System Informatics-based Services: A Conceptual Framework

Kwang-Jae Kim†
Department of Industrial and Management Engineering
Pohang University of Science and Technology, Pohang, Korea
Tel: (+82) 54-279-2208, Email: kjk@postech.ac.kr

Chie-Hyeon Lim
School of Engineering
University of California, Merced, California, USA
Tel: (+1) 415-657-6261, Email: clim28@ucmerced.edu

Jun-Yeon Heo
Department of Industrial and Management Engineering
Pohang University of Science and Technology, Pohang, Korea
Tel: (+82) 54-279-8249, Email: bluejy@postech.ac.kr

Min-Jun Kim
Department of Industrial and Management Engineering
Pohang University of Science and Technology, Pohang, Korea
Tel: (+82) 54-279-8249, Email: minjun@postech.ac.kr

Ki-Hun Kim
Department of Industrial and Management Engineering
Pohang University of Science and Technology, Pohang, Korea
Tel: (+82) 54-279-8249, Email: ksw12312@postech.ac.kr

Chang-Ho Lee
Department of Industrial and Management Engineering
Pohang University of Science and Technology, Pohang, Korea
Tel: (+82) 54-279-8249, Email: dlckdgh@postech.ac.kr

Abstract. Various types and massive amounts of data are being collected these days in multiple industries with the rapid advancement of data collection technologies. Such a big data proliferation has provided new service opportunities. For example, heavy equipment manufacturers monitor, diagnose, and predict product health through prognostics and health management services using the data collected from heavy equipment. Consequently, equipment managers can cope with potential product breakdowns and maximize product availability for clients. This paper proposes a conceptual framework of a new class of services, called system informatics-based service (SIS), where the main contents and values are created based on the analysis of the system data. A review of related literature and real cases of SIS will be presented. The characteristics and properties of SIS will also be discussed.

Keywords: system informatics, system informatics-based services, new service development, service model

1. INTRODUCTION

We live in an information economy, in which data and information are increasingly exchanged in activities in the global economy (Apte and Karmarkar 2007). In particular, various types and massive amounts of data are being collected these days in multiple industries with the rapid advancement of data collection technologies (Atzori *et al.* 2010). Such a big data proliferation has provided new service opportunities. For example, heavy equipment manufacturers monitor, diagnose, and predict product health through prognostics and health management (PHM) services (Lee *et al.* 2014). Consequently, equipment managers can cope with potential product breakdowns and maximize product availability for clients. In this service, the manufacturers use PHM algorithms (Mortada *et al.* 2014; Mehta *et al.* 2015) to analyze data collected from heavy equipment.

A prerequisite for realizing such service opportunities is an understanding of the identity of such services and their development. However, related studies are nearly unknown. Thus, this paper defines a new class of services called the "system informatics-based services (SIS)." In SISs, the main contents and values are created based on the analysis of the data collected from the system in question. Furthermore, this paper also proposes a conceptual framework of SIS. The proposed conceptual framework of SIS aims to represent the overall production and delivery processes of SIS and helps one to understand the unique characteristics and values of SIS. This paper is expected to contribute to new SIS development in this data-intensive information economy.

2. REVIEW OF RELATED STUDIES

SIS refers to a new class of services, where the main contents and values are created based on the analysis of the data collected from the system in question. The emergence of SIS cases can be observed in diverse industries. This type of service is based on the SI and related technologies, which enables the collection and analysis of a huge amount of data. Aside from current situation, academic research on SIS is insufficient. In order to support and stimulate this research area, the authors firstly reviewed various cases and related literature for gathering insights about SIS. For instance, by utilizing car's engine rpm, temperature, or velocity data, the telematics service has been developed by various automobile companies and research institutes (Kakizawa *et al.* 2013). In addition, there are many researches and practical service cases regard to the building energy management service (BEMS). Based on sensor-collected the data collected from buildings, many researchers have investigated how to control the building energy consumption in more efficient and environmental-friendly ways (Klein *et al.* 2012).

This section introduces some of the studies highly relevant to this paper. Subsection 2.1 reviews studies related to the SIS concept. Subsection 2.2 reviews studies related to the SI-NSD framework.

2.1 Studies Related To the SIS Concept

Researchers have discussed the contribution of IT to service using several concepts such as the information-intensive service (Karmarkar and Apte 2007), IT-related service (Huang and Rust 2013), technology-mediated service (Schumann *et al.* 2012), and smart interactive service (Wünderlich 2012). Each of the concepts has a different scope and focus. The information-intensive service concept focuses on the information interaction itself, regardless of technology involvement. The IT-related service concept includes any type of service creation and delivery in which IT plays a substantial role. The technology-mediated service concept focuses on the immediate exchange of information over long distances while the smart interactive service concept focuses on intensive human (i.e. customer and employee) actions in the smart service in which services are delivered to or through intelligent products.

The product–service system (PSS) concept is also highly relevant with the SIS concept. The service-led competitive strategy employed by manufacturing companies has generated specific types of value propositions that integrate products and services in a single system. Recent studies have called this servitized value proposition "PSS" (Mont 2002). PSS has been investigated in literature as a means of innovating product-based offerings in an economically, environmentally, and socially sustainable manner (Tukker 2015). Over the past decade, researchers have investigated PSS development to facilitate PSS development tasks, such as strategic planning, conception, and implementation (Cavalieri and Pezzotta 2012; Kim *et al.* 2012).

Studies from an IT- or a product-oriented perspective are also useful to understand data utilization in services although they do not emphasize a service-oriented perspective. Atzori *et al.* (2010) conducted an early survey to see various aspects of the Internet of Things (IoT) phenomena. The study defines the key components to actualize IoT, such as identification, sensing and communication technologies, and a software layer or a set of sub-layers interposed between the technological and the application. Barnaghi *et al.* (2013) discuss that the process chain for Web of Things involves sensing raw data; pre-processing, aggregation and filtering; metadata integration and annotation; post-processing, abstraction, pattern

Table 1. Representative SIS cases in multiple industries

Types of Services	Description
Telematics Service	The integrated use of telecommunications and informatics for application in vehicles with control of moving vehicles
Predictive Assets Maintenance Service (PHMS)	The total management service of a large plant system to avoiding unplanned downtime
Building Energy Management Service (BEMS)	The computer-based service that helps to manage, control and monitor building technical services and energy consumption

recognition; semantic analysis and interpretation; and knowledge extraction and information visualization. Smart, connected product is a type of product in which physical, smart, and connectivity components are integrated to provide functions (Porter and Heppelmann 2014). The study argues that what is fundamentally important of IoT phenomena is not the internet, but the changing nature of things and the expanded capabilities of things and the data they generate.

Compared to the traditional IT-based service concepts, SIS focus mainly on "creating" information that effectively accomplishes stakeholder goals, whereas the traditional ones have emphasized the efficient "delivery" of information to patients. Compared to the PSS concept, SIS focuses mainly on the service using the data from product systems. Compared to the IoT and smart, connected product concepts, SIS emphasizes a service and customer-oriented viewpoint.

2.2 Representative cases of SIS

Data analytics technologies have been improved, resulting in new types of services. For investigating these cases, the authors collected more than 100 cases from various service areas. Some representative SIS cases are presented in Table 1.

Various manufacturers have provided SISs as service components of their products (Lim et al. 2015). For example, agricultural machine manufacturers provide the precise farming service that delivers farmers information on the exact amount of fertilizer to spray on crops (Bettencourt 2010). This service helps increase yield and minimize the amount of fertilizer used. In this service, information identification is based on the analysis of navigation and operation data collected from agricultural machines. Meanwhile, heavy equipment manufacturers monitor, diagnose, and predict product health through prognostics and health management (PHM) services (Lee et al. 2014). Consequently, equipment managers can cope with potential product breakdowns and maximize product availability for clients. In this service, the manufacturers use PHM algorithms (Schwabacher and Goebel 2007; Zhang et al. 2013; Chien et al. 2014; Mortada et al. 2014; Mehta et al. 2015) to analyze data collected from heavy equipment. Similarly, manufacturers of documentrelated products monitor and analyze data collected from the document management processes of business customers (i.e., organizations that purchased copymachines or printers) to acquire the necessary information to assist customers in completing document-related tasks at reduced cost, hassle, and consumable use (Rothenberg 2007).

Various SIS cases are seen in multiple industries and essentially share a common framework: (1) data is collected from target system(s), (2) data is analyzed and processed into valuable information for potential demand from system(s) or customers, (3) a new customized service is provided based on the processed information.

3. A CONCEPTUAL FRAMEWORK OF SYSTEM INFORMATICS-BASED SERVICES

As mentioned earlier, SIS is a new class of services that fulfills system stakeholders' needs and creates new value based on results generated from system informatics. SIS has several distinctive characteristics compared with other existing services. Fundamentally, SIS is based on system informatics and related technologies, which enables the collection and analysis of a huge amount of data. Such data proliferation lays the foundation for service provision, and consequently, the result of data analytics unveils stakeholder's needs more objectively and effectively. Proactive customization is another feature of SIS. When a system and its stakeholders continue their interaction during service provision, the SIS's target is not only the system but also its stakeholders.

Based on various exploratory reviews, we derived a common conceptual framework of SIS (Lee et al. 2015), which is presented in Figure 1.

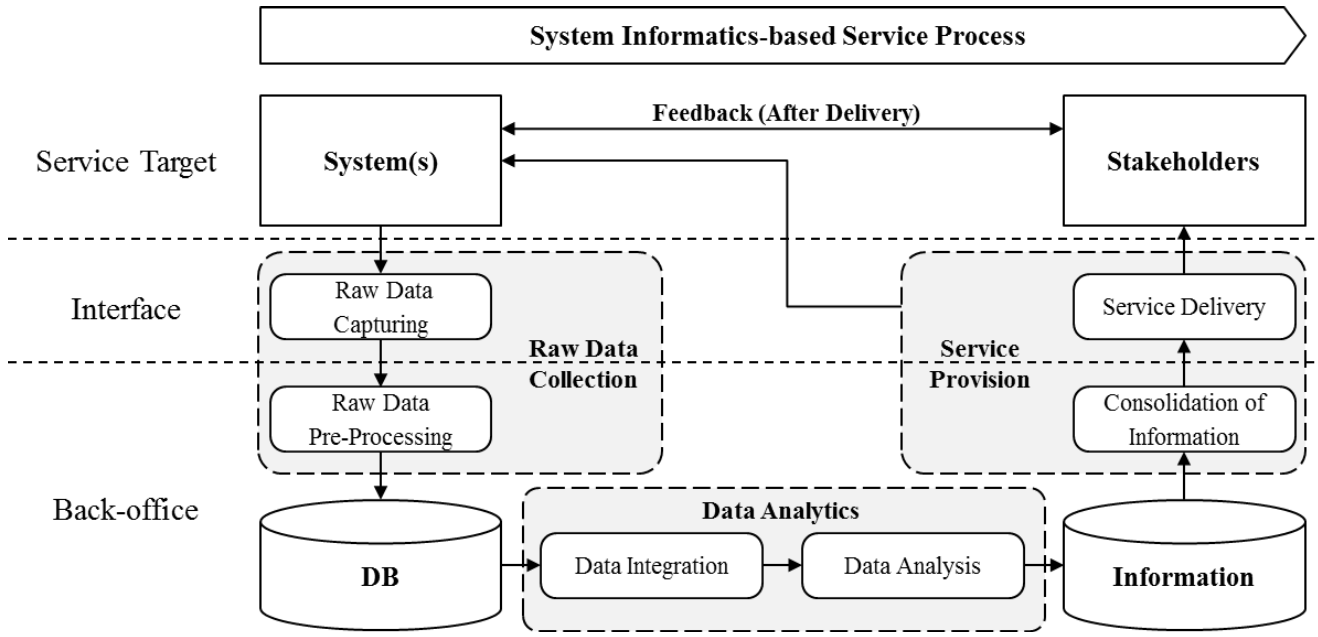

Figure 1. SIS conceptual framework (Lee et al. 2015)

The SIS delivery procedure undergoes three phases: (1) raw data collection, (2) data analytics, and (3) service provision. First, the service provider collects raw data from a target system. The raw data is collected by physical measurement tools such as sensors or wearable devices, and saved in the DB. Second, the pre-processed raw data goes through data analysis tools (or machines). Data analytics process results in useful information or knowledge in the form of SIS content. Third, once information is accumulated, it is packaged and delivered to the target stakeholders. Each of the main components or activities of the SIS conceptual framework is described next.

System: The system in the SIS conceptual framework is a target of data acquisition for service provision, which includes engineering systems, such as automobiles and buildings, as well as natural systems, such as human beings, plants, and animals. System is usually a primary source of data, but in some cases, it can be a recipient of SIS as well.

Raw Data Collection: Raw data collection comprises gathering the raw data of interest. This process consists of two sub-processes, raw data capturing and raw data pre-processing. In the former, a service provider must decide the type of raw data to collect first. In raw data pre-processing, data-gathering methods and gathered data are often loosely controlled. Thus, the collected data must be screened into a usable form in the DB.

Database: Database is any collection of the raw data of what designer wants and the way it is organized (Ullman, 1997). In the SIS conceptual model, raw data before DB storage exists as an arbitrary form and does not have meaning itself. Thus, the DB stores the data, which is already preprocessed to fit the service provider's purpose.

Data Analytics: Data analytics is the process of converting raw data into useful information via data analysis techniques (commonly called informatics). This process comprises two sub-processes: data integration and data analysis. Data integration involves combining different pieces of data into an analyzable form. Data analysis involves utilizing and refining a variety of techniques to analyze system data and interprets the analysis results.

Information: Information has a meaning in a specific context, mediating between data and its environment. In SIS, information is extracted from raw data by proper data analytics tools (or machines). Information represents considerable potential to the system itself or its stakeholders. However, it should be consolidated and refined so as to be delivered as a service.

Service Provision: Service provision is to deliver the SIS contents to the stakeholders. This process also involves consolidating information as a deliverable service. The SIS delivery should be made at a proper time, in a proper place, and in a proper manner.

SIS Stakeholder: SIS stakeholders are defined as the beneficiary of the SIS deliverables. They can be classified into system providers and customers. The former consists of system operator, administrator, or system designer. They are usually insiders of the firm that provides the SIS. SIS customers consist of business stakeholders (i.e., system users) and social stakeholders (e.g., regulateors).

4. MAPPING SIS CASES ONTO SIS CONCEPTUAL FRAMEWORK

Two representative cases of SIS (namely, prognostics and health management service and building energy management service) are mapped onto the SIS conceptual framework presented in Section 3.

Case 1 – Prognostics and Health Management Service (PHMS)

In equipment prognostics and health management service (PHMS) (Lee et al., 2014), customers (i.e., system administrators and managers) are concerned with the loss from unexpected breakdowns or prolonged lead time in heavy equipment operation processes. Thus, the service provider collects equipment health and operation data, such as operation rate, temperature, or usage time, for analysis (raw data collection). The analysis process extracts useful information, which contains equipment's safety prediction information or breakdown symptom information (data analytics). The service provider combines these pieces of information to form a deliverable service that enhances the performance of equipment directly to the system itself or sends an abnormal signal to stakeholders and system administrators (service provision). After the service delivery, follow-up remedial actions may be taken by the stakeholders.

Case 2 – Building Energy Management Service (BEMS)

In building energy management service (BEMS), the owner of a building may be interested in saving cost by enhancing energy efficiency. Therefore, many kinds of data, such as energy resource consumption (electricity, gas, water, and so on), status of light bulbs, or indoor/outdoor temperature, are collected via IT-based sensors (raw data collection). Based on the gathered data, an analytics process extracts hidden information or patterns on energy consumption (data analytics). By utilizing the information, the service provider provides a solution to the building owner. For example, an intelligent solution controls building's energy usage depending on people's movement or external environment (service provision). Similar to the preceding case, the building administrator may take remedial actions to better control the energy consumption.

5. CONCLUDING REMARKS

Data proliferation is among the most noticeable trends in the modern data-rich economy. More and more companies in various industries wish to utilize their system data. SIS is a natural outcome of such trends and concerns. Although many cases have been observed and implemented in practice, academic studies on SIS are scarce. This paper introduces SIS and its conceptual framework by integrating insights in the related literature of system informatics and service science. The SIS conceptual framework will help understand SIS and its production and delivery process. This work is expected to aid practitioners in designing, developing, and operating new SISs. In addition, this work presents an academic basis for future studies on SIS. A series of follow-up studies on system informatics-based new service development, SIS design, and operation are warranted.

ACKNOWLEDGMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(NRF-2014R1A2A2A03003387).

REFERENCES

Apte, U.M. and Karmarkar, U. (2007) *Managing in the information economy: current research issues*, Springer.

Atzori, L., Iera, A., and Morabito, G. (2010) The internet of things: A survey, *Computer networks*, **54**, 2787-2805.

Barnaghi, P., Sheth, A., and Henson, C. (2013) From Data to Actionable Knowledge: Big Data Challenges in the Web of Things, Intelligent Systems, IEEE, 28, 6-11.

Bettencourt, L. (2010) *Service innovation: How to go from customer needs to breakthrough services*, McGraw-Hill, London.

Cavalieri, S. and Pezzotta, G. (2012) Product–Service Systems Engineering: State of the art and research challenges, *Computers in Industry*, **63**, 278-288.

Chien, C., Chang, K. and Wang, W. (2014) An empirical study of design-of-experiment data mining for yield-loss diagnosis for semiconductor manufacturing. *Journal of Intelligent Manufacturing*, **25**, 961–972.

Huang, M.H. and Rust, R.T. (2013) IT-Related Service A Multidisciplinary Perspective, *Journal of Service Research*, **16**, 251-258.

Kakizawa, H., Kato, T., Oue, T., Kiyohara, R., Kitagami, S., Terashima, Y., and Saito, M. (2014) Reduction in the Amount of Probe Data During Smartphone Use of Telematics Services, 2014 Seventh International Conference on Mobile Computing and Ubiquitous Networking, Singapore, 74-75.

Karmarkar, U.S. and Apte, U.M. (2007) Operations management in the information economy: Information products, processes, and chains, *Journal of Operations Management*, **25**, 438-453.

Kim, K.J., Lim, C.H., Lee, D.H., Lee, J., Hong, Y.S., and Park, K. (2012) A Concept Generation Support System for

Product-Service System Development, *Service Science*, **4**, 349-364.

Klein, L., Kwak, J., Kavulya, G., Jazizadeh, F., Becerik-Gerber, B., Varakantham, P., and Tambe, M. (2012) Coordinating occupant behavior for building energy and comfort management using multi-agent systems, *Automation in Construction*, **22**, 525-536.

Lee, J., Kao, H.A., and Yang, S. (2014) Service innovation and smart analytics for industry 4.0 and big data environment, *Procedia CIRP*, **16**, 3-8.

Lee, C., Heo, J., Lim, C., and Kim, K. (2015) A Conceptual Model of System Informatics-based Service, 18th QMOD-KSQM International Joint Conference, Seoul, Korea, October 12-14.

Lim, C., Kim, M., Heo, J., and Kim, K. (2015) Design of informatics-based services in manufacturing industries: case studies using large vehicle-related databases, *Journal of Intelligent Manufacturing*.

Mehta, P., Werner, A., and Mears, L. (2015) Condition based maintenance-systems integration and intelligence using Bayesian classification and sensor fusion, *Journal of Intelligent Manufacturing*, **26**, 331–346.

Mont, O.K. (2002) Clarifying the concept of product–service system, *Journal of Cleaner Production*, **10**, 237-245.

Mortada, M.-A., Yacout, S., and Lakis, A. (2014) Fault diagnosis in power transformers using multi-class logical analysis of data, *Journal of Intelligent Manufacturing*, **25**, 1429–1439.

Porter, M.E. and Heppelmann, J.E. (2014) How smart, connected products are transforming competition, *Harvard Business Review*, **92**, 11-64.

Rothenberg, S. (2007) Sustainability through servicizing, *MIT Sloan Management Review*, **48**.

Schumann JH, Wünderlich NV, and Wangenheim F (2012) Technology mediation in service delivery: A new typology and an agenda for managers and academics, *Technovation*, **32**, 133-143.

Schwabacher, M., and Goebel, K. (2007) A survey of artificial intelligence for prognostics. In AAAI fall symposium, Arlington, VA, 107–114.

Tukker, A. (2015) Product services for a resource-efficient and circular economy–a review, *Journal of Cleaner Production*, **97**, 76-91.

Ullman, J.D., (1997) Information integration using logical views, Database Theory — ICDT '97, Delpi, Greece, 1186, 19-40.

Wünderlich, N.V., Wangenheim, F.V., and Bitner, M.J. (2013) High Tech and High Touch A Framework for Understanding User Attitudes and Behaviors Related to Smart Interactive Services, *Journal of Service Research*, **16**, 3-20.

Zhang, Z., Wang, Y., and Wang, K. (2013) Fault diagnosis and prognosis using wavelet packet decomposition, Fourier transform and artificial neural network, *Journal of Intelligent Manufacturing*, **24**, 1213–1227.