Collaboration Management by Smart Voice Messaging for Physical and Adaptive Intelligent Services

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Abstract--**In light of the ongoing transformation from a traditional industrial society to a post-industrial society as a service society, it is unquestionably required to improve efficiency and quality of services. Especially, we focus on physical and adaptive intelligent services (PAI services) like nursing and caregiving where efficiency and quality are critical for an aging society. In these PAI services, several people have to collaborate to provide services, and a collaboration support system would be necessary. This paper proposes an information supervisory control model for a collaboration support system; furthermore, we have developed a smart voice messaging system based on this model. This model has a hypothesis that appropriate information sharing based on awareness of clients situation and task processes can be utilized and effective for improving efficiency and quality of services. We then formulate several hypotheses including the above one to be examined through field tests, virtual field tests, and simulation from the perspective of information supervisory control, and show some preliminary experimental results.**

I. INTRODUCTION

With the ongoing transformation from a traditional industrial society to a post-industrial society in the highly developed countries of the world, the service industries become more important. In order to improve both efficiency and quality of services, some design and management methods and tools are required when implementing the service systems [1, 2]. This is especially true in the nations where the demographic ratio has shifted to more elderly and to fewer young people in the population and higher quality and greater efficiency are needed in the healthcare service systems.

This paper focuses on physical and adaptive intelligent services (PAI services) as represented by nursing and caregiving where several people have to collaborate physically and intellectually to provide services in adapting to changing situation. Extensive research has been conducted on computer-supported cooperative work [3], but conventional PC-based support tools introduce problems of their own. PC-based support tools are not well suited to PAI service systems because using such tools creates an additional burden, both mentally and physically, on service providers (e.g., nurses and caregivers). Therefore, new less stressful human-computer interaction technologies are required to improve PAI service systems by lowering the burden imposed on the service providers. Moreover, new service design and evaluation methodologies are also necessary for stepwise improvement of PAI service systems.

To satisfy these requirements, we have proposed an information supervisory control model for a collaboration management system and developed a novel temporal-spatial communication system using smart voice messaging through an industry-academia collaborative project supported by Japan Science and Technology Agency (JST) Service Science, Solutions and Foundation Integrated Research Program [4, 5, 6, 7].

This paper is organized as follows. In Section II we discuss the characteristic features of PAI services, and in Section III, we give an overview of the communication for collaboration management. We propose an information supervisory control model in Section IV, and we explain a smart voice messaging system in Section V. Section VI discusses hypotheses to be tested and shows some preliminary experimental results. Section VII discusses related research, and Section VIII gives our conclusions.

II. PHYSICAL AND ADAPTIVE INTELLIGENT SERVICES

Service system consists of service providers and service receivers which make value co-creation by observation and treatment that changes a state of the service receivers [8] (Figure 1). We focus a service system having the following six features, called "physical and adaptive intelligent service" (PAI service). These features are general, but we explain them in a nursing and caregiving context for understandability.

- Knowledge-based tasks: Nursing and caregiving require expert knowledge and skills in order to avoid malpractice.
- Adaptation: The conditions of patients and care recipients change, so it is necessary to adapt to such changes flexibly.
- Multitasking: Multiple tasks must be handled at the same time (e.g., call handling during regular care).
- Spatial tasks: Tasks must be performed at various locations, such as the hospital ward, nursing center, and pathology laboratory, necessitating considerable movement.
- Collaboration: Many tasks must be done collaboratively, for example, bathing assistance, pressure ulcer care, and transfer of a patient between a bed and wheelchair.

- Recordkeeping: Accurate records of patient condition and treatment must be kept for future care conferences and evidences.

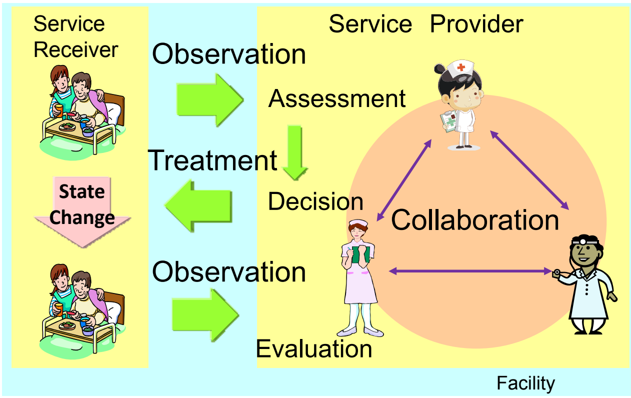

Figure 1: Value co-creation in physical and adaptive services

Maintenance service of facilities (i.e., elevator, air conditioner, and plant equipment), retail services in large-scale shopping malls, and guide services in amusement parks are also regarded as PAI services. Traditional PC-based tools for computer-supported collaborative work are ineffective at supporting PAI services. Table 1 shows a comparison between PAI services and the software development as a typical PC-based collaborative work.

TABLE 1: COMPARISON BETWEEN PAI SERVICE AND SOFTWARE DEVELOPMENT

Feature	PAI Service	SW Development
Knowledge-based tasks	High	High
Adaptation	High	Low
Multitasking	High	Middle
Spatial tasks	High	Low
Collaboration	High	High
Recording	High	Middle

III. COMMUNICATION IN PAI SERVICES

The communication is placed with a base of the collaboration. Here, knowledge management is included in communication management in a broad sense. Based on observations and interviews in a hospital and a care facility, which are participants in our project, the objectives and methods of communication for the better collaboration management in nursing and caregiving as PAI services are analyzed.

A. Objectives of Communication

The objectives of communication among nurses, caregivers, and other staff can be classified as follows.

- Information sharing: Nurses and caregivers communicate with others to share information (awareness) about patients and care recipients (client information sharing) and information (awareness) of the progress of tasks (process information sharing). In information sharing, information receiver's actions are actively-controlled according to the receiver's observation. These information sharing activities realize knowledge management.
  - Client information sharing includes face-to-face communication at a shift-change meeting and PC-based communication via a healthcare information system for recording and viewing patient information.
  - Process information sharing is necessary for collaboration with colleagues at remote locations (e.g., a nurse in the nursing center confirms progress of bathing services in the bath room).
- Instruction and request: Nurses and caregivers communicate with others to transmit instructions and make requests. Instructions and requests include the following forms of communication. In instruction and request, information receiver's actions are passively-controlled according to the sender's will.
  - Transmitting instructions/orders to staff (e.g., medical instruction from a doctor to a nurse).
  - Real-time requests for transportation services (e.g., patient transportation between a patient's room and the operating room).
  - Non-real-time requests from clients and clients' families (e.g., requests for changes in meal service and meeting request from a client's family).

B. Methods of Communication

Table 2 lists communication methods that are used in actual nursing and caregiving settings. In the table, "operator/supervisor" indicates operator-controlled communication, analogous to radio dispatching of taxis and traditional telephone controlled by a switchboard operator. During direct nursing and caregiving with physical actions, it is not so easy to use these communication devices. Recently, hands-free devices based on voice recognition technologies are highly-promising. Human operators are also effective but expensive, so automatic intelligent operators (communication supervisors) are required.

TABLE 2: COMMUNICATION METHODS IN NURSING AND CAREGIVING
(Sync: Synchronization, Async: Asynchronization)

Method	Media	Distance	Timing	Channel	Record	Direction
Face-to-face communication	Voice	Near	Sync	Many to Many	None	Push
Memorandum	Paper	Near	Async	One to one	None	Pull
Phone	Voice	Far	Sync	One to one	None	Push
Bulletin board	Board	Near	Async	Many to Many	None	Pull
Inter communication system	Voice	Far	Sync	Many to Many	None	Push
Mail	Text	Far	Async	One to many	Exist	Push
SNS	Text & Image	Far	Async	Many to Many	Exist	Pull
Operator/supervisor	Voice	Far	Sync + Async	Many to Many	None	Push

TABLE 3: COMMUNICATION METHODS AND OBJECTIVES IN PAI SERVICES
("+" shows degree of suitability)

Method	Information sharing		Instruction and request		
	Client	Process	Instruction	Request (Real-Time)	Request (Non-Real-Time)
Face-to-face communication	+++	+	+++	++	++
Memorandum	++	+	+	-	+++
Phone	+++	+	+++	+++	-
Bulletin board	++	++	+	-	+++
Inter communication system	+++	+	+++	+++	-
Mail	++	+	+++	-	+++
SNS	+++	+++	+	-	++
Operator/supervisor	++	+++	+	++	++

Table 3 shows the suitability of communication methods in nursing and caregiving for meeting communication objects. Because each communication method has particular advantages and disadvantages, they are used in combination to achieve communication objectives. However, it is hard for nurses and caregivers to carry many communication devices. Now smartphones show great promise for integrating multiple communication tools into a single device. Furthermore, hands-free interface applications of the smartphones with voice recognition engines become available and in widespread use. We introduce a communication model called an "information supervisory control model" to explain these communication methods, including the operator/supervisor, in an integrated fashion.

IV. INFORMATION SUPERVISORY CONTROL MODEL

To design and evaluate a temporal-spatial collaboration support system, a communication model is required. Several studies on models of communication in nursing and caregiving have been reported [9,10]. We have also modeled collaborative processes in nursing and caregiving by means of Petri nets and evaluated the efficiency of communication through computer simulation [11]. Here, we must model not only the communication system but also humans (the senders and receivers) of information. However, the human behavior of nurses and caregivers is difficult to model. Accordingly, human behavior modeling of nurses and caregivers remains an important issue.

Supervisory control is a well-studied model of a discrete-event system in which events occur concurrently and collaboratively [12]. In traditional supervisory control, a supervisor controls the target system by permitting the occurrence of events in order to satisfy a given specification. We call the traditional supervisory control "event supervisory control."

The controlled objects in event supervisory control are machines, not humans, and thus human behavior modeling of nurses and caregivers requires the following additional considerations.

- Humans finally make decisions and take action based on available information (shared information, instruction, and request).
- Humans use tacit knowledge to decide upon actions in addition to available information, but a complete model of tacit knowledge is impractical.
- The information processing capability of humans is limited.
- Human behavior differs between individuals according to their mental and physical condition.
- Humans can inquire about information and verify it, if desired.

We introduce information supervisory control as an alternative to event supervisory control. In the proposed control scheme, a supervisor indirectly controls the target collaborative system, including humans, by controlling the information distribution flow. Here, indirect control means that humans ultimately decide upon and implement actions autonomously, and only the provided information is controlled. In information supervisory control, the necessary information (what) is distributed to the right person (who) at an appropriate time (when) and an appropriate place (where) by a suitable means (how). In other words, information supervisory control acts as if it were a responsive administrative assistant. Figure 2 depicts event supervisory control and information supervisory control. Since raw information generated by colleagues are too much, the supervisor controls the information distribution flow. Then, a service provider observes the controlled information, infers the status of clients and processes, decides, and makes actions. In previous research, the blackboard model and the agent model have been proposed, in which processes and agents autonomously operate on the basis of the information provided. In those models, however, information flow control is not explicitly adopted.

Information supervisory control features the following specific information control items.

- Who:
  Information is distributed to only the person who needs it, thus avoiding interruptions caused by unnecessary information (spam). This control is designed to accommodate the limited information processing capability of humans.
- What:
  Information is distributed after customization based on the recipient's context, according to which some information may be added or deleted.

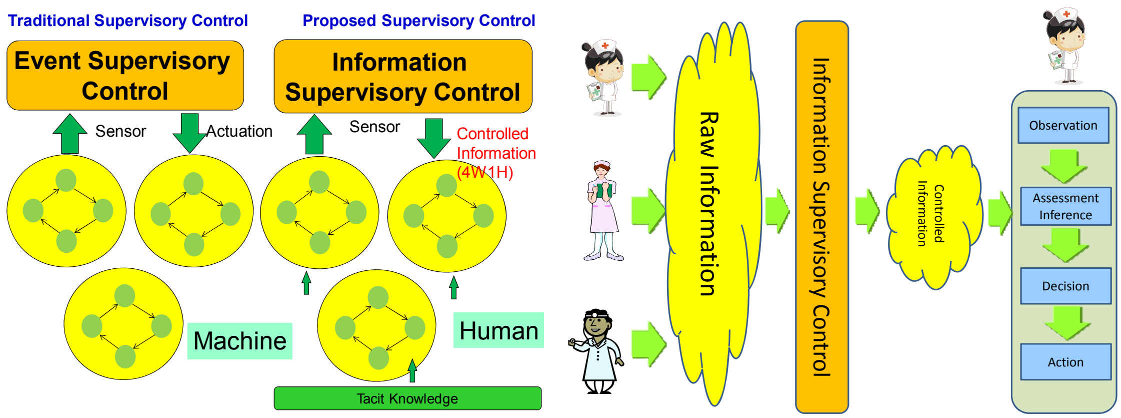

Figure 2: Information Supervisory Control

- When:
  The timing and recipient priority of information distribution are controlled in order to minimize ambiguity. For example, ambiguity occurs when a nurse call request is sent to several nurses simultaneously.
- Where:
  Information is distributed with consideration given to the recipient's context. For example, low-priority information is sent after, not during, important work in a patient's room or in the operating room.
- How:
  The mode of information distribution is changed according to the objective. For example, there are several modes including "urgent," "regular," and "reference."

Furthermore, supporting the cultivation and utilization of tacit knowledge is also important for better collaboration.

V. SMART VOICE MESSAGING SYSTEM

In accordance with the information supervisory control model, we have developed a smart voice messaging system (Fig. 3), which provides a handsfree communication method for temporal-spatial collaboration in PAI services.

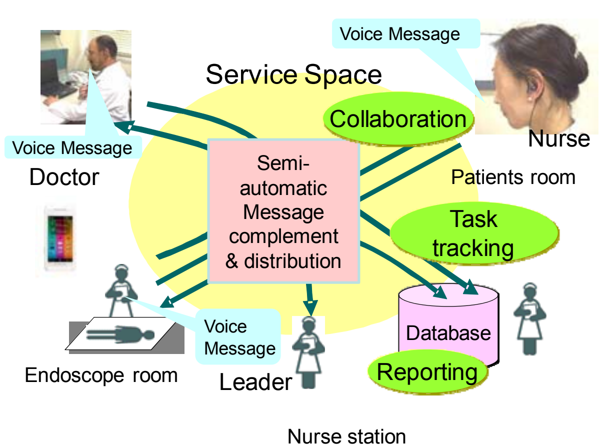

Figure 3: Smart Voice Messaging System

In the proposed smart voice messaging system, voice messages can be automatically distributed to the right person at the right time and place in the right way (who, what, when, where, and how) without cumbersome input operations. To do so, the automatic voice message distribution engine uses tags appended to the voice messages.

Figure 4 shows the voice message distribution engine. Voice message tags annotate the message and indicate contextual information about the message. These tags are generated from keywords (voice recognition) and location and acceleration (from sensor data) [7].

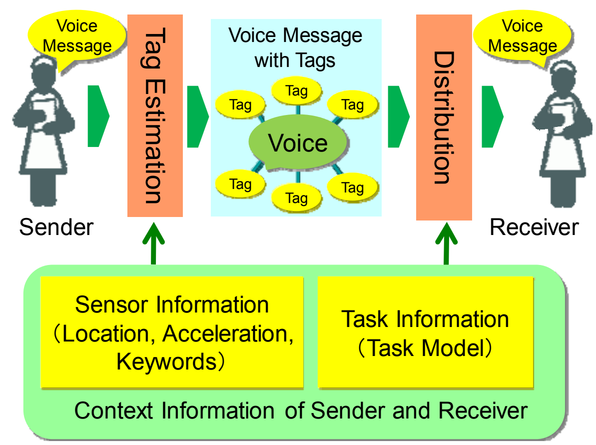

Figure 4: Message Distribution Engine

This smart voice messaging system makes a strong showing in client and process information sharing explained in Section III. Typical use cases of the smart voice messaging system in nursing and caregiving are given below.

- Client Information sharing in regular information transfer:
  Nurses and caregivers record voice messages of information observed about patients and care recipients during work. Tiny awareness of patient's and care recipient's conditions is recorded by voice more easily. The messages are then used at the shift-change meeting.
- Client information sharing as voice sticky notes:
  Nurses and caregivers record voice messages of tasks to be done. Afterward, a reminder about the task is given.

- Process information sharing in collaborative works
  Nurses and caregivers report and share their progress status. Then, appropriate actions and support can be adaptively implemented in collaborative work.

Figure 5 shows an example of voice message distribution. A nurse speaks with Patient X during a round and records the following messages about the patient.

- Message A: “Patient X reports foot pain. Please be careful at bath time.”
- Message B: “Patient X hopes to change his meal service from rice porridge to normal rice.”

Message A will be distributed to a bath caregiver at bath time in the bathroom. Message B will be distributed to other nurses during a shift meeting at the nursing station. These massages are automatically classified and distributed without any smart phone operations. In the traditional communication, information is shared with sender’s intentions and efforts (operations). Therefore, only critical information is shared and most non-critical information is lost. While instructions and requests are often critical, information sharing of client and process are often non-critical. The smart voice messaging system can handle the non-critical information without sender’s strong intentions and efforts.

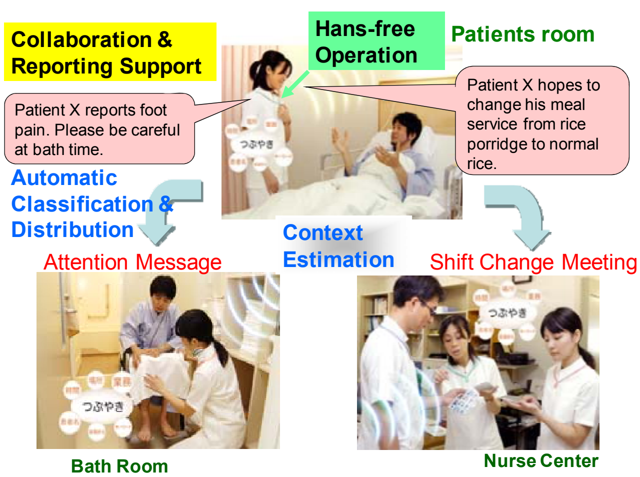

Figure 5: Example of Smart Voice Messaging

The smart voice messaging system can store past records of traces and voice messages of nurses and caregivers. We have developed a service-space visualization and evaluation system that utilizes these records (Fig. 6) [13]. This tool enables the evaluation of operational efficiency and of the burden on nurses and caregivers, and is intended to support managers in redesigning work processes and the spatial layout of patients, staff, and equipment and in designing new hospitals or care facilities. This tool is also useful for the education of nurses and caregivers through retrospective analysis. In particular, tacit knowledge can be effectively externalized and shared among staff, which provides “Ba” and SECI processes [14].

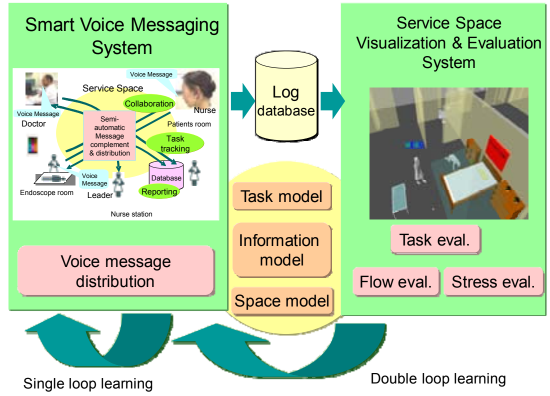

Figure 6: Service Space Visualization and Evaluation Tool

VI. HYPOTHESIS AND EVALUATION

A. Hypothesis

In traditional event supervisory control, a basis for evaluating the system is controllability and optimality. However, since humans can decide actions autonomously, controllability is an insufficient basis for evaluating the proposed system. Instead, here we adopt the following evaluation items (I, II, III), one of which is the conventional item of efficiency improvement (I).

I. Efficiency improvement: Reducing moving distance/time and working hours in nursing and caregiving.
II. Quality improvement: Minimizing malpractice and maximizing client satisfaction.
III. Employee satisfaction improvement: Reducing physical and mental burdens.

To determine whether the smart voice messaging system will achieve the intended benefits according to the above evaluation items, we will test the following hypotheses.

- H1: The system makes collaboration smoother and more efficient by reducing ineffectual and redundant actions through appropriately distributed information.
  -> I, III
- H2: Many tiny awareness of patient's and care recipient's condition is easily recorded by simple information input in smart voice messaging, which may be lost in the traditional communication. -> II
- H3: The information processing capability of humans is limited. The system lessens the harmful effects of information overload. -> I
- H4: Using tacit knowledge enables a higher level of performance in comparison with using explicit information only. -> I, II
- H5: Recording voice message is easier than writing messages by hand. -> I, III
- H6: Adequate feedback promotes utilization of recorded information. -> II, III
- H7: The system provides functions of an internal communications system, mail, and a social networking service in an integrated fashion, as well as easy-to-use

face-to-face communication and telephone in a complementary manner. -> III

B. Triangulation for Service Evaluation

Our research and development project has conducted several field experiments in collaboration with a hospital in Kanagawa and a care facilities in Tokyo. Although actual field experiments are effective for identifying real-world targets and potential needs, a quantitative and objective evaluation is difficult for the following reasons.

- Authorized standard work in hospitals and care facilities take precedence over field experiments. An experiment is not permitted to interfere with care. Interfere with the experiment are basically not allowed.
- Worker activities depend on situational demands which change day to day; thus, control of experimental conditions is not feasible.
- Habituation to the system has a great influence on the experiment.

One way to overcome these obstacles is to use a virtual field experiment and computer simulation to complement a field experiment. We have developed a triangulation environment for service evaluation (Fig. 7).

- Field Experiment
  First, a work analysis of current nursing and caregiving operations is performed by using measurement hardware (voice, location, and acceleration) and conducting interviews with workers. Then, a developed system (prototype) is tested to identify real-world targets and potential needs [7].
- Virtual Field Experiment
  A virtual field (virtual hospital, virtual care facility) is constructed by using lecture halls and university students to simulate typical field operations. In this virtual field, experimental conditions can be iteratively changed to perform a number of variations on an experiment [15], thus enabling the above hypotheses to be tested qualitatively and objectively.

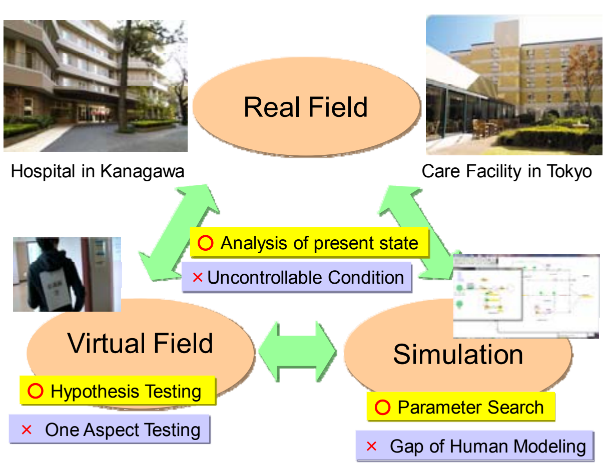

Figure 7: Triangulation for Service Evaluation

- Computer Simulation
  A virtual field is simulated on a computer by modeling humans and the communication among them. This computer simulation makes it possible to reduce the service design space and the search design parameters [11].

C. Preliminary Experimental Results

We have conducted five field experiments and five virtual field experiments, as well as computer simulation of the virtual field experiments. In each virtual field experiment, three or four sets of unit experiments were performed under different conditions [15].

To test hypothesis H1, we compared traditional communication using face-to-face meetings and mobile phones, and communication using the proposed smart voice messaging system complementary with face-to-face meetings. We received both positive feedback and negative feedback from nurses who participated in the virtual field experiment.

- Positive Feedback
  - The smart voice messaging system enables easy information sharing, whereas a traditional mobile phone is used for important communications only. Since they feel burdened when using a traditional mobile phone, they don't send non-critical information like their task progress.
  - Making inquiries to others is easy because their situation can be recognized by the smart voice messaging system. It is possible to ask questions about patients who are assigned to other staff without going back to the nursing station.
- Negative Feedback
  - It is difficult to hear voice messages during conversations with patients and during intensive work. They dislike frequent and redundant voice messages. The current implementation of message distribution engine is primitive. It is required to sophisticate the engine.
  - Compared with a mobile phone, the smart voice messaging system lacks interactivity due to the distribution delay.

We explain one of virtual field experiments in which three actively working nurses join. Figure 8 shows the arrangement of the rooms. Here, #301, #302 and #303 are patients' rooms and each room has three patients. Three nurses take care of nine patients cooperatively for regular services (meal, rehabilitation and bathing services) and adaptively for irregular nurse calls. Bathing services require two nurses.

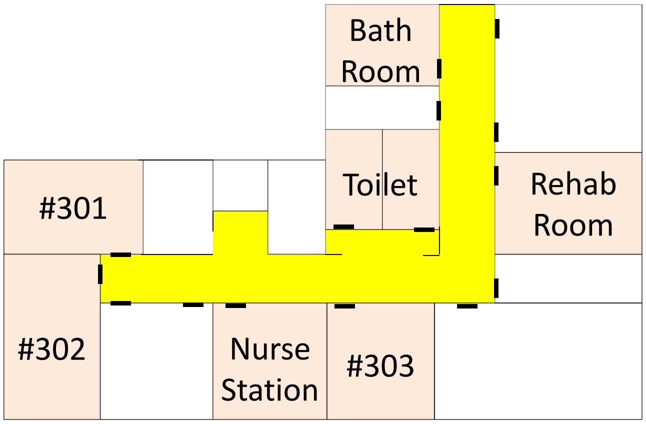

Figure 8: Arrangement of the Rooms in Virtual Field Experiment

In the virtual field experiment, the following items related to the hypotheses are examined.

1. Comparison of service quality in the experiments with the voice messaging system and without the voice messaging system (H1).
2. Potential ability of smartness (message distribution control) of the voice messaging system (H1, H2).

Figure 9 shows comparison of remaining tasks and patients' total waiting time between with and without the voice messaging system. By using the voice messaging system, total waiting time is reduced, that means service quality is improved. On the other hand, remaining tasks are smaller without the voice messaging system. Two reasons should be considered. One reason is that the simple voice messaging system may have the harmful effects of information overload. Another is that closer collaboration with the smart voice messaging gives priority to reduction of waiting time (customer satisfaction) than reduction of remaining tasks (operational efficiency). According to other several virtual experiments, these evaluation metrics strongly depend on team work of examinee and coincidence even in the virtual experiment environment. It is important to analyze individual collaboration cases in addition to simply compare total times.

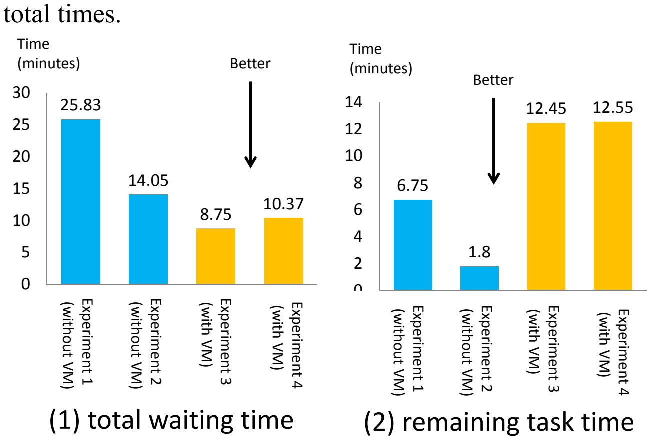

Figure 9: Comparison of service quality

Figure 10 shows a traffic line of nurses in some experiment. In a prophetical evaluation, 54 broadcast messages could be reduced to 35 messages by the smart message distribution engine because 19 messages are no relevance to the collaboration. We can also find a potential ability to support better collaboration in bathing service in Figure 10. In this case the nurse #3 missed an important voice message for better collaboration among the verbose and noisy messages, and then the nurse #1 was waiting for nothing until the nurse #2 came back.

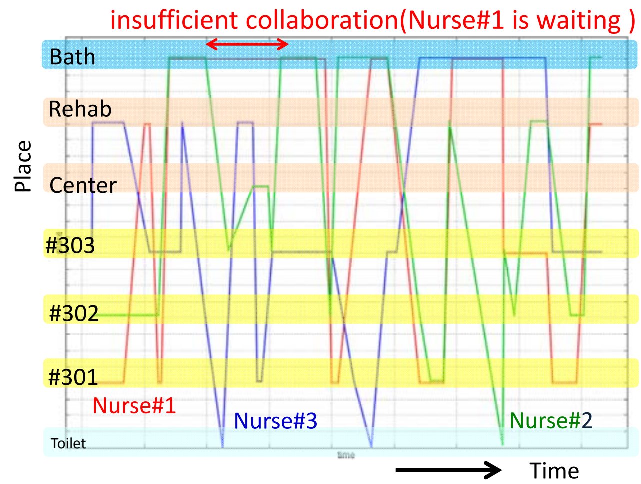

Figure 10: Traffic Line of Nurses

VII. RELATED WORKS

Tang's group has intensively investigated hospital communications [16, 17, 18, 19]. They have analyzed the impact of new communication technology (the Vocera(R) Communication System) introduced into a hospital. They introduced the InfoFlow framework, which considers six interrelated factors: information, spatiality, temporality, personal, artifacts, and communication mode.

According to this framework, Tang and co-workers also reported a fishbone diagram for visualizing and analyzing the findings (positive and negative) on the deployment of Vocera communications systems in a hospital. There method is useful when analyzing and evaluating communications systems in a healthcare setting. However, the Vocera communication system and InfoFlow framework do not consider information supervisory control that employs information on who, what, when, where, and how.

VIII. CONCLUSION

With the aim of improving the efficiency and quality of nursing and caregiving service systems as physical and adaptive intelligent services, this paper proposed an information supervisory control model and a smart voice messaging system based on the model. We also formulated hypotheses to be tested for evaluating the system. Based on triangulation for service evaluation, we show some preliminary experimental results. The further works include refinement of a message distribution engine and comprehensive hypothesis testing based on a number of experiments.

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