# Evolutionary Design Framework for Smart PSS: Service Engineering Approach

Kentaro Watanabe, Dr.

Human Augmentation Research Center, National Institute of Advanced Industrial Science and Technology

Takashi Okuma, Dr.

Human Augmentation Research Center, National Institute of Advanced Industrial Science and Technology

Takeshi Takenaka, Dr.

Human Augmentation Research Center, National Institute of Advanced Industrial Science and Technology

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Title

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Abstract

Digital technology is transforming industry, economy, and society. Under this digitalization trend, a new concept of product and service offerings, Smart PSS has been introduced. While the Smart PSS concept aiming at data-driven innovation attracts more attentions, there are two major challenges in designing Smart PSS. First, available data from digital technologies are actually limited by technical, financial, and social reasons. Second, the context of applying Smart PSS dynamically changes, which makes designed Smart PSS unfit to the target situation. To overcome these challenges, we propose an evolutionary design framework for Smart PSS. Our approach is based on the service engineering research, which has been contributing to the design and development of PSS. The proposed framework consists of three conceptual spaces and three cycles. The main features of the framework were two design cycles; in-system and ex-system design cycle. In-system design cycle is a process of creating and applying human knowledge for making the most use of data collected by digital technologies. Ex-system design cycle is to adapt to dynamic changes in contexts of the applied Smart PSS. We examine how the proposed framework works for designing a Smart PSS, with a case study about the digitalization of a restaurant business.

Keywords

service engineering; Smart PSS; digitalization; evolutionary design framework

## 1. Introduction

Digital technology is transforming industry, economy, and society on a global scale. It is commonly acknowledged that data collected with digital technologies is a new resource that can promote innovations in various industries [1]. Advanced sensors attached to products and environments, known as the Internet of Things (IoT) are able to collect huge amounts of data about our life and work. The analysis of these data, for example, by using statistical methods and rapidly evolving machine learning techniques, is changing business processes in an efficient and effective way.

Digitalization promotes servitization [2, 3]. A Product-Service System (PSS) as an integrated product and service offering that delivers value in use to the customer [4], is naturally influenced by digitalization. Recently, new types of PSS which are supported or enhanced by digital technologies attract strong attentions. One of the representative concepts is Smart PSS [5]. The Smart PSS concept covers a wide variety of value propositions in different industries and life and work settings, while the traditional PSS concept mainly focuses on product-based industrial offerings [4, 9]. The Smart PSS concept is expected to create greater value with the full use of digital technologies. However, available data from digital technologies is actually limited by technical, financial, and social reasons. Smart PSS needs to be designed by considering and even overcoming this limitation. In addition, the context for applying Smart PSS dynamically changes, which makes a designed Smart PSS outdated rapidly. These aspects have not been sufficiently examined in the previous studies.

In this study, we propose an evolutionary design framework for Smart PSS to overcome these challenges. Our approach is based on the service engineering research, which has been contributing to the design and development of PSS. We examine how the proposed framework works for designing a Smart PSS, with a case study about the digitalization of a restaurant business.

This paper consists of the following sections. In Section 2, we explore related studies on Smart PSS and its design, specifically focusing on PSS and service engineering studies. Then, we illustrate two research challenges in Smart PSS design. In Section 3, we propose an evolutionary design framework that consists of three conceptual spaces and three cycles. Section 4 shows an illustrative case study for the proposed framework. After a discussion of the case study in Section 5, we provide concluding remarks in Section 6.

## 2. Theoretical Background and Research Challenge

### 2.1. PSS and Smart PSS

The term Product-Service System (PSS) was coined in the late 1990s. Goedkoop et al. [7] defined PSS as “a system of products, services, networks of ‘players’ and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models.” As is seen in this definition, the original focus of PSS lies in environmental sustainability. Thus, life cycle analysis has been an important topic in PSS design [8]. The PSS concept has been widely accepted as a form of delivering value to customers in the trend of servitization, especially in industrial service sectors [4, 9]. The research on PSS design covers a wide variety of topics such as business models, customer processes, and product and service composition [9, 10]. Vasantha et al. [10] categorized the elements of PSS into four layers: Products and Services, Business Models, Innovative Service Additions, and Other Elements such as stakeholders, environments, requirements, and processes. There are various PSS design methods taking care of these elements. For example, Aurich et al. [11] proposed the integration framework of product and service development. As another example, Song and Sakao [12] proposed a design framework for customization of PSS in response to user needs.

As digitalization has become a major trend, the role of digital technology in industry has been strongly emphasized. IoT is considered a key technology to obtain information during the use phase of product and service offerings in order to improve their performance [13], and even for realizing new types of services such as sharing economy [14]. The impact of digitalization has been also studied from the management perspective, using various cases [2-3].

In this situation, a new concept called Smart PSS was proposed. Valencia et al. [5] coined the term, which focuses on the integration of smart products and e-services. Zheng et al. [6] defined Smart PSS as "an IT-driven value co-creation business strategy consisting of various stakeholders as the players, intelligent systems as the infrastructure, smart, connected products as the media and tools, and their generated e-services as the key values delivered that continuously strives to meet individual customer needs in a sustainable manner." The significant difference of Smart PSS from the conventional PSS concept lies in the utilization of data taken from digital technologies for value creation [5-6]. Compared to conventional PSS, Smart PSS focuses not only on industrial businesses but also more on consumer businesses [5]. Some studies highlighted smart products as catalysts for value co-creation with consumers [15-16]. Meanwhile, Chowdhury et al. [17] focused on the inter- and intra-organizational aspects of Smart PSS in Business-to-Business settings, and identified digital resources for value creation as boundary objects for organizations.

Smart PSS is characterized by interactions between physical and digital elements [5-6], which corresponds to the concept Cyber-Physical System (CPS). CPS is a system of "collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the Internet" [18]. CPS has been highlighted under the trend of Industrie 4.0 [19], especially as the application for manufacturing [19, 20]. Digital twin is another important concept accepted in the studies of Smart PSS. This concept is also widely accepted in industries, including manufacturing [21-22]. Digital twin represents "the virtual and computerized counterpart of a physical system that can be used to simulate it for various purposes" [21]. These concepts are described using two conceptual spaces, "real space (or physical space)" and "cyber space." Cyber space for Smart PSS is ideally a digital twin which represents and simulates the corresponding real space precisely [6].

Designers need to consider how data are collected and utilized for operation and design of Smart PSS. This is a new challenge from the aspect of conventional PSS research. As one of the earlier studies related to Smart PSS, Hussain et al. [23] proposed a PSS conceptual design process which utilizes the system-in-use data for developing better solutions. Zheng et al. [6] put the emphasis on data-driven design based on digital twin realized by smart products. Their design process consists of four steps: platform development, data acquisition, data analytics for service innovation, and digital twin-enabled service innovation. Several studies propose data-driven design methods for Smart PSS. Wang et al. [24] proposed a requirement elicitation process based on collected big data and the domain ontology. Zheng et al. [25] proposed an engineering change management approach for Smart PSS in a data-driven manner. In addition, several modeling schemes for designing product-service offerings based on digital technologies have also been proposed [26–27]. Meanwhile, Kuhlenkötter et al. [28] emphasize the importance of holistic integration of discipline-specific models and multi-stakeholder consideration.

## 2.2. Service Engineering

Service engineering has a close relationship with the PSS research, as shown in Fig. 1. While the concept of service engineering was proposed from several disciplines in parallel in the 1990s and early 2000s [29–32], the concept from Japan focuses on the sustainability of manufacturing and servitization, which fits the original PSS concept [30–31]. Tomiyama [31] proposed service engineering as a new engineering discipline that regards service as a design object and as a means of providing more value while reducing the amount of mass production. Under this concept, researchers first started to provide systematic design and development methods based on product design research, which Watanabe et al. [33] called "model-driven approach." Shimomura et al. [34] provided basic structural models of services that represent the relationship among stakeholders, the composition of products and services, and their functions. In addition, different types of modeling methods such as for service processes [35] and customer values [36] were proposed. Computational design support is another feature of service engineering. Service CAD was developed as a supporting system for service designers [37]. In addition to computational service modeling using the aforementioned modeling methods, several design support functions such as process simulation [8, 38] and design concept generation using reasoning techniques [39] were developed. These methods and tools were widely acknowledged as effective for PSS design [10, 40].

Meanwhile, a data-driven approach was actively adopted for service engineering in the 2010s [33]. As a fundamental methodology of data-driven design in service engineering, the optimum design loop for the continuous improvement of services was suggested [41–42]. This design loop consists of four iterative steps: observation, analysis, design, and application, in which collected data from digital technologies in the observation step are analysed and a newly designed solution based on the analysis results is applied. One application example is a digital payment system installed in a hot spring area [43]. This system replaced public bath entrance tickets. Tourists staying in the area were able to enjoy taking public baths and also purchasing meals and souvenirs using this local payment system. Furthermore, the local Non-

Profit Organization (NPO) analyzed the anonymized collected data based on their local knowledge for promoting social events to revitalize area activities. Similarly, various types of digital technologies such as a behaviour measurement system and a knowledge sharing system were applied and utilized to improve the productivity of services [33]. As another case, Takenaka et al. [44] analysed the usage data of smart home appliances and illustrated how data from home appliances are applicable to estimating the behavioural patterns of consumers. The projects using these technologies emphasized user autonomy in innovating service practices because knowledge on service context is required to understand what the collected data meant [43]. For example, Watanabe et al. [42] put emphasis on interpretation by service workers for the better use of collected data and employee-driven deign activities to change their practices. They call such an occasion to reflect and redesign service practices by employees themselves, as design space [42].

This data-driven service engineering research is strongly relevant to the aim of Smart PSS pursuing new value creation enabled by digital technologies.

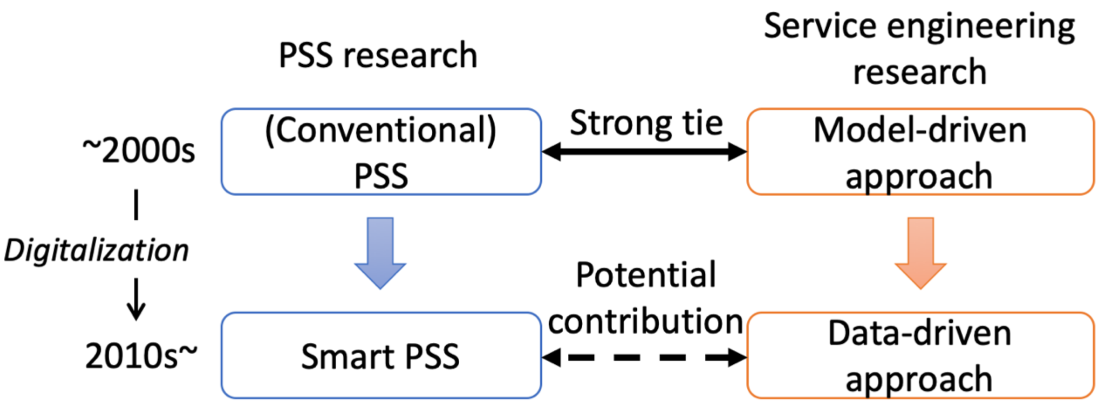


Fig. 1 Relationship between PSS and service engineering research

## 2.3. Challenges in Designing Smart PSS

In the current Smart PSS concept, cyber space is implicitly or explicitly expected to be a "digital twin" to represent and simulate the states of the corresponding real space precisely for providing better services. However, cyber space usually cannot represent all of the states in its real space, which can hinder the effective operation of Smart PSS. This imperfectness of cyber space comes from the following two causes.

- Unobservable states in real space

There are theoretically and practically unobservable states in real space. For example, it is important to recognize human intention and emotion for better service provision. However, it is difficult to observe them directly with current digital technologies in the real work and life settings. In addition, contextual knowledge is required to understand the meanings of data [42]. Even observable states such as physical changes in actors and the environment are difficult to collect perfectly because of technological and financial limitations. In addition, ethical issues such as privacy affect how these technologies are applied [45]. As a result, cyber space tends to be "smaller" than the corresponding real space and consequently, technological support from cyber space could be limited or even ineffective. Although this does not mean that it is impossible to develop a practically useful Smart PSS, it is a challenging task to design an effective Smart PSS with incomplete data.

- Dynamic changes in real space

The other challenge is the dynamism of the real space. As digital technologies are implemented, behaviors of actors involved in a Smart PSS may change. When new actors join the targeted real space, different interactions may occur. In addition, the needs and expectations of actors may also change through their experiences. Through such changes in the real space, the developed Smart PSS can easily become outdated.

Concerning the challenge of a smaller cyber space, service engineering research provides useful insights. For example, the employee-driven design by service workers is a good example which extends the impact of collected data using the workers' contextual knowledge in design space [42]. As another related topic, there is an emerging concept called digital triplet [46]. Digital triplet is a concept that extends the digital twin to the intelligent activity world of human workers, in which human intelligence and experience are emphasized for better utilization of data in manufacturing processes. Although this concept is mainly discussed in digital manufacturing and training [46], it is relevant to the aforementioned design space concept [42].

Concerning dynamic changes in real space, the adaptive design process in response to such changes is needed. Smart PSS is characterized by its ever-evolving nature [47] and the continuous redesign of its contents is required. While the data-driven design approach such as [24-25] contributes to adaptation to the changing needs based on collected data, the aforementioned dynamic changes could even cause the needs away from the presumed design issues and require different types of data and corresponding technologies in Smart PSS. Toward this challenge, a design process to set an adequate frame to the new problem situation is needed [48].

## 3. Evolutionary Design Framework for Smart PSS

Based on the limitations of existing studies on Smart PSS design, we suggest an evolutionary design framework for Smart PSS, shown in Fig. 2.

In this framework, Smart PSS consists of three space concepts, including real space, cyber space and knowledge space. Specifically, knowledge space aims to fill the research gap about unobservable states of real space. In addition, this framework contains three cycles, including data cycle, in-system design cycle and ex-system design cycle, to drive and evolve Smart PSS. Data cycle and in-system design cycle represent the processes in cyber space and knowledge space respectively. Ex-system design cycle is the other process to adapt a Smart PSS to the dynamic change in real space. Specifically, in-system and ex-system design cycles take important roles for the evolution of Smart PSS. These design cycles are also supported and enhanced by various types of computer-aided technologies.

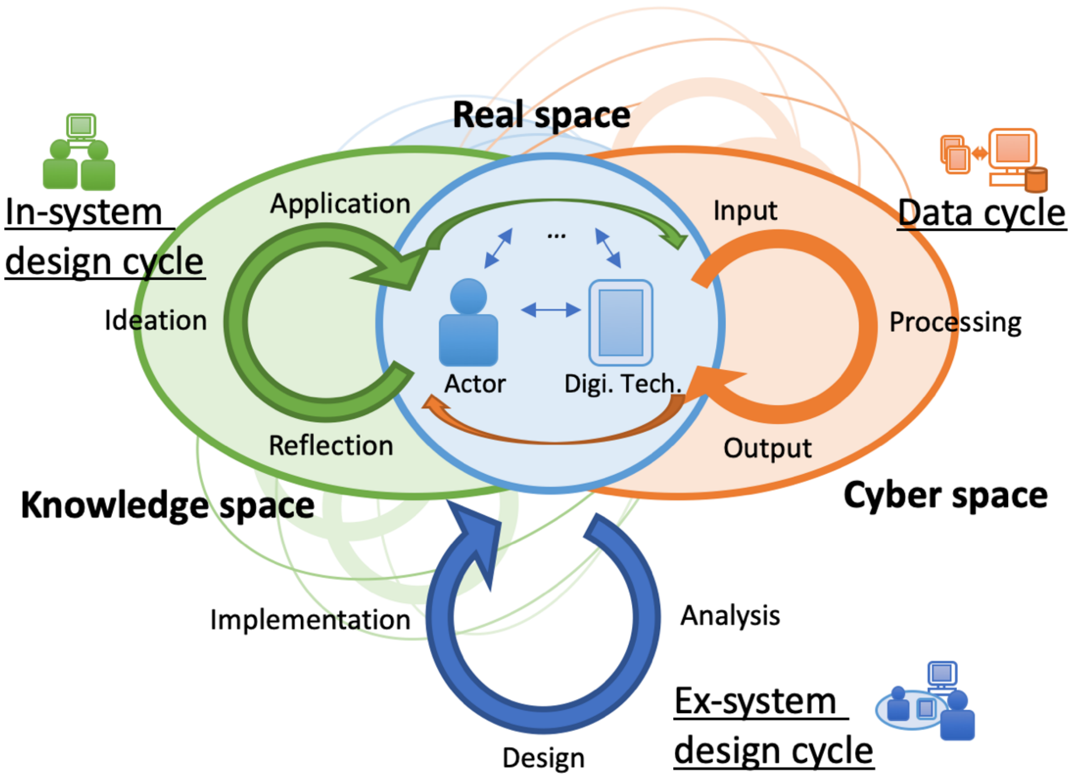


Fig. 2 Evolutionary design framework for Smart PSS

## 3.1. Real, Cyber, and Knowledge Spaces

Real space in Smart PSS includes actors and digital technologies interacting with each other within its boundary. Actors include both individuals (e.g., consumers) and organizations (e.g., companies, communities, and municipalities). Digital technologies including IoT, smart devices, and robotics influence actors' behavior through interactions. Compared to the cyber-physical system concept for manufacturing [20], real space in this model is more open to the external environment, and its socio-technical configuration, interactions and boundary may change unintentionally in response to internal and external stimuli.

Data collected from digital technologies are handled in cyber space. Cyber space represents real space with collected data set, which is available for analyzing and simulating real space for the operation of Smart PSS. Data cycle explained later represents how data are handled in cyber space.

Knowledge space originates from the design space concept in service engineering research [42] and the digital triplet concept [46]. Knowledge space is a conceptual space where actors create and share knowledge required for operating and improving Smart PSS. Knowledge in this space originates from actors in Smart PSS. Unlike data in cyber space, it may be implicit and can be transferred by offline communication (e.g. verbally) among them. Explicit knowledge can be also shared as data in cyber space. Knowledge space is conceptually essential in two ways. First, knowledge space produces interpretation of data from cyber space for better operation of Smart PSS. Second, knowledge space plays an important role in estimating unobservable states in real space and determining required actions. In-system design cycle, explained later provides the concrete process for them.

### 3.2. Data Cycle and Two Design Cycles

Next, we introduce data cycle and two design cycles in the proposed framework.

#### 3.2.1. Data Cycle

Data cycle in cyber space, which consists of the following three steps (input, processing, and output), conveys and processes data to affect real space and knowledge space.

- Input

Input involves taking data from real space using digital technologies. For example, sensors and human interfaces provide the input functions of digital technologies. A human behavior sensing method was mainly used in the following case study. Social Network Services (SNS) and other types of communication systems are also effective tools that collect data about actors in Smart PSS.

- Processing

Collected data from input are processed by means of computational algorithms in the processing step. Statistical analysis and machine learning are common analytical techniques. In addition, simulation based on data from real space is effective in predicting changes that will occur in the future.

- Output

Output is a step to provide feedback to real space and knowledge space based on the processing result. This feedback can be provided in the form of visualized data, for example. Virtual Reality (VR) and Augmented Reality (AR) are effective tools that provide the intuitive understanding of the data. Processed data can also be provided in the form of recommendations for actors. Physical interactions by robots such as social robots are additional approaches to intervene in a situation in real space.

### 3.2.2. In-System Design Cycle

In knowledge space, in-system design cycle works to improve the effectiveness of Smart PSS. In-system design cycle is a process that utilizes and supplements the limited data from cyber space in order to promote value creation among actors. In-system design cycle also contributes to better integration of digital technologies in Smart PSS. This cycle is conducted mainly by actors in Smart PSS.

In-system design cycle consists of three steps: reflection, ideation, and application.

- Reflection

Reflection is a step in which actors reflect on what occurs in Smart PSS. Data from cyber space, contextual knowledge of actors, or both can be used to obtain insight into Smart PSS. Computational support such as data visualization is effective for this step. Visualized data from the output of data cycle can assist actors in obtaining insights into what is occurring in the real space, in conjunction with the contextual knowledge based on their experiences [42, 49]. For example, Watanabe et al. [42] used visualization results of the analysis of text messages among caregivers to explore potential risks at care work. In this case, the caregivers at a care facility specified potential risk issues by seeing the visualized co-occurrence network analysis result, which includes frequently used words and their correlation (see the left figure in Fig. 3). This is only possible by the caregivers who actually provide services at the site and know the situation there [42]. Another example of visualization is the heat map of employees' location distribution at a service environment (see the right figure in Fig. 3). This was used in the restaurant case explained later. To hold a workshop using such visualization results is an approach to utilize the actors' contextual knowledge for better service operation.

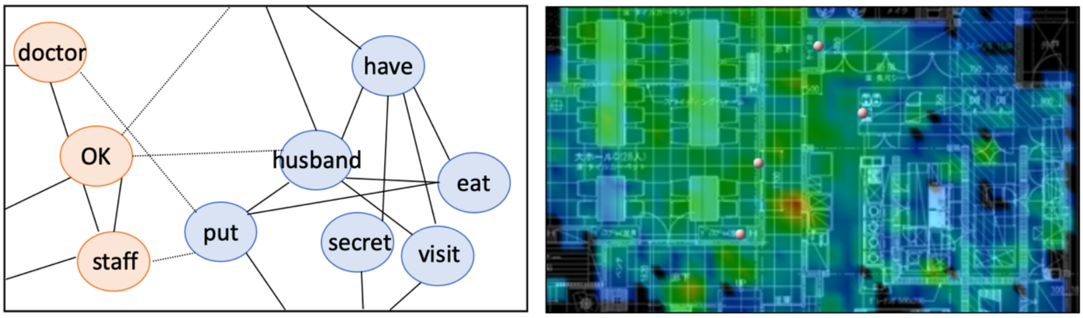

Fig. 3 Examples of data visualization (based on [50, 63])

- Ideation

Ideation is a step that creates new knowledge to improve Smart PSS by using the results of reflection. Knowledge may be explicit or implicit, but explicit knowledge can be easily transferred to other actors. In the aforementioned case at a care facility [42], the workshop participants generated an idea to improve their service process to mitigate the risk. Small group activities such as Quality Control (QC) circles [51] and Lean [52] are also effective to create knowledge intentionally. In the case study part, we will introduce a QC circle activity with computational support.

- Application

Application is a step to apply created knowledge to Smart PSS. This step can also be supported and enhanced by digital technologies and cyber space. For example, a knowledge sharing tool and groupware can assist sharing of knowledge with other actors [53]. In the case of the care facility [42], the information of the redesigned service process was shared with the other caregivers through the messaging system.

### 3.2.3. Ex-System Design Cycle

Ex-system design cycle is for adapting to dynamic changes in real space. This cycle is a continuous design process for adjusting, refining, and innovating the entire Smart PSS, including digital technologies used therein. Through this cycle, not only the elements and the boundary of the real space in Smart PSS, but also the corresponding cyber space and knowledge space are redesigned. This cycle is conducted not only by actors in the Smart PSS but also external actors such as designers, consultants, and researchers. Such external views are essential to set a new frame to the changing environment [48].

Ex-system design cycle consists of the following three steps: analysis, design, and implementation.

- Analysis

Analysis is a step that clarifies the performance and challenges of Smart PSS or understands the situation of real space for implementing Smart PSS. Smart PSS consists of multiple actors and elements, and issues to be tackled by Smart PSS design dynamically change. Therefore, a multifaceted analysis is needed. A qualitative study such as stakeholder analysis and participatory observation [54] is effective for this purpose. In addition, an evaluation framework from multi-stakeholder perspectives is available for this purpose. For example, the multi-actor multi-criteria framework provides evaluation criteria that consist of a two-dimensional map representing different actors and five different perspectives (industrial and technical, markets and finances, relational, responsible, and reputation) when applying innovation to service systems [55]. These perspectives provide general criteria to assess a Smart PSS away from its original aim. It is important to clarify issues which were not the main targets of the existing Smart PSS.

- Design

Design is a step that explores and determines the configuration of Smart PSS to tackle the issues clarified in the analysis phase. The elements and boundary of real space in Smart PSS, including actors, digital technologies and their interactions, and the corresponding data cycle in cyber space and the in-system design cycle in knowledge space are designed in this phase. The participation of actors is encouraged in order to have a better fit of the designed solutions to the actors and their behaviors [42-43]. Codesign [56] and living lab [57] are effective approaches. In addition, systematic modeling of Smart PSS [26-27] by using a computer-aided design system is also effective in clarifying and communicating precise specifications of Smart PSS.

- Implementation

The designed solution is applied in the implementation step. Adaptation to the new system is a challenge for actors [58]. Sufficient introduction and training using e-learning, for example, are needed for a better fit. The result of implementation should be monitored continuously in ex-system design cycle.

Table 1 shows the summary of three cycles and corresponding methods and technologies in the design framework. These methods and technologies are selectively used for each individual design case to realize each cycle.

Table 1 Summary of the design framework and corresponding methods and technologies

| Cycles | Step | Contents | Method/technology (example) |
|---|---|---|---|
| Data cycle | Input | Collect data from real space using digital technologies | Sensors (human behavior, things, environment), digital recording, digital communication system (e-mail, SNS, groupware) |
| | Processing | Apply computational algorithms to collected data | Statistical analysis, machine learning, simulation |
| | Output | Provide feedback to real space based on the processing result | Visualization, Virtual Reality (VR), Augmented Reality (AR), recommendation, curation, robotic intervention |
| In-system design cycle | Reflection | Reflect what occurs in Smart PSS using data and contextual knowledge of actors | Self-expression for reflection, reflective workshops, retrospective interview, video reflection, data visualization for reflection support |
| | Ideation | Create new knowledge for improving Smart PSS by using the results of reflection | Small group activities (e.g. QC circle and Lean) with computational support (e.g. visualization), user-driven innovation program, co-creation workshops |
| | Application | Apply created knowledge in the process of Smart PSS | Knowledge sharing tool, process modeling, manual documents (paper/digital) |
| Ex-system design cycle | Analysis | Clarify the situation and challenges for Smart PSS | Stakeholder analysis, participatory observation, interviews, multi-actor multi-criteria analysis |
| | Design | Explore and determine the configuration of Smart PSS | Service modeling methods, Service CAD, codesign, living lab, process simulation |
| | Implementation | Implement a designed solution | E-learning, employee training, customer education |

## 4. Case Study

We examine the proposed framework with an illustrative case study. This case is a series of research projects toward digitalization of service work at a Japanese cuisine restaurant company. This restaurant company has been keen on digitizing their service operations and has adopted various digital technologies such as an information sharing system of customer information and requests [59] and a demand forecasting method based on Point-Of-Sales (POS) data [60].

This case study covers four sequential projects. Table 2 shows a summary of the projects. Based on the individual results of designed technologies and applications that have already been published [61–64], we analyze how the Smart PSS in the restaurant company has evolved through the projects using the proposed framework. We specifically focus on how the in-system and ex-system design cycles were conducted in each project.

Table 2 Project summary

| Project num. | Contents (period) |
|---|---|
| #1 | Introducing Computer Supported Quality Control Circle (CSQCC) to a restaurant (2011) [61] |
| #2 | Updating technologies for CSQCC (2012) [62] |
| #3 | Launching a new flagship restaurant with CSQCC (2014) [63] |
| #4 | Introducing Automated Guided Vehicle (AGV) for meal delivery into restaurant operation (2017–2018) [64] |

### 4.1. First Project

#### 4.1.1. Ex-System Design Cycle

- Analysis

The aim of the first project was to increase the productivity in the restaurant service. For this, the ex-system design cycle started with an analysis of the original restaurant operations and challenges. Through a stakeholder analysis via discussion with company managers and staff, the improvement activity at the restaurants became a research target. This restaurant chain had originally applied QC circle activities [51] to improve restaurant operations. However, the data of employee behaviors in the restaurant had not been collected sufficiently. Unlike manufacturing workplaces, employees need to move around while serving customers and interacting with the other employees in a large space of the restaurant. Therefore, measurement of employees' behaviors was the main issue in the project.

- Design

For the measurement of employees' behaviors, Pedestrian Dead Reckoning (PDR) as one of the indoor positioning technologies was applied. In addition, the Voice Activity Detection sensor and Point-Of-Sales (POS) data from the restaurant were used. A visualization system to show collected data in the variety of format was also developed. Fig. 4 shows the composition of technologies in this project.

These systems were used to enhance QC circle activities. This concept, Computer Supported Quality Control Circle (CSQCC) [61] was to combine subjective and objective views to ideate creative ideas.

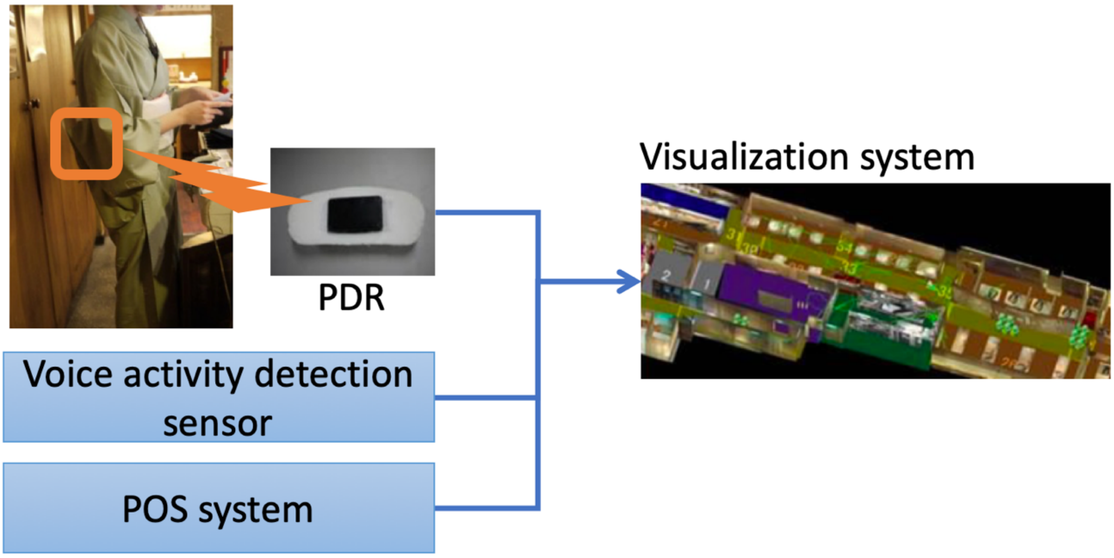


Fig. 4 Measurement and visualization system applied in the first project (based on [61])

- Implementation

For this study, the behavior of about 20 workers including three types of job categories; kitchen staff, waitstaff, and assistant waitstaff (who convey food and dishes from the kitchen to the pantry, prepare drinks, and do other miscellaneous tasks), were measured in a two-story Japanese cuisine restaurant over a one-month period (January-February 2011) [61]. The PDR module was put on the obi-makura (a pad to keep the shape of the sash on the back of the waitstaff) as shown in Fig. 4. In this project, researchers supported the entire process for behavior measurement, including attaching sensors to the employees and troubleshooting during measurement. In the later projects, the efficiency of the behavioral measurement became a challenge.

4.1.2. In-System Design Cycle

- Reflection

The CSQCC session was conducted in February 2011, during the period of behavior measurement. Three executive team managers and three local staff members joined this session. Behavioral data of seven employees in the first week of the measurement were used in the session. These data were visualized with a variety of tables and graphs, combining different datasets using the same time scale.

- Ideation

The participants discussed problems in their service operation, seeing the data with the visualization system. In the session, the trajectory data of employees' movement became a topic. Employees often shuttled back and forth between the front and back offices. The reason was identified by the participants as follows: the reservation book was in the back office, and the employees needed to move to the back office in order to check it. While it became a future agenda item to introduce a computerized reservation system, staying in the dining hall and communicating with customers for longer periods became a short-term goal [61].

- Application

After the session, a manager asked the waitstaff to spend more time in the dining area and to increase their communication with customers. As a result, the total time spent in the service area per customer slightly increased from 2.4 minutes (before the session) to 2.6 minutes (after the session) [61].

4.2. Second Project

4.2.1. Ex-System Design Cycle

- Analysis

Based on the experience of the first project, a second project was planned and held in 2012 [62]. One technological and operational challenge was the research members' cost for behavior measurement. The technology available with shorter preparation time was expected.

- Design

In the design step, some new measurement support technologies were introduced. One was a touch panel display system for assigning a sensor to each participant when she/he started working. Another was an automatic data upload system attached to sensor module battery chargers. These technologies were helpful for reducing the number of measurement support staff. In addition, the evaluation process of the improvement results was also rearranged. After the CSQCC session, another one-week measurement period was applied: the earlier half of the period without new improvements, and the latter half with new improvements for more accurate evaluation.

- Implementation

According to the designed plan, the newly designed technologies and evaluation process were applied in January-February 2012. The first measurement was held for 8 days. Based on the result, two CSQCC sessions were held. Then the second measurement for evaluation was conducted on the first 3 days without improvement and on the latter 3 days with improvement.

4.2.2. In-System Design Cycle

- Reflection

The reflection process was not significantly different from that of the first project. The visualization system was still operated by the research members.

- Ideation

While the procedure did not change significantly, the concepts developed through CSQCC became more sophisticated. The participants suggested three major actions for improvement: 1) staying longer in the dining area, 2) reducing movement to the other area, and 3) remaining in the employees' designated territories. In particular, the action 3) included a new concept: territory in the workplace. For better efficiency, each employee needed to have her/his own area to serve on the restaurant floor, and it was not recommended to serve customers in other territories.

While these actions were taken into account in the service process, the evaluation criteria to assess the actions were also reconsidered. The research members considered the metrics such as the ratio of waitstaff's staying time in territory areas and the walk distance per customer, and the CSQCC session participants accepted them.

- Application

After applying the actions to the workplace, the result was evaluated with the proposed metrics. As a significant result from these actions, the average walk distance per customer decreased from 103.7 meter to 61.6 meter [62].

4.3. Third Project

4.3.1. Ex-System Design Cycle

- Analysis

The third project was held at a new flagship restaurant launched in 2014, based on the previous project experiences [63]. It was naturally expected that CSQCC would contribute to the smooth launch of the new restaurant. Meanwhile, the efficiency of the behavior measurement was still an issue to be solved.

- Design

In the third project, the behavior measurement and visualization system became available for waitstaff without the support of research members (see Fig. 5). An automatic measurement system with a touch panel display was newly designed and developed. In addition, the sensor module became small enough to put it in a small sack in front of the sash, instead of attaching it to the obi-makura. This change made it easier to attach a sensor module. The visualization system was also renewed in a way that CSQCC participants were able to control it by themselves.

- Implementation

The measurement was scheduled for 13 days, one week after the launch of the restaurant to minimize the burden of the waitstaff. After the measurement, the prior check of data was scheduled for experienced CSQCC members. Then they decided the topic of the CSQCC session and held it. After that, the second measurement was taken place for 14 days in November.

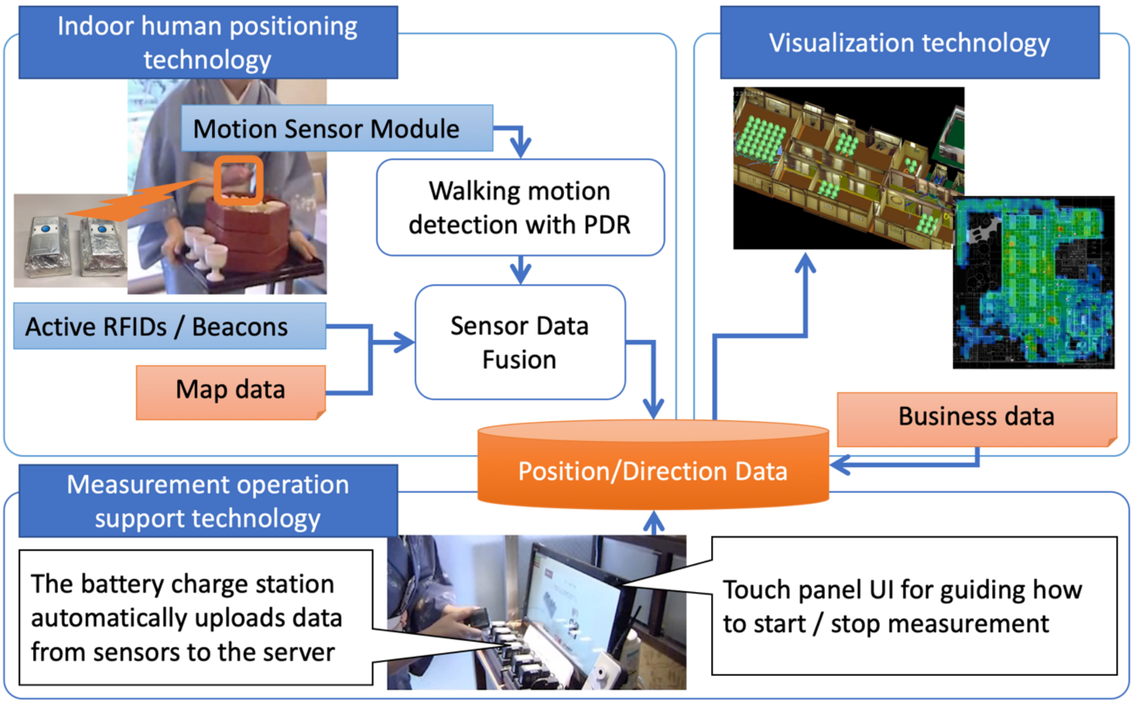


Fig. 5 Measurement and visualization system used in the third project (based on [63])

4.3.2. In-System Design Cycle

- Reflection

The experienced workers in the CSQCC members checked the visualized data and found some problems in inexperienced waitstaff's operation. The identified problems were the inefficient use of the handheld terminal device and slow preparation for serving [63]. Based on their findings, they set a CSQCC theme as how to increase time for attending customers. The participants held the session using the visualization system by themselves. The visualization result was used not only for discussion but also for explanation to inexperienced waitstaff. According to the participants, experienced participants were able to share problems calmly with inexperienced staff members and to lead them to tackle problems without pointing out the problems of each staff member [63].

- Ideation

In the CSQCC session, various ideas were considered for the smooth launch of the new restaurant. First, the participants developed additional instruction documents that were easy to understand at a glance. These documents illustrated a dish placement for each menu, how-to-use of the handheld terminal device, information about the facilities, cuisine, and the recommended menu. In addition, the participants reorganized the item layouts in the crowded pantry and established an appropriate role allotment for waitstaff.

- Application

These ideas were acted upon. One of the managers pointed out that the restaurant started up more quickly than a typical restaurant. Actually, the labor productivity of the new restaurant was better than at other restaurants in the company, as shown in Fig. 6 [63].

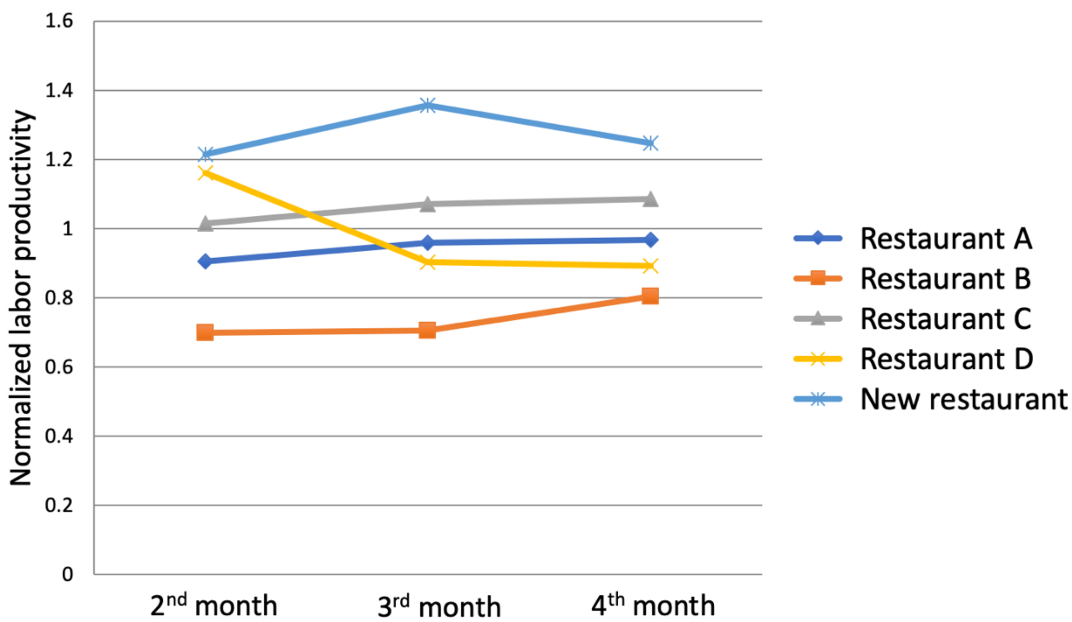


Fig. 6 Comparison of labor productivities (based on [63])

4.4. Fourth Project

4.4.1. Ex-System Design Cycle

- Analysis

The fourth project focused on the different aspect of the restaurant management. In recent years, labor shortage has become a more serious issue for restaurant businesses because of declining working population. In addition, the Quality of Working has become a social issue and a policy target of the Japanese government [65]. Given this situation, more direct contribution of automation technologies to human labor was expected.

- Design

As a new solution for the restaurant, a new system including an Automated Guided Vehicle (AGV) for delivering meals was introduced [64] as shown in Fig. 7. This robot delivered meals near the customers, and floor staff then brought the meal from the robot to customers. For better cooperation between human and robot, the data analysis system integrated the robot's operational record in collaboration with the robot manufacturer. Hence, it became possible to detect the positions of waitstaff and the robot at the same time and to analyze the distance between them.

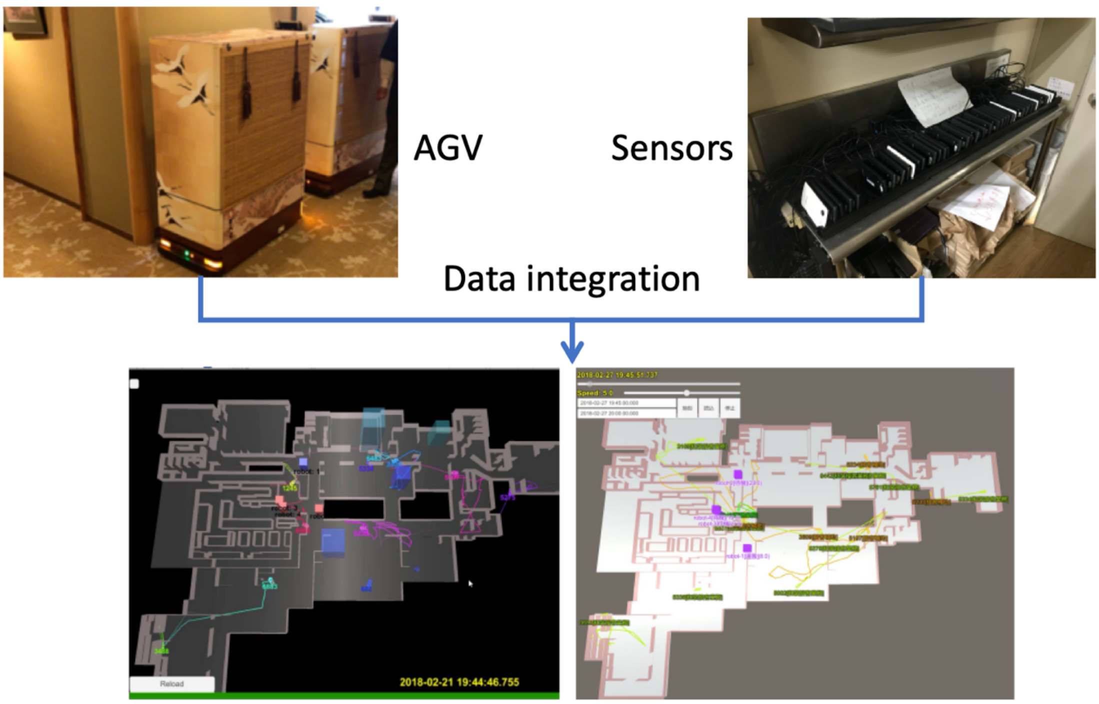


Fig. 7 New system including AGV for meal delivery

- Implementation

When the AGV was installed in the restaurant, behavior measurement was also conducted for evaluation. This measurement was done in December 2017 (before installation) and in February-March 2018 (after installation).

#### 4.4.2. In-System Design Cycle

The measurement result showed the significant increase of the waitstaff's attending time in the lunch time (1 min. 24 sec. increase per 15 min. working hour) [64]. The in-system design cycle based on this result is still on-going.

## 5. Discussion

### 5.1. Effectiveness for Designing Smart PSS

We first discuss the effectiveness of the proposed framework toward the challenges in designing Smart PSS. Concerning the issue of unobservable states in real space, the first project showed the effectiveness of the proposed approach. The collected data were able to represent the trajectories of the waitstaff between the front and back offices, but it was difficult for the research members to tell why those trajectories appeared. The participants of the CSQCC session were able to interpret the meanings of the trajectories using their contextual knowledge. This exactly depicts why the correspondence of knowledge space to cyber space is important, and how in-system design cycle can fill the gap between real space and smaller cyber space. Naturally, this case illustrated that collected data enabled waitstaff to detect the problem of their service operation. This process is applicable beyond small group activities at workplaces. For example, IoT in consumer electronics, such as in a case by Takenaka et al. [44], allows product manufacturers to consider a better lifestyle for users through their participation.

The second project showed that the evaluation criteria for service processes were developed with the waitstaff. These criteria are important for assessing the impact of knowledge obtained through in-system design cycle and also for figuring out new requirements for digital technologies for a Smart PSS.

Adaptation process of a Smart PSS to the real space can be explained in two ways in this case study. First, sensing and visualization technologies were redeveloped in the second and third projects to improve the efficiency of behavior measurement, which was an issue in the analysis steps. This "fill-the-gap" process is one approach for realizing better Smart PSSs. Second, the fourth project depicted a different challenge caused by the change in the labor market, which led the project to a new technology application, in-store AGV. This case was beyond the experiences in the last three projects and depicted the adaptation to the changing context in the real space. These cases represent the importance of the ex-system design cycle. In addition, it is also an important contribution of this study to illustrate the evolving Smart PSS in the iterative design cycles with the long-term case study.

### 5.2. Co-Evolution in Three Cycles

The case study further illustrated that the three cycles (data, in-system design, and ex-system design cycles) co-evolved in the Smart PSS. The experience with the in-system design cycles provided important feedback to the next ex-system design cycle. As a result, the sensors and the visualization system were updated, and new types of data were circulated. These data again provided new insight into service processes such as the territory concept. In this process, research members and restaurant managers and staff mutually learned from each other. The restaurant obtained an updated management model with concrete criteria, and the researchers obtained clearer requirements for digital technologies and the implementation process. The next challenge will be industrializing this co-evolution cycle to realize the better fit of Smart PSS to related actors.

## 5.3. Evolution Process of Smart PSS

This case study also showed detailed steps of Smart PSS evolution through in-system and ex-system design cycles (see Fig. 8). The sequence of these steps shows an evolution process of Smart PSS.

After the first project, the second project became more sophisticated. The sensing and visualization technologies were updated, while the main functions remained the same. The criteria for service operations were developed through the in-system design cycle. This refinement of Smart PSS is the first step. In the third application, the behavior measurement system was more automated and standardized. It worked almost without the support of researchers. Hence, the designed Smart PSS worked well in the new environment. The modularization of Smart PSS is the second step, which enables a new solution to be disseminated [66]. The final project combined an AGV and the behavior measurement and analysis to deal with the lack of human resources. AGV is a new system to the existing CSQCC, and the data from AGV were being integrated into the in-system design cycle. This integration between Smart PSSs as the third step, illustrates the adaption to the change in the real space more directly.

This evolution process with three steps indicates the importance of incremental design for Smart PSS. The process will not explain every case but are theoretically meaningful. For example, the maturity of Smart PSS may need to be considered. This could be a future research topic.

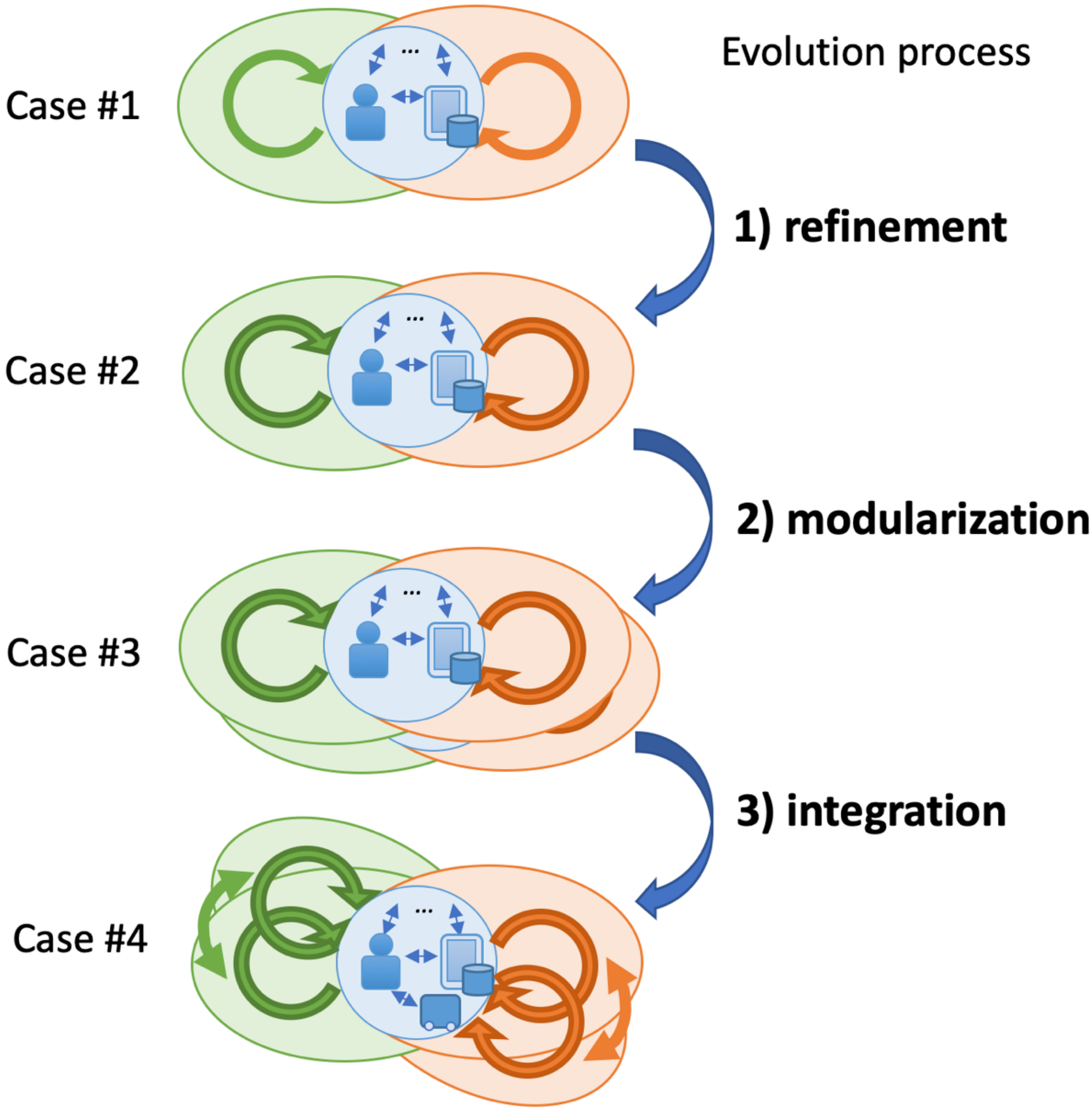

Fig. 8 Evolution process of Smart PSS

5.4. Limitations

This study relies on a long-term but single case study. The versatility of the proposed framework and the evolution process need to be verified with more cases. Different application domains such as healthcare and tourism and different types of technologies such as natural language processing and VR/AR should be considered as research targets. The types of the actors involved in the Smart PSS and its design cycles should be also diversified more. The design cycles involving multiple types of actors could become more complicated and challenging. Further studies on such design practices are necessary for the successful Smart PSS design.

In the proposed cycles, concrete technologies for the support of design and implementation steps in the ex-system design cycle were not mentioned because the target application was a restaurant with a limited number of actors. The application of the service modelling and simulation methods will be effective for designing and developing more complicated PSS. The potentials of such technologies need to be investigated. The investigation and assessment method for the analysis step should be further studied also. Recently, the social and ethical aspect of digital technology has been actively discussed [45, 67], which needs to be taken into account in the Smart PSS design.

## 6. Conclusion

In this study, we explored the challenges in designing a Smart PSS from the theoretical perspective and developed a design framework to overcome these challenges. We first figured out the challenges in designing Smart PSS, caused by the theoretically and practically imperfect digital twin; these challenges are unobservable states and dynamic changes in real space. To respond to these challenges, we proposed an evolutionary design framework for Smart PSS based on the service engineering research. The proposed framework integrated three spaces and three cycles. Especially, in-system design cycle as the process of creating and applying human knowledge into the Smart PSS supplements a smaller cyber space. In addition, ex-system design cycle makes Smart PSS more adaptable to dynamic changes in the real space. A case study about the digitalization of the restaurant service showed how these two design cycles evolved the Smart PSS for restaurant businesses.

As future research, we will conduct more case studies using the proposed framework to generalize it further. The application of different types of design support technologies and methods, especially for ex-system design cycle should be also considered. We hope that this study will contribute to further activating Smart PSS businesses.

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