual) during the process operations should be timestamp logged. This should be enforced for all levels of processes for a given *service system* although in reality it is well understood that only part of the needed data and information might be saved and collected.

Figure 7 Object Model for a Process Model and Its Instances, revised based on Weske (2007)



2.3 The Dynamics of a Service System

A formal computational model of a *service system* is an unambiguous description of the system dynamics in light of control, communications, and interactions across all the involved processes. It is an abstract view of the system, which specifies the functionality and behavior of the system without being constrained by implementation details.

Formally, a *service system* can be defined as a 5-tuple

$$M = (Q, top, T^{\Diamond}, map, \Pi) , \quad (2)$$

where

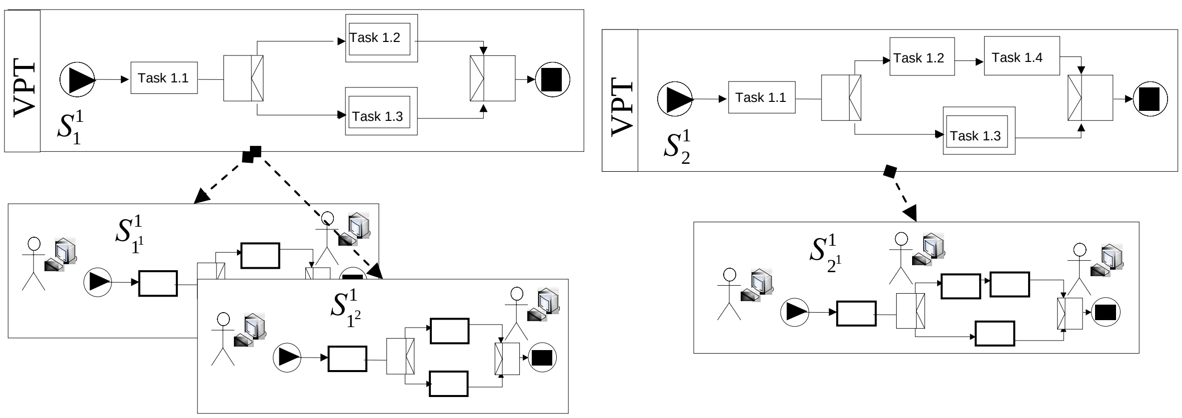
- $Q = \bigcup S$ is a set of *service system* processes;
- $top \in Q$ is the top level processes;
- $T^{\Diamond} = \bigcup_{S \in Q} T_S$ is the set of all tasks, such that $(\forall i)(\forall j)(S_i, S_j \in Q), i \neq j, S_i \neq S_j$ $\Rightarrow (C_{Si} \cup T_{Si}) \cap (C_{Sj} \cup T_{Sj}) = 0$;

- *map*: $T^{\Diamond} \nrightarrow \Phi(Q - \{top\})$ is a mapping function that specifies the task hierarchies for each composite task in the *service system*;
- $\Pi = \bigcup_{S \in Q} \pi_S$ is the set of all collaborative communications in the *service system*.

2.3.1 The Top Level of a Service System

When multiple services are engineered throughout a *service system* simultaneously, there will be multiple processes at the top level. Each unique type of service engineered and delivered by the *service system* could require a unique process model as it might require a unique collection of related, ordered, and structured tasks. However, the same type of services should be developed by following the same process model. In other words, multiple instantiated process instances from the same process model can be executed to deal with the same types of services. Figure 8 schematically illustrates the top level of a *service system* by which 3 projects are developed at the same time, where 2 out of 3 belong to the same type of services.

Figure 8 Parallel Process Instances at the Top Level



According to the above proposed *service system* formal model *M*, its parallel computational process models executed at its top level can be further defined by

$$top = (S_1^1 \,||\, S_2^1 \,||\, \cdots \,||\, S_i^1 \,||\, \cdots \,||\, S_m^1) \text{ or } top = (\bigcup_{j=1}^{n_1} S_{1^j}^1 \,||\, \bigcup_{j=1}^{n_2} S_{2^j}^1 \,||\, \cdots \,||\, \bigcup_{j=1}^{n_i} S_{i^j}^1 \,||\, \cdots \,||\, \bigcup_{j=1}^{n_m} S_{m^j}^1), \tag{3}$$

where superscript 1 indicates level 1 (i.e., the top level); *i*=1, …*m*, *m* is the number of unique processes running simultaneously at the top level. For each process model, if multiple instances are instantiated, then the process can be further defined by

$$S_i^1 = \bigcup !S_{i^j}^1 = \bigcup_{j=1}^{n_i} S_{i^j}^1 , \tag{4}$$

where $!S_{i^j}^1$ is a process instance (i.e., process replication) for the i^{th} type of service, $j=1,\ldots n_i$, n_i is the number of instances for this service.

The top level of the example shown in Figure 8 can be then defined as

$$top = (S_1^1 \,||\, S_2^1) \text{ or } top = (\bigcup_{j=1}^{2} S_{1^j}^1 \,||\, \bigcup_{j=1}^{1} S_{2^j}^1) . \tag{5}$$

2.3.2 The Hierarchy of a Service System

As discussed earlier, it is very typical for a *service system* to have a hierarchical structure, aimed at effectively taking advantage of divide-and-conquer approach to dealing with complex and/or global services. Each lower process is typically created by focusing on developing specific task components, so right skill sets and resources can be identified and allocated for efficient and cost-effective use. For instance, the above discussed VPDS that spans institutional, geographical, and cultural boundaries is such a *socio-technical service system*. It is established for gaining competitive advantage through leveraging the best-of-breed talents across the continents.

Based on the definition of a generic process, a process model at the l^{th} level ($l \geq 2$, i.e., lower level) can be then defined by

$$S^l = (C^l, i^l, o^l, T^l, F^l, A^l, \pi^l) \text{ iff } \exists((t^{rem})^{l-1}) \text{ and } (t^{rem})^{l-1} \in T^{l-1} \rightarrow S^l, \quad (6)$$

where S^l is essentially a subnet of net S^{l-1}. S^{l-1} might have several subnets, depending on the number of specific sub-tasks defined in S^{l-1}. Of course, lower level processes can be further defined if a composite task requires descending numerous levels from the top.

Assume without loss of generality that there is only one business process in the leading team and two processes executed by two other support teams in the presented VPDS example. As each of them is operated in a different country, any project will thus be divided and formed as a composite task as shown in Figure 9. Accordingly, a hierarchy of the *service system* can be established. For this simple illustration (Figure 10), no matter which level only one process instance is instantiated from its corresponding model.

Figure 9 Task Breakdown Hierarchical Structure and Tree Mapping Scheme

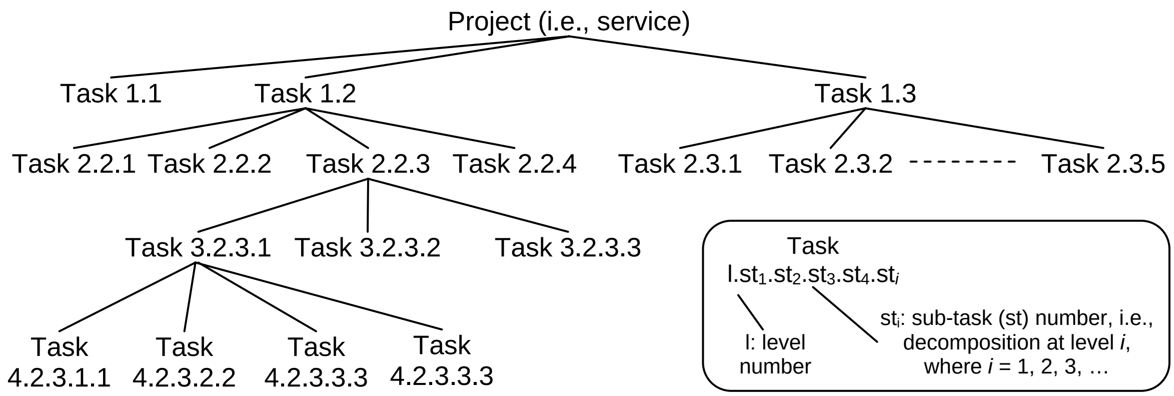
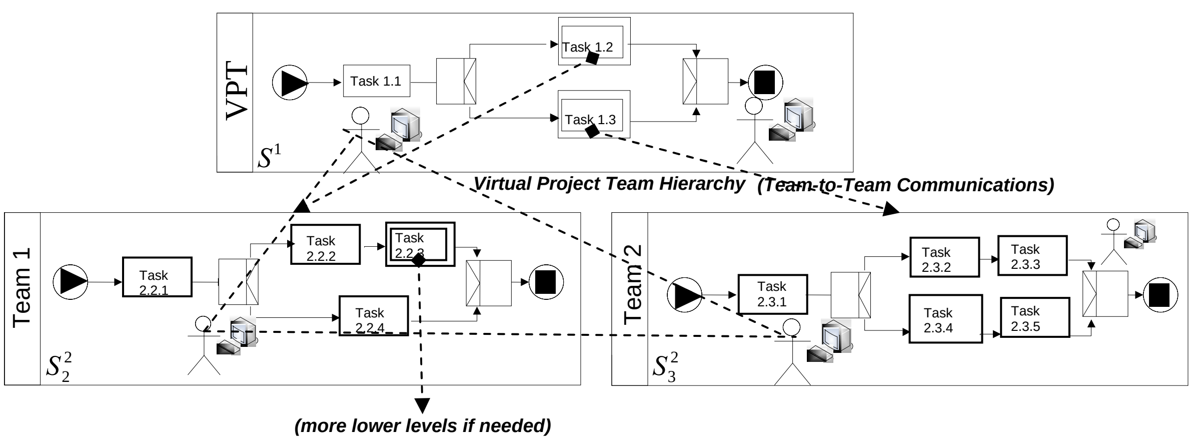


Figure 10 Process Hierarchy Model



2.3.3 System Data and Process Logs

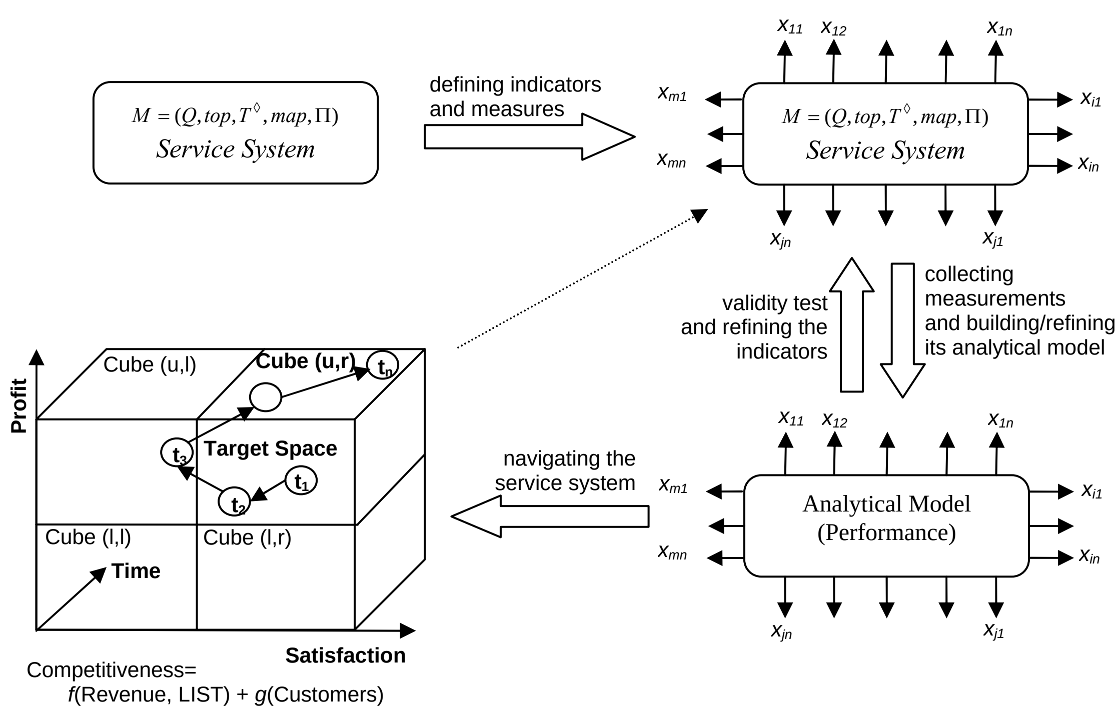
As mentioned earlier, data and information related to all the activities (tasks, communications, system behaviors, and so on and so forth, either automated or manual) during the service operations should be timestamp logged. However, it is well understood that in reality the collected and aggregated data and information for any today's *service system* are typically overwhelming, in which a high percentage of the collections could be non-associated, redundant, and context-insensitive. Discussions on how to design, develop, and implement systematic or standardized methods to perform data, information, and knowledge integration led to the constructs of consistent, relevant, and sound data, information, and knowledge bases are out of scope of this paper but our future interests.

3. Performance, Metrics, and Measures

As discussed earlier, to stay competitive it might make more sense to measure the viability rather than simple profitability of a *service system*. At a given time and market for a given service, the viability of a *service system* might rely on a combination of both profit and user satisfaction as shown in Figure 2 (b). To retain its competitive advantage, it is obvious that the *service system*'s trajectory should be well controlled throughout the service lifecycle. Adequate metrics with applicable measures to be used for evaluating how a *service system* performs from time to time are indispensable to making swift and informed decisions, so that the *service system* can successfully navigate throughout uncertainties and be viable in the long run.

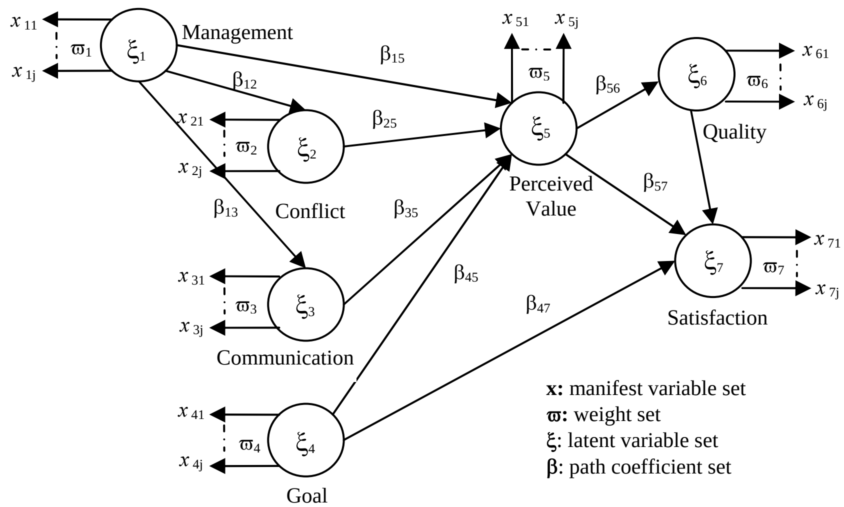
Modeling using *computational thinking* focuses on exploring, capturing, understanding, and managing *systemic* behaviors, interactions, connections, complex relations, and interdependencies of a *service system*. However, resources, largely *people* **-** the main focus of a *service system*, are more complex to model and study as *people* participating in service production and consumption have physiological and psychological issues, cognitive capability, and sociological constraints, etc. Therefore, measurements of a *service system* should be collected using methods and means capable of capturing the insights and dynamic *social-technical* behaviors of the *service system*, directly and indirectly. Ultimately, through qualitatively and quantitatively analysis a *service system* can successfully navigate throughout a variety of uncertainties and stay competitive (Figure 11).

Figure 11 Computational Thinking Modeling for Competitive Service Systems



Structure equation modeling (SEM) has been widely used to study social and/or economic behavior of organizations. By carefully designing the indicators (i.e., measurements) from both social and technical perspectives of a *service system*, improved SEM can be effectively applied in this interdisciplinary field. As an example, the dynamics of the presented VPDS might be essentially described using the following latent model constructs/variables: 1) Conflicts (indicated by culture issues, managerial styles, personalities, tasks, etc.); 2) Communication effectiveness (indicated by language barrier, customs, infrastructures, meeting setting, etc.); 3) Size of project (indicated by geographical locations, the number of members, etc.); 4) Project management (indicated by project management method, tools, cost, commitment, risk matrices and control, etc.); 5) Project goal (indicated by targeted marketplace, timeframe, etc.); and 6) Quality, and Satisfaction (Figure 12).

Figure 12 An SEM for the Presented VPDS



Different from many covariance-based modeling approaches, the Partial Least Squares approach to Structural Equation Modeling (PLS SEM) is a soft modeling with relaxation of measurement distribution assumptions. In addition, PLS SEM requires only a small size of measurement samples and tolerates measurement errors. For the measurement model, the latent variables ξ is a linear function of its measurement variables plus a residue δ, i.e.,

$$\xi = \sum_j \varpi_j x_j + \delta, \quad E(\xi \mid x) = \sum_j \varpi_j x_j. \tag{7}$$

For the structural model, the path coefficients between latent variables ξ is given by

$$\xi_j = \sum_i \beta_{ij} \xi_i + \zeta_j, \tag{8}$$

where ζ is the vector of residual variance.

Note that the operational dynamics of a *service system* can be easily and well explored and studied using a PLS SEM. To illustrate the proposed modeling, this research initially focuses on the following analyses about the *service system* (e.g., the presented VPDS) at the point of need through the PLS SEM approach:

- Performance index – What kind of level of the business operational objective was achieved (e.g., the customer satisfaction level for a given engineered and delivered service)?
- Impact scores - How did an individual measured factor affect the performance index (e.g., the final customer satisfaction level)?

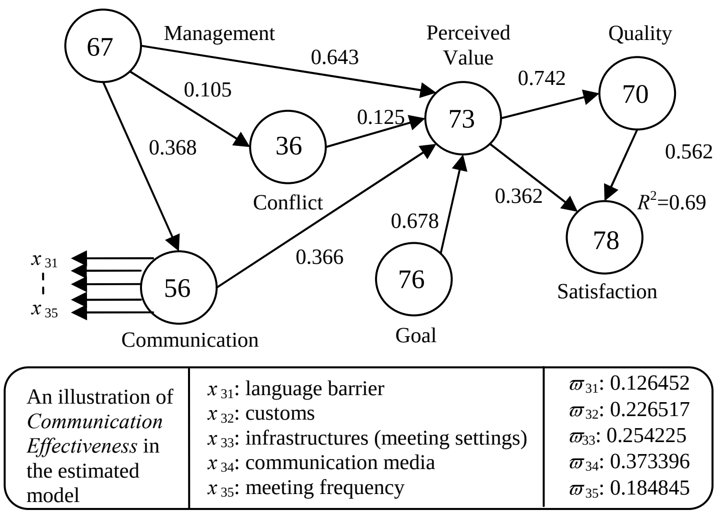
As an example, Figure 13 shows an estimated model for the presented VPDS. The performance index for a latent variable is estimated at a 1-to-100 scale basis for easy human interpretation. Thus, a weighted average of scores from corresponding measurement variables is used by converting the original 7-point (***X***) scale to a 100-point scale (***V***) (Martensen and Gronholdt 2003).

More specifically, Figure 13 gives some analytical results from one group of collected measurements for the presented VPDS:

- Performance index – The service satisfaction is at the performance index of 78 out 100. As the model is able to explain 69% of what drives user satisfaction (R^2=0.69), the model indeed delivers a high and substantial explanatory level.
- Impact scores – In regard to communication effectiveness in the VPDS, the effect of 1-point increase in the communication effectiveness results in 0.284 (0.366x0.362+0.366x0.742x0.562) points' improvement in the satisfaction performance index.

As schematically illustrated in Figure 11, once we can directly and indirectly collect adequate measurements of a *service system* that truly and timely capture the insights and dynamic *social-technical* behaviors of the *service system*, the organizational effectiveness, operational efficiency, and adaptiveness of the *service system* can be analyzed and evaluated in a quantitative and qualitative manner, which optimally ensure smarter decision-making for business to stay competitive. If needed, proper transformation can be applied, resulting in the successful navigation throughout a variety of uncertainties.

Figure 13 An Estimated Model for the Presented VPDS



4. Conclusions

In today's globalized economy, enterprises are keen on building highly profitable service-oriented businesses by taking advantage of their own unique engineering and service expertise, aimed at shifting gears towards creating superior outcomes to best meet their customer needs in order to stay competitive. However, there lack of full-fledged sciences that could systematically guide the plan, design, marketing, engineering, and delivery of services to meet the challenges highlighted by changes, complexity, and dynamics from political, social, and economic aspects, thus we are in great need of the theory and principles towards engineering, operating, managing, and evolving *service systems* in the service-led economy.

By fully leveraging today's ubiquitous digitalized information, computing capability and computational power, this paper presented an approach to modeling of the dynamics and adaptiveness of *service systems*, enabling mechanisms of *people-sensing* to capture their physiological and psychological issues, cognitive capability, and sociological constraints during the lifecycle of services. More potential includes the enablement of system configurability as we fully took into account service system's characteristics (e.g., people-sensing, co-creation values, human interactions and consequences). This research should lay out a solid foundation for our future research. As discussed earlier, the following mechanisms should be developed to implement and enhance *service systems*:

- A mechanism to timely capture end users' requirements, changes, expectation and satisfaction in a variety of technical, social, and cultural aspects;
- A mechanism to efficiently and cost-effectively provide employees right means and assistances to engineer services while promptly responding the changes;
- A mechanism to allow involved *people* consciously infuse as much intelligence as possible into all levels and aspects of decision-making to assure necessary system adaptiveness for smarter operations.

Ultimately, *service systems* will then be operated in a smarter, competitive, and satisfactory fashion.

Acknowledgement

This work was done with great help from Dr. Ruoyi Zhou's research team at IBM Almaden Research Center, USA. We highly appreciated Dr. Ray Strong's many insightful comments and suggestions. This work was partially supported by US NSF Grants (DMI-0620340, DMI-0734149), Nanjing University of Aeronautics and Astronautics Endowed Professor Scholarships (1009-905346, 1009-908332), Chinese NSF Grants (70541007, 70772073), Department of Education Grant (08JA630040, China), and IBM Faculty Award (2008-2009, China).

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