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Nursing Care Scheduling Problem: Analysis of Inpatient Nursing

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In most Japanese hospitals, different nurses handle the pre-assigned nursing cares in different ways, which directly affect the quality of nursing cares. Thus, it is necessary to quantitatively elucidate the nurses' action rules for nursing instruction in high-quality care provision and evaluation of staffing levels. Keeping track of times of relative effectiveness in meeting and connecting with another can reveal and extend one's skills of engagement in practical nursing cares. Therefore, modelling inpatient nursing from the viewpoint of scheduling, we propose a new method to quantitatively elucidate the implicit action rules of nurses on their provision of nursing cares engaged in practical nursing cares, according to a set of candidate existing dispatching rules. In simulations to match the nursing care schedules planned by dispatching rules with the observed ones, we conclude that (1) nurses make schedules based on the rules similar to the dispatching rule of earliest due date (*EDD*), which means they refer the evaluated preparation times of activities and their expected finishing times assigned in worksheets, and (2) nursing staffing level have an inverse relation (-0.68 for preparation coefficients - the ratio of preparation time evaluated to that in manuals - to work tenures based on the linear regression analysis) with the evaluated preparation times, which should be one issue on the possibilities that nurses provide nursing cares as scheduled in worksheets.

Keywords: Nursing modeling, nurse action rule, dispatching rule, staffing level.

1. INTRODUCTION

Inpatient nursing is defined as the diagnosis and treatment of patient responses to actual or potential health problems. It highly depends on the dynamic hospital environment and diverse nurse staffing levels, which directly result in an undesirable waiting time (that is, a delay from the planned time) of patients. In addition, Japanese hospitals have to face two serious problems in recent years: (i) shortage of nurses: contrast to the ratio of the number of nurses in per 1,000 population in Sweden: 10.3 population, the ratio in Japan is 6.4 population only in 2004[(1)]; (ii) complexity of nursing due to the increasing responsibility for providing high quality nursing cares in the aging society (the rate of the elderly 65 years old and over in the population is 20.2% in 2005[(2)]). In this respect, nursing is recognized as one of the toughest job in Japan, especially for the nurse novices. As we know, with the development of medical technology in recent years, the nurses' responsibility for providing high quality cares with effectiveness and efficiency is pursued by the hospitals and the public.

In general, it is recognized that more nursing time per patient results in better patient outcomes, so that a lot of practitioners contribute to increasing their working hours. However, it will result in higher rates of the risk of misses like sharp and needle-stick injury[(3)]. In a total view, nurses provide the cares, which consist of a set of expected activities pre-assigned in worksheets and unexpected activities termed as interruptions, according to the technological procedures in the manuals. As described by the abstract nursing model in **Fig.1**, they determine the processing orders of the pre-assigned nursing activities in their own ways (termed as the nurses' action rules, including referenced information and scheduling algorithm), and quickly response to the unexpected activities. Normally, nurses with lower nurse staffing levels provide their nursing cares in worse processing orders, which directly lower the quality of nursing cares. Thus, hospitals with low nursing staffing levels tends to have higher rates of poor patient outcomes[(4)]. Consequently, to provide a high-quality of nursing cares, besides the technology of nursing, it is more important to define the processing orders of nursing cares.

As we know, scheduling is a problem to define the processing orders of a serial of jobs. In recent years, similar to the normal scheduling problems, several methods have been proposed to nursing scheduling problems[(5)(6)]. Using the agent-based scheduling methods, they can obtain a nursing schedule in a better quality. However, these methods are limited on their practical application by current staffing levels and realistic nursing environments. In current hospital societies, nurses mainly acquire their own ways to provide the nursing cares by gaining the fragmentary knowledge of the elder nurses in hospitals on their case-by-case ways to provide nursing cares. However, in actual, no one can explain the detailed way to define the processing orders of pre-assigned activities, that is, to summary that (1) what is based on and (2) how do they define the processing orders, during the provision of nursing cares.

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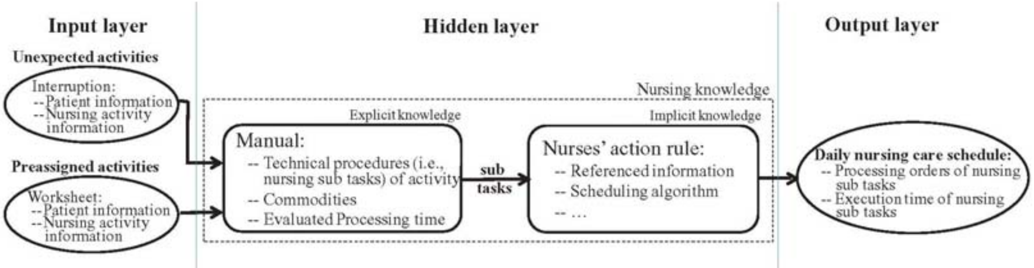

Fig.1 The abstract nursing model

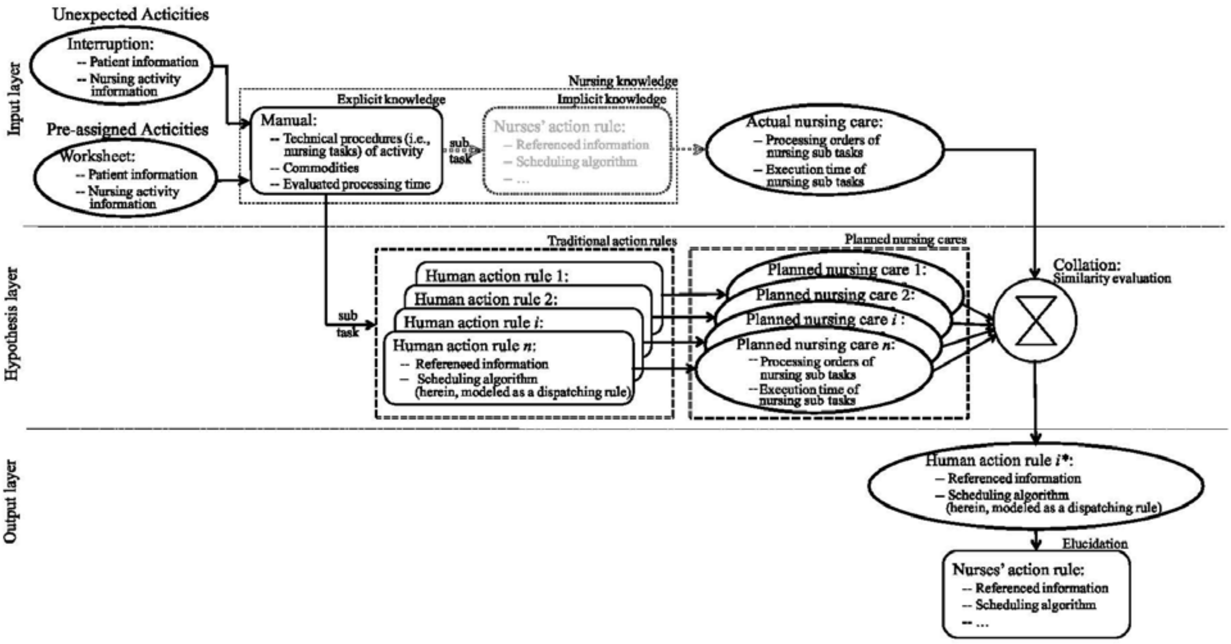

Fig.2 The abstract model of the analysis method

In this respect, it is practically mandatory to quantitatively elucidate the implicit nursing scheduling algorithms of nurses by analyzing their inpatient nursing cares. Therefore, we are possible to (i) have a quantitative evaluation of the nursing staffing levels other than the working tenures, and furthermore (ii) propose an effective nursing care instruction system in actual nursing environments based on the elucidated referenced information during the nurses' provision of nursing cares.

In recent years, more and more researchers have emphasized their studies on the analysis of inpatient nursing cares aiming at extracting important points during the provision of nursing cares(7)(8)(9)(10). From the study by Benner in 1982, a lot of researches have been studied on the decision making models (scheduling algorithm in Fig.1) of nurses, mainly according to the dialogues (interviews and/or questionnaires) on their provision of nursing cares. Benner(8) did a research about the nursing staffing levels by studying the experiential learning. It is based on the dialogues about the therapeutic cases of nurses. In addition, Lauri(9) emphasized the research on the identification of decision making model. Using the structured questionnaires with 5 point scale on 56 items, the research shows the result on the variables of the decision making. And furthermore, Yokouchi(10) proposed a task classification system using the ethno-methodological word mining method. Based on the interviews with nurses on their scheduling methods, the research shows a comparison of experts and nurse novices. As we know, almost all of these literatures obtained their conclusions based on the nurses' dialogues. In this way, there may be an influence of nurses' subjective thoughts on the results to some extent. To our knowledge, there is not any research on the quantitatively analysis of nursing cares to elucidate the nurses' implicit scheduling algorithms.

On the other hand, many researches on the modeling of action rules have been studied based on the stochastic models(11)(12). Considering the human action rules as a serial of stochastic transitions from one state to another state, they can recognize human actions, and furthermore induct the human actions with the empirical support. However, these models are only of the descriptions of human action rules to some extent. As we know, it is impossible to explain human action rules like referenced information in nurse action rules.

Consequently, in this paper, we will quantitatively explain the implicit nursing action rules from the viewpoint of scheduling, by analyzing their inpatient nursing cares. Now, in our E-Nightingale project(13), using the ubiquitous sensor network (mainly including the voice records and infrared passing sensors, according to which we obtain the voice data on the execution of providing nursing cares and location data of nurses) technology, we are developing a nursing support system to measure and analyze inpatient nursing cares(14) by furthermore segmenting it into a serial of nursing activities (the ones pre-assigned in worksheets, and interruptions)

Date	Feberary 28, 2008							
Time	8:30	9:00	9:30	10:00	10:30	11:00	12:00	13:00
Patient a 501A	>Foot Bath >Shampoo Poratable toilet (can be used)	>09:00Gauze change (right hand)		>10:00Blood-pressure check		>11:30Bscheck >11:30Preprandial medicine	>12:00Serve and clear off tray >12:30Teeth brushing	
Patient b 501B	>Drinking Restriction 1000ml/day	>09:00Antibiotic DIV		>10:00Blood-pressure check >10:00Instillation of drop (right)			>12:00UV check (with Order) >12:00Serve and clear off tray >12:30Compliance check	

Fig.3 Part of a sample worksheet

according to the manuals. Contrary to the normal scheduling problems to propose a method to generate optimal schedules, we aim at elucidating the implicit nursing action rules according to the obtained data (worksheets, interruptions, manual, and actual nursing cares), as shown in **Fig.2**. Hypothetically modeling the nurses' action rules as a set of candidate dispatching rules, according to which different nursing care schedules can be generated for actual worksheets and interruptions, we quantitatively elucidate nurses' action rules based on the most similar dispatching rules, obtained by evaluating the similarities of the planned nursing cares with observed ones.

The remained of this paper is organized as follows. Section 2 describes the nursing care scheduling problems. Section 3 introduces several single dispatching-rule based methods. Section 4 elucidates the implicit nursing scheduling algorithms, and discusses the difference of staffing levels. And finally, Section 5 has a description of conclusions and future works.

2. NURSING CARE SCHEDULING PROBLEM

In hospitals, nurses provide patients with direct or indirectly nursing cares up to 24 hours a day, which is generally consisting of a serial of nursing activities.

2.1. Inpatient Nursing Care

Normally, nursing care, including the pre-assigned nursing activities in worksheets and unexpected nursing activities (interruptions), is provided to corresponding patients according to the nursing procedures in the manuals.

(1).Worksheet: A piece of paper recording a serial of nursing activities planned or done on a therapeutic plan. As a sample of worksheet in **Fig.3** shows, the worksheet is mainly including the following information:

- Patient information (patient name and bed information).
- Nursing activities category.
- Expected execution time constraint (the constraint that the care included in the nursing activity should be provided to patients in the expected execution time.).

For example, the nursing activities of "Blood pressure check" in Fig.3 are desired to be provided to "Patient a" and "Patient b" within the interval from 10:00 to 10:30.

(2).Interruption: the nursing activities, different from those pre-assigned in the worksheet, are occurring at an unexpected time, and should generally be handled immediately, such as the contact among nurses/patients, and interruptions from the nurse call. The interruption is mainly including the following information when it occurs:

- Patient information (patient name and bed information).
- Nursing activities category.

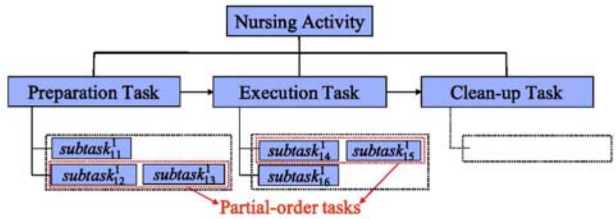

Fig.4 Construction of nursing activity

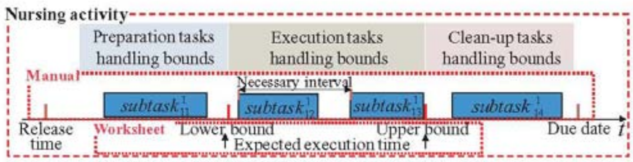

Fig.5 Nursing care scheduling problem - allocation of nursing activity

- Occurring time.

(3).Manual (Nursing Activity & Tasks): Documents describing the standard methods to handle the nursing activity with the purpose to care patients, e.g., blood pressure measure, environment maintenance. It is mainly including the following information:

- Commodities.
- Technical procedures of nursing.
- Evaluated processing time of nursing activities.

In actual, nursing is practiced in real settings with real constraints, possibilities, and resources, and working environments may constrain one's practice beyond his or her ability to respond effectively. Here, to represent the constraints in actual nursing, we model the manual in a hierarchical frame. **Fig.4** shows the construction of an nursing activity. In this figure, the vertical representation shows the decomposition of nursing activity by nursing tasks, and nursing task by nursing sub-tasks, which is connected by the straight lines. In addition, the horizontal arcs shows the procedure constraints among tasks. Moreover, in the hierarchical construction of sub-tasks, the vertical representation states the procedure constraints among sub-tasks, and the horizontal representation states the partial order relations of sub-tasks, respectively. For example, $subtask^1_{11}$ should be performed before $subtask^1_{12}$ and $subtask^1_{13}$, while $subtask^1_{12}$ can be performed before or after $subtask^1_{13}$ because of their partial order relations.

Normally, each nursing activity generally consists of preparation tasks, execution tasks, and clean-up tasks according to the description in manuals. Moreover, each task can also be decomposed into a set of sub-tasks according to its characteristics.

As we know, the execution of each nursing task involves a transition or movement between locations. Thus, we introduce the sub-tasks according to the transitional positions in this study. For

Table I Dispatching Rules

Items			Expected execution time: $[T_{LB}, T_{UB}]$*	
			LB	LB&UB
Evaluated processing time**	No		***FCFS***	***EDD***
	Yes	Execution tasks only	***MPT***	***SLACK***
		Execution & Preparation tasks	***extended MPT***	***extended SLACK***

* T_{LB}: lower bound of expected execution time, UB: upper bound of expected execution time in the worksheet;
** "No": out of consideration of evaluated processing times, "Yes": in consideration of evaluated processing times.

example, as for the preparation task of intravenous drip, we define a set of sub-tasks: sub-task in Nurse Station (for Karte check), sub-task in Drip Preparation Room (for the preparation of medicine, drip tube), and sub-task in Sick Room (for the confirmation of the patient on its in the room). Therefore, in our E-Nightingale project [14], we can properly know the activity information pre-assigned in the worksheet or interruptions based on the voice data [15, 16], and the sub-task information of the activity based on the location data during the provision of nursing cares. In this way, we are possible to model the nursing manual through observed inpatient nursing cares.

2.2. Nursing Care Scheduling Problem

Nursing care scheduling problem, defined as the problem to decide the processing orders to handle a set of nursing activities, is to allocate the subtasks of each activity over time while obeying the technical procedures in manuals and time constraints in worksheets (**Fig.5**). This allocation must obey a set of constraints that reflect the temporal relationships between the tasks and the capacity limitation of the nurse. In general, there are several basic kinds of constraints as follows:

(i) Release time constraints: For any nursing activity, its any task cannot be handled until its release time. For some reasons like the absence of the nurses or the shortage of medicine, the nursing activities cannot be handled. In this paper, we restrict ourselves to the case where it is the prefered start point of the nursing activity, which is mainly determined by its preparation time (later we will state a detailed description).

(ii) Procedure Constraints: The processing of nursing tasks of a nursing activity should observe the technical procedure in manuals, that is, a nursing task cannot be handled until the previous task of the same nursing activity is finished. For example, the execution task cannot be handled before the preparation task.

(iii) Capacity Constraints: Nurses have the limited processing capacity to handle their work. In general, they can handle only one nursing task at a time. For example, during the provision of intravenous drip, it is impossible to provide the toilet assistance to patients.

Besides the above three kinds of constraints (termed as *hard* constraints, which a nursing care schedule should observe), there is the other three (termed as *soft* constraints, which the schedule should satisfy as possible as it can).

(iv) Due date constraints: The last nursing tasks of a certain nursing activity must finish before the due date of the nursing activity. In this paper, we simply model it as the end point of the duty time.

(v) Implicit time constraints: Some nursing tasks cannot be handled immediately after their previous task of the same nursing activity due to some reasons like the lasting characteristic of nursing tasks. For example, the nursing task of intravenous drip reservation should be handled after the start of the drip with an expectable interval, during which the other tasks can be handled.

(vi) Expected execution time constraints: Some execution tasks of nursing activities should be handled during an expected execution time interval $[T_{LB}, T_{UB}]$ as planned in the worksheets. For example, the nursing activity of food provision should be handled during the noon time (normally from 11:00 to 13:00).

In a word, nursing care scheduling problem, formulated as the problem to determine the processing orders of nursing tasks, is to observe the above soft constraints when satisfying the hard constraints. To elucidate the implicit nursing scheduling algorithms of nurses, we should find out a scheduling algorithm among the candidate ones, according to which we generate the most similar nursing care schedules with the actual ones, as described in Eq.1.

Problem:

$$\arg\max_{Rule} \mathit{Similarity}_{Rule} \qquad \ldots\ldots\ldots\ldots..(1)$$

Subject to:

Observe the above six kinds of constraints.

Here, $\mathit{Similarity}_{Rule}$ is the performance to evaluate the rate of the similar part between the actual nursing cares schedule and the planned one, which is obtained based on the candidate scheduling algorithm *Rule*.

To model and elucidate the implicit nursing action rules, we will introduce a set of candidate scheduling algorithms to the nursing care scheduling problems in the next section, followed by the detailed induction of the performance measure on similarity.

3. NURSING SCHEDULING METHODS

As described in the literatures of scheduling methods, dispatching rule is a policy according to which the processing orders of a set of jobs are defined. It is recognized as the implementation of human thoughts, and widely used in the scheduling fields. Therefore, to elucidate the implicit nursing scheduling algorithms, we will model them as a set of candidate dispatching rules and evaluate their similarities by comparing planned nursing care schedules with the actual observed ones.

In general, nurses can only grasp the following information before the provision of nursing cares: (1) expected execution time $[T_{LB}, T_{UB}]$ from the worksheet, and (2) evaluated processing time with different slack times from their experience. Thus, we hypothesize that a nurse make schedules for assigned nursing activities according to the above two information. By evaluating all of possible dispatching rules considering expected execution time and evaluated processing time, we are able to elucidate the action rules of nurses on their provision of nursing cares. In recent years, above 100 dispatching rules has been proposed [13], and most of the complicated dispatching rules can be considered as an extension or combination of some single ones. As mentioned by Panwalkar in 1977, the most prominent dispatching rules are first-come-first-service (*FCFS*), shortest processing time (*SPT*), most work remaining (*MWKR*), minimum batch size (*MBS*), earliest arrival time (*EAT*), largest processing time (*LPT*), shortest setup plus processing time (*SSPT*), shortest remaining processing time (*SRPT*), shortest slack time (*SLACK*), and earliest due date (*EDD*). As interviewed with several nurses on their action rules on the provision nursing cares, they general handle the nursing activities by referring the information in worksheets. In these rules, only *FCFS*, *SPT*, *EAT*, *LPT*, *SLACK*, *EDD* can simply consider the information in worksheets. Here, FCFS and EAT are of the similar functions, and SPT and LPT are of the opponent functions during the scheduling process. As shown in some observed nursing cares, nurses perform the activity with larger processing time first. Consequently, we only consider 6 kinds of single dispatching rules in this study: *FCFS*, *EDD*, *MPT* (maximal processing time, also termed as *LPT*), *extended MPT*, *SLACK*, and *extended SLACK*, as shown in **Table I**.

3.1. Referenced Information

3.1.1 Evaluated Processing Time

In actual dynamic nursing environments, considering the possible occurrence of unexpected events, nurses handle their nursing activities with slack times to ensure to provide the nursing cares as pre-assigned in the worksheets, as described by several nurses in our companied hospital. Normally, the slack times are recognized as the enlarging of the processing times from the average values of the nursing activities. Thus, here we considered the following two coefficients: preparation coefficient α for preparation tasks and execution coefficient β for execution tasks, and hypothesis that the evaluated processing time has a linear relation with average processing times of nursing tasks:

$$\mathrm{PT}_i = \alpha \sum_{j \in J_{Pi}} \mathrm{pt}_{ij},\ \alpha : \text{preparation coefficient.} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$\mathrm{ET}_i = \beta \sum_{j \in J_{Ei}} \mathrm{pt}_{ij},\ \beta : \text{execution coefficient.} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Where, $1 \le i \le N$.

Here, N is the total number of the activities pre-assigned to a nurse, J_{Pi}, J_{Ei} are the collections of the preparation subtasks and execution subtasks of i-th activity, pt_{ij} is the average processing time of j-th subtask, and PT_i, ET_i are the evaluated preparation time and evaluated execution time of i-th activity. The larger the preparation coefficient α is, the more the slack time that a nurse considers for handling the preparation tasks is during the scheduling process, and the earlier the nurses will start to deal with the preparation tasks. Similarly, the larger the execution coefficient β is, the more the slack time is for handling the execution tasks during the scheduling process. Besides the preparation and execution tasks, the clean-up tasks may also affect the nursing cares. In this paper, we will simply consider clean-up

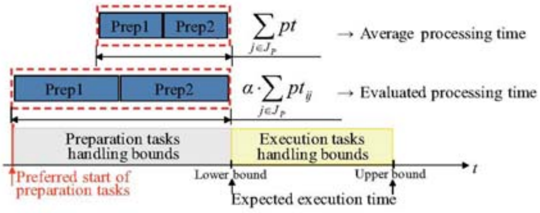

Fig.6 Illustration of evaluated processing time of preparation tasks

tasks to be handled immediately after finishing the execution tasks during the scheduling process, which is certificated by most of nursing activities in the obtained nursing cares.

3.1.2 Release Time of Nursing Activity

In addition, as for the preparation tasks, it is unrealistic to be dealt at any time before the handling of the execution tasks. In this paper, we simply consider the lower bound of preparation tasks handling bounds to be release time of the nursing activity, as shown in **Fig.6**, which is decided only by the preparation coefficient α and defined by Eq.2. On the contrary, the lower bound of the execution task handling bounds is pre-assigned in the worksheet as described in Section 2. In this respect, we considered the execution time coefficient β only in the process of scheduling in this paper.

As mentioned, all of the above 6 kinds of dispatching rules are related to the preparation coefficient α; meanwhile, *MPT*, *extended MPT*, *SLACK*, and *extended SLACK* is also related to the execution coefficient β.

3.2. Dispatching-Rule based Methods

3.2.1 Dispatching Rule

Dispatching rule is a policy according to which the processing priorities of nursing activities are determined. In general, the nursing activities with higher priority would be handled first. Here, we will have a detailed description of 6 kinds of dispatching rules.

a) First Come First Service (FCFS)

Step1: Define the lower bound T_{LB} of expected execution time as the arrival time of the nursing activity.

Step2: Decide the processing orders of nursing activities according to the arrival time: the earlier the arrival time is, the higher the priority of the activity is.

Step3: If there is some idle time before handling a execution tasks with the highest priority, deal with the following acceptable task (preparation task or execution tasks) according to its possible start time (i.e., the lower bound of preparation/execution task handling area), and go to ***Step2***. Otherwise, update the current time and deal with the execution tasks.

b) Earliest Due Date (EDD)

Step1: Define the upper bound T_{UB} of expected execution time as the expected finishing time of the nursing activity.

Step2: Decide the processing orders according to the expected finishing time: the earlier the expected finishing time is, the higher the priority the nursing activity is.

Step3: If there is some idle time before handling a execution tasks with the highest priority, deal with the following acceptable task (preparation task or execution tasks) according to its possible start time (i.e., the lower bound of preparation/execution task handling area), and go to ***Step2***. Otherwise, update the current

Table II Illustration of Dispatching Rules – Nursing Activity Information

Items/Nursing Activity		Nursing Activity A **Blood pressure measure**	Nursing Activity B **Foot bath**
Worksheet Information - Expected execution time		[9:30, 10:00]	[9:30, 10:00]
Processing time	Preparation sub-task	10 minutes	20 minutes
	Execution sub-task	20 minutes	15minutes
	Clean-up sub-task	10 minutes	10 minutes
Representation		Prep / Exec / Clean	Prep / Exec / Clean

time and deal with the execution tasks.

c) Maximum Processing Time (MPT)

Step1: Decide the processing orders according to the total processing time of the execution tasks: the larger the processing time is, the higher the priority of the nursing activity is.

Step2: If there is some idle time before handling a execution tasks with the highest priority, deal with the following acceptable task (preparation task or execution tasks) according to its possible start time (i.e., the lower bound of preparation/execution task handling area), and go to ***Step1***. Otherwise, update the current time and deal with the execution tasks.

d) extended MPT

Step1: Decide the processing orders according to the total processing time of the preparation tasks and execution tasks: the larger the processing time is, the higher the priority of the nursing activity is.

Step2: If there is some idle time before handling a execution tasks with the highest priority, deal with the following acceptable task (preparation task or execution tasks) according to its possible start time (i.e., the lower bound of preparation/execution task handling area), and go to ***Step1***. Otherwise, update the current time and deal with the execution tasks.

e) SLACK

Step1: Define the upper bound T_{UB} of expected execution time as the expected finishing time of its execution tasks.

Step2: Decide the processing orders according to the SLACK rule based on expected finishing time: the lower the slack time (that is, the time for handling the remained nursing execution tasks) before the expected finishing time is, the higher the priority of the nursing activity is.

Step3: If there is some idle time before handling a execution tasks with the highest priority, deal with the following acceptable task (preparation task or execution tasks) according to its possible start time (i.e., the lower bound of preparation/execution task handling area), and go to ***Step2***. Otherwise, update the current time and deal with the execution tasks.

f) extended SLACK

Step1: Define the preparation tasks and execution tasks of a nursing activity separately. Furthermore, consider the lower bound T_{LB} of expected execution time as the expected finishing time of preparation tasks, and the upper bound T_{UB} as the expected finishing time of execution tasks.

Step2: Decide the processing orders of the nursing activities according to the slack time for parathion tasks and the slack time for execution tasks. The lower the slack time for handling the remained tasks, the higher the priority of the nursing activity is.

Step3: If there is some idle time before handling a execution tasks with the highest priority, deal with the following acceptable task (preparation task or execution tasks) according to its possible start time (i.e., the lower bound of preparation/execution task handling area), and go to ***Step2***. Otherwise, update the current time and deal with the execution tasks.

3.2.2 Illustration

To explain the detailed procedures of each dispatching rule, we provide a simple nursing care scheduling problem including 2 nursing activities (blood pressure measure and foot bath). The basic information in the worksheet and manual is listed in **Table II**. Furthermore, we consider the preparation coefficient α to be 3.0 and execution coefficient β to be 1.0. In this way, we can obtain the relative information referenced in the process of scheduling (**Table III**), according to which a series of nursing care plans can be generated based on the above 6 dispatching rules (**Fig.7**[1]):

a)First Come First Service (FCFS): In this case, blood pressure measure and foot bath have the same lower bound of expected execution time (i.e., 9:30am). This means that blood pressure measure is of the same priority with the foot bath. However, in the scheduling process, blood pressure measure is of the higher priority, since it precedes foot bath in the input order, The scheduling process is as follows:

Step (1): Handled the preparation sub-task of blood pressure measure first, and update the current time CT to be 9:10am.

Step (2): Due to the current time CT 9:10am < 9:30am which is the lower bound of the execution sub-task of blood pressure measure, handle the next acceptable sub-task - the preparation sub-task of foot bath, and update the current time CT to be 9:30am

Step (3) and (4): Due to 9:30am >= 9:30am, handle the execution sub-task of blood pressure measure, and then the clean-up sub-task since it is considered to be handled immediately after the execution sub-tasks are finished, as mentioned above. Furthermore, update the current time CT to be 10:00am.

Step (5) and (6): Due to the current time CT 10:00am > 9:30am, which is the lower bound of the execution sub-task of foot bath, handle the remaining sub-tasks of foot bath.

b)Earliest Due Date (EDD): In this case, blood pressure measure and foot bath have the same upper bound of expected execution time (i.e., 10:00am). This means that blood pressure measure is of the same priority with the foot bath. Similar to the descriptions in the illustration of the rule of FCFS, blood pressure measure is of the higher priority. The scheduling process (Step (1) to Step (6)) is similar to that based on the rule of FCFS.

c)Maximum Processing Time (MPT): In this case, the priority is determined by the execution sub-tasks' processing time of blood

[1] In this figure, emphasizing the difference on the processing orders determined by the dispatching rules, we exclude the parts representing the movement between two sub-tasks.

Table III Referenced information

Items	Notation	Definition	Value
Current time before scheduling	CT		9:00
Preparation coefficient	α		3.0
Execution coefficient	β		1.0
Nursing activity A			
Expected execution time			
Lower bound	LB_A		9:30
Upper bound	UB_A		10:00
Evaluated processing time			
Preparation sub-tasks	PT_{PA}	α * 10 min.	30 min.
Execution sub-tasks	PT_{EA}	β * 20 min.	20 min.
Possible start time of preparation task	ST_A	LB_A - PT_{PA}	9:00
Nursing activity B			
Expected execution time			
Lower bound	LB_B		9:30
Upper bound	UB_B		10:00
Evaluated processing time			
Preparation sub-tasks	PT_{PB}	α * 20 min.	60 min.
Execution sub-tasks	PT_{EB}	β * 15 min.	15 min.
Possible start time of preparation task	ST_B	LB_B - PT_{PB}	8:30

pressure measure and foot bath. The processing time of the execution sub-task of blood pressure measure (i.e., 20 minutes) is larger than that of foot bath (i.e., 15 minutes). This means that blood pressure measure is of the higher priority than the foot bath. The scheduling process (Step (1) to Step (6)) is similar to that based on the rule of FCFS

d)extended MPT: In this case, the priority is determined by the processing times of preparation sub-tasks and execution sub-tasks of blood pressure measure and foot bath. The scheduling process is as follows:

Step (1): The processing time of the preparation sub-task and execution sub-task of blood pressure measure (i.e., 50 minutes: 30 + 20 minutes) is smaller than that of foot bath (i.e., 75 minutes: 60 + 15 minutes). This means that foot bath is of the higher priority than blood pressure measure. Therefore, handle the preparation sub-task of foot bath first, and update the current time CT to be 9:20am.

Step (2): The processing time of the preparation sub-task and execution sub-task of blood pressure measure (i.e., 50 minutes: 30 + 20 minutes) is smaller than that of foot bath (i.e., 15 minutes: 0 + 15 minutes). This means that blood pressure measure is of the higher priority than foot bath. Therefore, handle the preparation sub-task of blood pressure measure, and update the current time *CT* to be 9:30am.

Step (3) and (4): The processing time of the preparation sub-task and execution sub-task of blood pressure measure (i.e., 20 minutes: 0 + 20 minutes) is smaller than that of foot bath (i.e., 15 minutes: 0 + 15 minutes). In addition, the current time *CT* 9:30am >= 9:30am, which is the lower bound of the execution sub-task of blood pressure measure. Therefore, handle the execution sub-task, and then clean-up sub-task of blood pressure measure. Moreover, update the current time *CT* to be 10:00am.

Step (5) and (6): Due to the current time *CT* 10:00am >= 9:30am, which is the lower bound of the execution sub-task of foot bath, handle the remaining sub-tasks of foot bath.

e)SLACK: In this case, the slack time of the execution sub-task of the blood pressure measure (i.e., 9:40 - CT minutes: 10:00am - 20 minutes - CT) is smaller than that of foot bath (i.e., 9:50 - CT minutes: 10:00am - 10 minutes - CT) in the whole scheduling process. This means that the blood pressure measure is of the higher priority than foot bath. The scheduling process (Step (1) to Step (6)) is similar to that based on the rule of FCFS.

f)extended SLACK: In this case, the priority of an nursing activity is determined by the slack time for its preparation sub-tasks and that for its execution sub-tasks. The scheduling process is as follows:

Step (1): The slack times of the preparation sub-task of blood pressure measure (i.e., 0 minutes: 9:30am - 30 minutes - 9:00am) is larger than that of foot bath (i.e., -30 minutes(9:30am - 60 minutes - 9:00am). This means that foot bath is of the higher priority than blood pressure measure. Therefore, handle the

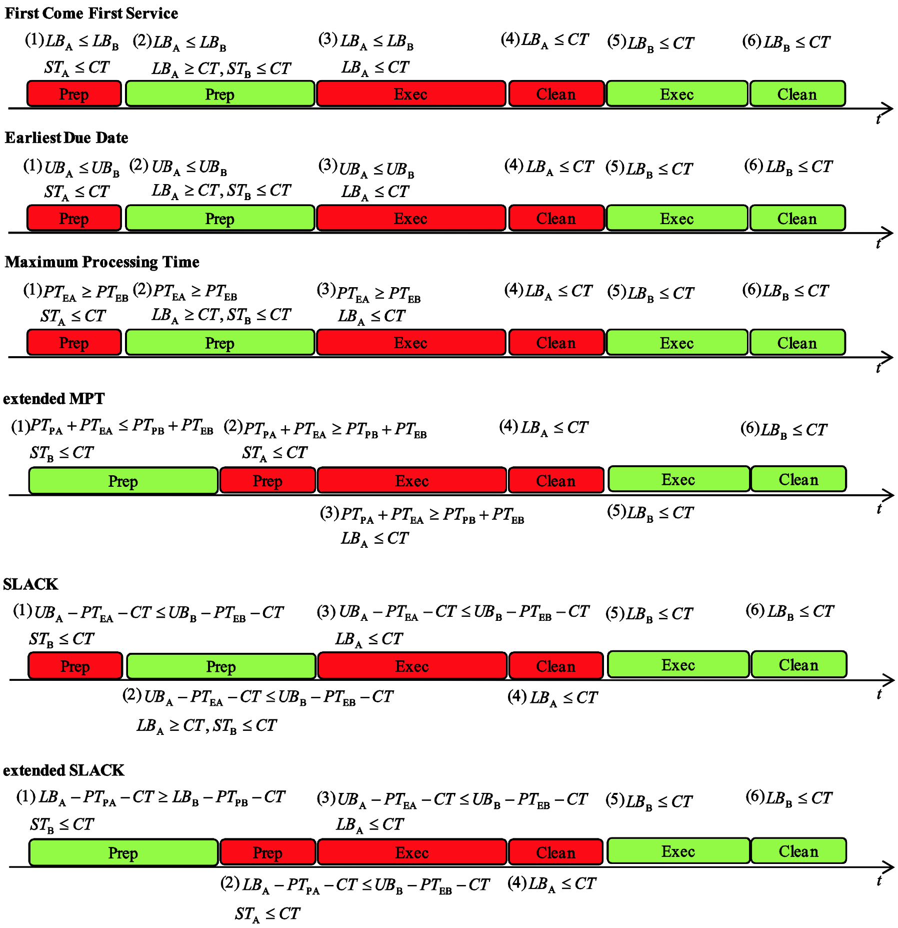

Fig.7 Illustration of dispatching rules - planned nursing cares

preparation sub-task of foot bath first, and update the current time *CT* to be 9:20am.

Step (2): The slack times of the preparation sub-task of blood pressure measure (i.e., -20 minutes: 9:30am - 30 minutes - 9:20am) is smaller than that of the execution sub-task of foot bath (i.e., 25 minutes(10:00am - 15 minutes - 9:20am). This means that blood pressure measure is of the higher priority than blood pressure measure. Therefore, handle the preparation sub-task of blood pressure measure, and update the current time *CT* to be 9:30am.

Step (3) and (4): The slack time of the execution sub-task of blood pressure measure (i.e., 10 minutes: 10:00am - 20 minutes - 9:30am) is smaller than that of foot bath (i.e., 15 minutes: 10:00am - 15 minutes - 9:30am). In addition, the current time *CT* 9:30am >= 9:30am, which is the lower bound of the execution sub-task of blood pressure measure. Therefore, handle the execution sub-task, and then clean-up sub-task of blood pressure measure. Moreover, update the current time *CT* to be 10:00am.

Step (5) and (6): Due to the current time *CT* 10:00am >= 9:30am, which is the lower bound of the execution sub-task of foot bath, handle the remaining sub-tasks of foot bath.

3.3. Interruption Accommodation

In general, nursing is a high statistic work with a high occurring frequency of disturbances (about 8.4 operational failures/8-hour shift[16]), which are recognized to be one of the most important items affecting the execution of nursing cares. In this paper, for the sake of convenience, the interruptions are assumed to be the nursing activities that should be started by corresponding attendant nurses without any delay from their starting time in the observed nursing cares. Once an interruption occurs during the execution of nursing cares, they will be assigned the highest priorities to be handled immediately. On the other hand, there should be some plural activities (the nursing activities that are done by two or more nurses), which are generally pre-assigned in the worksheet of one nurse. Therefore, we simply consider the activity as the unexpected events for the other companied nurses in this paper.

Based on the above candidate dispatching-rule based methods, we can obtain different nursing care schedules with different processing orders for the nursing activities in the actual nursing cares. Comparing the planned schedules with the actual ones, we can elucidate the implicit nursing scheduling algorithms in Fig.2. Moreover, according to the different slack times included in the processing times (that is, different value of preparation coefficient α and execution coefficient β) during the process of scheduling, we can analyze the inpatient nursing cares in a quantitative way.

4. SIMULATION AND RESULTS

4.1. Performance Measures

To evaluate how well a nursing algorithm schedule's result fits the actual schedule, we adopt a measure of similarity in time S_{Time} as the performance measure. It is defined as a measure considering the ratio of the difference of each nursing subtask on its execution

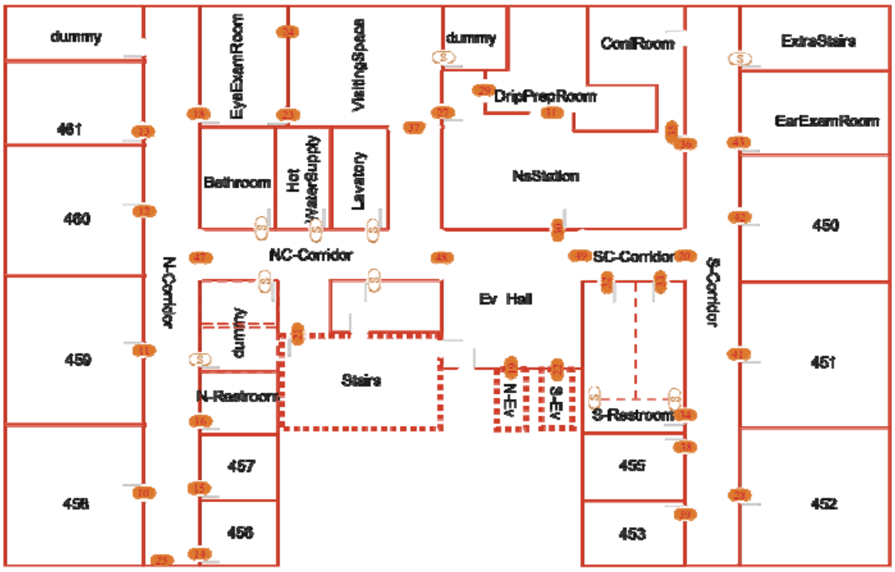

Fig.8 Nursing ward - Layout

times (starting time and ending time) to the *makespan* (defined as the total working time from the start to the end of the inpatient nursing care) between the planned schedule and the observed one:

$$S_{\text{Time}} = 1 - \frac{D_{\text{Middle}}}{makespan * N_{\text{Task}}} \times 100\%. \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

Where, $D_{\text{Middle}} = \sum_i \sum_j d_{ij} = \sum_i \sum_j \left(\left| st_{ij} - st_{ij0} \right| + \left| et_{ij} - et_{ij0} \right| \right) / 2$,

$$et_{ij} = st_{ij} + pt_{ij} .$$

Here, st_{ij}, et_{ij}, st_{ij0}, and et_{ij0} are the starting time and the ending time of the *j*-th nursing subtask of the *i*-th nursing activity in the planned schedule and that in the observed one, respectively; pt_{ij} is the real processing time of the *j*-th nursing subtask of the *i*-th nursing activity; D_{Middle} is the difference on the time (starting time and ending time) between the subtasks in the planned schedule and that in the actual one; and N_{Task} is the total number of the subtasks.

Next, we will evaluate the similarity of the described 6 dispatching rules through a set of actual nursing cares.

4.2. Experiments and Results

By evaluating the similarity on the execution time between the planned nursing schedules and the actual observed ones, we can find out the most similar rules to elucidate the implicit nursing scheduling algorithms, and furthermore, to discuss the nursing staffing levels in a quantitative way.

4.2.1 Simulation Set-up

To investigate the difference of ways of nurses to provide nursing cares to patients and their staffing levels, we implement the above dispatching-rule based methods on several observed nursing care scheduling problems, and evaluate the similarities of the planned nursing schedules with the observed ones. The basic information of the nursing ward and the nursing cares is summarized as follows:

Nursing ward:

- Ophthalmologic and otolaryngology department.
- 11 sickrooms: 4 of them are single rooms, 6 of them are six-patient rooms, and the other 1 are 3-patient rooms.

Figure 8 shows the detailed layout of the nursing ward in a hospital. As shown in this figure, the sickrooms are separated into two parts and laid on both sides of the nurse station. In addition, the whole size of the nursing ward is about 1000 m^2 (25 meters × 40 meters). The ellipses represents the passing sensors in E-nightingale project [14], each of which consists of a couple of sensor. As described by the Ohmura, each couple of sensors are located on both sides of the entrance of each room and accepting the signals individually from the sender located in the nurses' heads [17]. Once a nurse passes the entrance of a room, the couple of sensors will accept the signals from the nurse one by one, and on this basis we can conclude that the nurse enter into or go out of the room. In this way, we can accurately know the changing position of nurses in the time axis (with a synchronization error of 71ms/day). In addition, only the sensors marked by the ellipses with digital IDs in the figure are in action.

Actual observed nursing cares:

- 6 nurses[2]: ***Ns.a***, ***Ns.b***: experts with 5-year experience; ***Ns.c***: proficient with 4 years experience; ***Ns.d***, ***Ns.e***: advanced beginners with 2-year experience; and ***Ns.f***: novice with 1-year experience.
- Each nurse covers 5 ~ 7 patients' nursing cares, which is decided by the nurse leader according to the quantity of nursing cares and the danger level of patients.
- Totally 9 observed nursing cares[3] (day shift from 8:00 am to

[2] As mentioned by Benner, nurses can be classified in accordance with their experience into five stages that are called novice, advanced beginner, competent, proficient, and expert [8]. In this study, we simply classify expert and proficient into the expert nurses, advanced beginner and novice into the novice nurses, as described by most nurses in the hospitals in Japan.

[3] Here, 3 of the 9 observed nursing cares were performed by *Ns.c*, and 2 were performed by *Ns.f*, and the others were performed by other nurses one by one.

Table IV the Data from the Sensor Network - an example [15]

Elapsed Time	Time	Place	Utterance
11:01:00	18:01:00	Nurse Station	I'm going to join a conference.
11:20:48	18:20:48	Nurse Station	The short conference is finished
11:28:11	18:28:11	Room 401	I'm going to prepare a drip infusion set for Abe-san.
11:32:01	18:32:01	Room 401	I've finished preparaing the drip for Abe-san.

Table V Classification in Job Categories - an example [16]

Elapsed Time	Utterance	Job Category
11:01:00	I'm going to join a conference.	18-106 Conference
11:20:48	The short conference is finished	18-106 Conference
11:28:11	I'm going to prepare a drip infusion set for Abe-san.	13-63-6A0502 Intravenous infusion
11:32:01	I've finished preparaing the drip for Abe-san.	13-63-6A0502 Intravenous infusion

Table VI Classification of Nursing Activities and Sub-tasks - an example

Elapsed Time	Utterance	Job Category	Nursing activity	Nursing sub-task
11:01:00	I'm going to join a conference.	18-106 Conference	Short conference	Short conference @NsStation
11:20:48	The short conference is finished	18-106 Conference	Short conference	Short conference @NsStation
11:28:11	I'm going to prepare a drip infusion set for Abe-san.	13-63-6A0502 Intravenous infusion	Intravenous Drip	Drip infusion @Sickroom
11:32:01	I've finished preparaing the drip for Abe-san.	13-63-6A0502 Intravenous infusion	Intravenous Drip	Drip infusion @Sickroom

5:00 pm) provided by the above 6 nurses are applied in this paper.

The data including the actual times, positions, and utterance related to nursing cares are collected by a sensor network with a set of voice records and passing sensors. **Table IV** shows an example of the data from the sensor network. In this figure, "Elapsed Time" is the actual time recording by the passing sensors generated by their system clock; "Time" is the time of current utterance in all recording utterance, according to which we synchronizes the place and utterance; "Place" is current location of a nurse; and "Utterance" is the dialogues of the nurse related to nursing cares, respectively. According to the relation of the utterance with the job category, each nursing care is classified as a series of job categories (which is directly related to the nursing activities assigned in the worksheets) by several experienced nurses according to the dialogue recorded. **Table V** shows an example of classification of utterance into job categories. On these basis, we manually classified the nursing cares as a collection of the nursing activities in worksheets and interruptions (unpredictable nursing activities occurring at unexpected times), according to the information in the worksheets. Furthermore, we classified each nursing activity as a collection of sub-tasks including the preparation sub-tasks, execution sub-tasks, and the clean-up sub-tasks, with the changing of positions. **Table VI** shows an example on the classification of nursing activities and sub-tasks. Therefore, the final data can solved as a nursing care schedule, which mainly including the information of nursing activities, nursing sub-tasks, and their start time & end time.

In general, nursing is more complicated in the break-after part after a rest time due to some reasons like transferring of nursing to/from other parts such as the addition/decrease of the nurses, and admission/discharge of patients. Therefore, it will make it difficult to elucidate implicit nurses' action rules to some extent. Moreover, nurses generally dispose the pre-assigned cares in the break-before part and take rounds to collect patients' status for the handing over to the following attendants. By doing so, it tends to increase the rates of idle time in the break-after part, in which nurses mainly spend time on the handling of patients' records. Consequently, we only considered the former part of day shift before the rest time to elucidate nurses' way in defining the processing orders of pre-assigned nursing activities.

On the other hand, since the processing time of each sub-task varies statistically, this study simply treats it as the average processing time. Furthermore, to quantitatively analyze the actual nursing cares, we consider the different slack time by setting the preparation coefficient and execution coefficient with increment of 0.5 from 0 to 8 separately (i.e., $\alpha \in [0,8]$, $\beta \in [0,8]$) for each dispatching rule in the scheduling process. Therefore, we modeled the implicit nursing action rules as 1734 different candidate dispatching rules (6 single dispatching rules × 17 test values for preparation coefficient × 17 test values for execution coefficient).

4.2.2 Results and Discussions

By employing various dispatching-rule based methods, we can obtain different nursing care schedules for an actual observed schedule. Evaluating the similarity on the execution time between the planned nursing schedules and the actual observed ones, we can find out the most similar rules to elucidate the implicit nursing scheduling algorithms, and furthermore, to discuss the nursing staffing levels in a quantitative way.

Figure 9 shows the result about the comparison of the 6 described kinds of single dispatching rules on their maximal similarities to implicit nursing scheduling algorithm with the results on standard deviations. Here, the maximal similarities are selected from the 1734 average similarities, each of which is obtained by taking an average of the similarities obtained when matching the above 9 observed nursing cares according to the rule with the same function, i.e., the same preparation coefficient α and execution coefficient β. The horizontal axis shows the dispatching

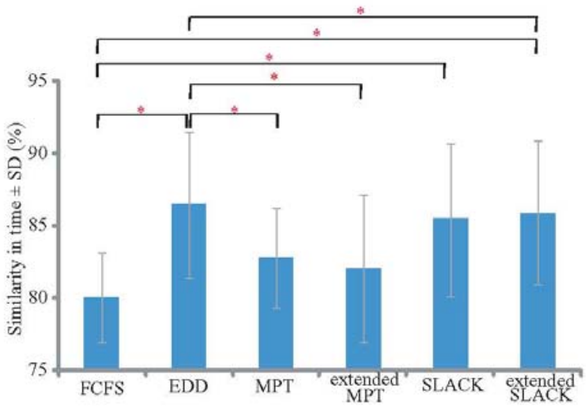

Fig.9 Similarity in time (*: $p<0.05$)
(Note: SD is standard deviation, and p is significant level.)

Table VII Preparation and Execution Coefficient with Maximal Similarities in Each Rule

Dispatching rule	*FCFS*	*EDD*	*MPT*	*extended MPT*	*SLACK*	*extended SLACK*
Preparation coefficient α	4.5	3.0	3.5	0.5	5.5	0.0
Ecution coefficient β	-	-	0.0	0.0	0.5	0.0

rules, and the vertical axis represents the similarity in time (start time & end time), respectively. Moreover, the figure includes the results of *t* test on the comparison of average performances, which is obtained by the statistic analysis tool of Excel 2007. In addition, **Table VII** shows the values of preparation and execution coefficients in each rules with the maximal similarities between the planned nursing care schedules and the actual ones. They represent the estimation of the processing times for preparation tasks and execution tasks, respectively. Moreover, the value '-' in the table represents the case for all test values, that is, $\beta \in [0,8]$.

As shown in Fig.9 and **Table VII**, *EDD* in (3.0, -), *SLACK* in (5.5, 0.5), and *extended SLACK* in (0.0, 0.0) obtain the most similarities. Note that, α is the coefficient of processing time for the preparation tasks, and β is the coefficient of processing time for the execution tasks. Moreover, *EDD* has a significant difference with *FCFS*, *MPT*, and *extended MPT*, *SLACK* has a significant difference with *FCFS*, and *extended SLACK* has a significant difference with *FCFS* and *MPT* by applying the significant level 5%. Here, considering the value of execution coefficient β to be approximately 0, *extended SLACK* and *SLACK* are of similar function during the scheduling process, that is, only referring the processing time of preparation tasks and upper bound of expected execution time. Moreover, among the rule of *EDD*, *SLACK*, *extended SLACK*, *EDD* obtains the most similarities. In this respect, we conclude that nurses, either experts or novices, might define the processing orders of nursing activities similar to *EDD*, which means they refer the information of the evaluated processing time of preparation tasks and upper bound of expected execution times of the nursing activities in worksheets.

As mentioned in Section 2, the part directly related to patients (i.e., the execution tasks in the nursing activity) is desired to be handled within an expected time interval. Therefore, the value of the execution coefficient has less impact on implicit scheduling algorithms of nurses. On the contrary, the variation of the start

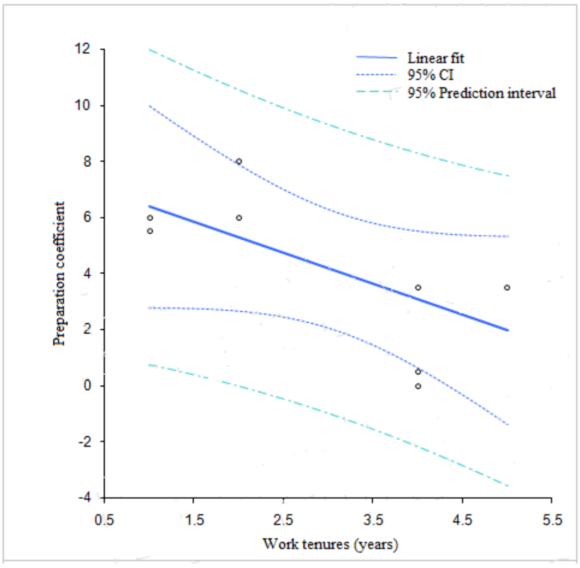

Fig.10 Discussion on staffing levels ($p<0.05$)
(Note: p is significant level.)

point of preparation tasks usually leads to the variation in the processing orders. In this respect, the value of the preparation coefficient has more impact on implicit scheduling algorithms.

In hospitals, it is general to describe the nursing staffing levels of nurses using work tenures. Here, to quantitatively evaluate the staffing levels, we investigate the relation of the preparation coefficients applied in *EDD* and the work tenures. **Figure 10** shows the results on the relation of the above 6 nurses' work tenures and their preparation coefficients in *EDD*. The figure also includes the results of scatter plot with fit according to the linear regression analysis on the relation of work tenure and preparation coefficient.

From the above results, we can conclude that the preparation coefficient has an inverse relation to the work tenure; that is, the preparation coefficients considered during the provision of nursing cares approximately decrease with the increase of the work tenures of nurses. Consequently, we conclude that the expert nurses start the handling of the nursing activities with less slack times than the novices; that is, the nurse with a higher staffing level generally considers less evaluated processing times for the preparation tasks, which somewhat results in the strong possibility of providing nursing cares as scheduled.

Based on the results in this figure, the correlation coefficient of the work tenure with the preparation coefficient is -0.68, which is significant by applying the significant level 5%. Since nursing is a high dynamic work with a lot of interruptions, especially for novice nurses, we believe that novice nurses generally start to handle the nursing activities in an earlier time. In actual, it generally results in an increase of nursing activities for determining their processing orders. Therefore, it confuses novice nurses with the performing of the accurate nursing activity for high-quality care provision, and thus it should be one issue on impossibilities that novice nurses provide nursing cares as scheduled in worksheets.

5. Conclusion

In this paper, by implementing several candidate dispatching rules on a set of nursing activities in the observed nursing cares,

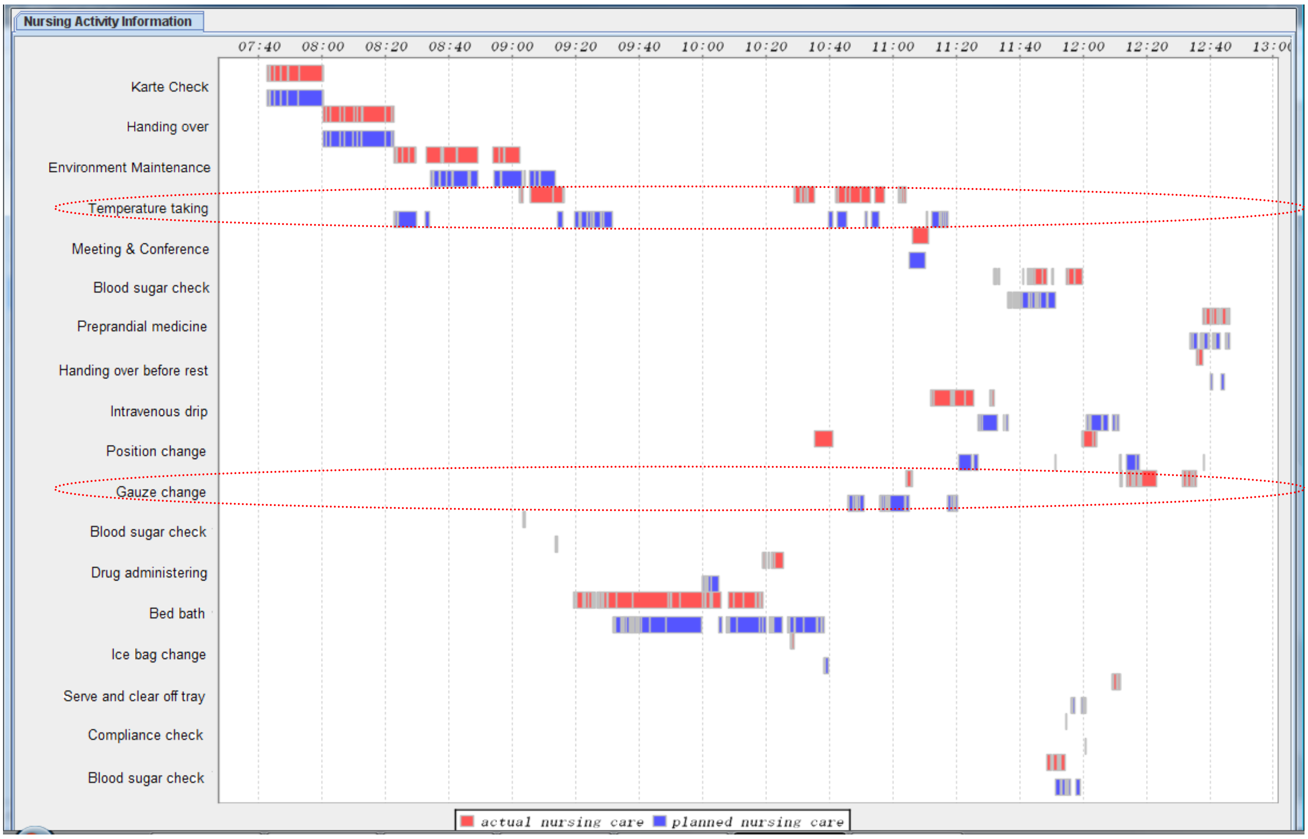

Fig.11 Comparison of an actual nursing care schedule with the planned one on their Gantt chart.

we proposed an effective method to elucidate the implicit nursing scheduling algorithm of nurses, and discuss the difference of staffing levels between novices and experts on their ways to handle the nursing activities. Our simulation results show that (1) nurses might handle the pre-assigned activities similar to *EDD*, that is, they refer the evaluated processing time of preparation tasks and their expected execution time; (2) there is an inverse relation of work tenures with preparation coefficients , which is recognized as one of the key points for expert nurses to provide high-quality nursing cares in this paper. Consequently, we believe that considering adequate slack times for preparation tasks should result in the provision of high-quality cares.

As a future work, we should do more experiments to certificate our standpoint. Morover, based on the obtained results, to propose and actualize an effective instruction system for high quality nursing cares is practically more mandatory for current hospitals.

ACKNOWLEDGEMENT

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APPENDIX

A. Similarity in Time: Representation on the Gantt chart

Figure 11 shows an example of the comparison an observed nursing care schedule (red rectangles) handled by Ns.c with the planned one (blue rectangles) based on *EDD* on their Gantt charts, where the similarity in time is 93.4%.

In this figure, the vertical axis represents the nursing activities, and the horizontal axis represents the time axis from 7:40am to 1:00pm, respectively. Moreover, the red rectangles represents the nursing tasks in the observed nursing care, and the blue rectangles shows the nursing tasks in the planned nursing care schedule obtained by a candidate dispatching rule. The parameters and the result is outlined as follows:

Setups of parameters:

Dispatching rule: ***EDD***

Preparation coefficient: **0.5**

Execution coefficient: **-**

Result:

Similarity in time: 93.48%

✧ Similarity

As shown in this figure, the blue rectangles cannot entirely match the red rectangles. In this study, we just test the similarity of the single dispatching rule with the action rules of nurses. Although the dispatching rule is described as the implementation of some human thoughts, the action rules of nurses are generally more complex than the single dispatching rules described above. However, we get about the 93% similar nursing care schedule with the actual one in this case, and thus we know that 93% of the action rule has the same function with *EDD*.

✧ Unsimilarity

Moreover, as shown in the figure, we can find that the error on the matching of the planned nursing care with the observed one is mainly resulted from the nursing activity of temperaturing and gauze change, as marked by the ellipse in red dot lines. As we know, these activities are belonging to those that are modeled as the nursing activity with the weak expected execution time constraints, that is, the nursing activity that can be handled in the break-before part of the assigned shift. As we know, EDD is a rule to decide the processing orders of nursing activities according to their upper bound of the expected execution time. Therefore, these two nursing activities will be normally handled in the latter part unless there exists the idle time in the former part. As a result, there might be some other rules to define the processing orders of these activities. However, as interviewed nurses explained on this phenomenon, it is not strange for these activities to be handled before or after, that is, there are not any specific rule or policy to define these activities and the definition of the processing orders of them is random during their provision of nursing cares. In addition, the performing of them before or after seldom impacts on the quality of nursing cares on providing the nursing cares as scheduled in case that other nursing activities are handled as scheduled. As a result, in our own opinion, to improve the EDD to match the error parts mentioned above for higher similarities becomes not so necessary.

References

(1) Japanese Nursing Association, Statistical Data on Nursing Service in Japan: 2006, http://www.nurse.or.jp/toukei/index.html, 2007.

(2) National Institute of Population and Social Security Research, Population projection for Japan: 2006/2055, http://www.ipss.go.jp/pp-newest/j/newest03/newest03point.pdf, (2007)

(3) N. Ilhan, E. Durukan, E. Aras, S. Tukcuoglu, and R. Aygun, Long working hours increase the risk of sharp and needlestick injury in nurses: the need for new policy implication, Journal of Advanced Nursing, **56**-5, 563/568, (2006)

(4) M. W. Stanton, Hospital nurse staffing and quality of care, U.S. Dept. of Health and Human Services, Public Health Service, Agency for Healthcare Research and Quality, (2004)

(5) I. Vermeulen, S. Bohte, K. Somefun, and H. L. Poutre, Improving patient activity schedules by multi-agent Pareto appointment exchanging, The 8th IEEE International Conference on E-Commerce Technology and The 3rd IEEE International Conference on Enterprise Computing, E-Commerce, and E-Services (CEC/EEE'06), 9, (2006)

(6) T.O. Paulussen, N.R. Jennings, K.S. Decker, and A. Heinzl, Distributed patient scheduling in hospitals, Proceedings of the 18th International Joint Conference on Artificial Intelligence, 1224/1229 (2003)

(7) J. Needleman, P. Buerhaus, S. Mattke, M. Stewart, and K. Zelevinsky, Nurse-staffing levels and the quality of care in hospitals, the New England Journal of Medicine, **346**-22, 1715/1722 (2002)

(8) P. Benner, From novice to expert: Excellence and power in clinical nursing practice, Addison-Wesley (1984)

(9) S. Lauri and S. Salantera, Decision-making models in different fields of nursing, Research in Nursing & Health, **21**-5, 443/452 (1998)

(10) M. Yokouchi, Y. Ohno, S. Kasahara, H. Numasaki, and A. Ishii, Development of medical task classification for job scheduling, Transactions of the Japanese Society for Medical and Biological Engineering, **43**-4, 762/768 (2005) in Japanese

(11) T. Murakami, A. Suyama, and R. Orihara, Consumer behavior modeling using bayesian networks, Proc. of the 18th Annual Conference of the Japanese Society for Artificial Intelligence, 3F3-01 (2004) in Japanese

(12) T. Sawaragi, Y. Horiguchi, and M. Ishizuka, Modeling ecological expert: comparative analysis of human skill development with fuzzy controller, Soft computing, **7**-3, 140/147 (2003)

(13) S.S. Panwalkar and W. Iskander, A survey of scheduling rules, Operations Research, **25**-1, 45/61 (1977)

(14) K. Kogure, Introduction to the E-nightingale project, the Technical Report of the Institute of Image Information and Television Engineers, **30**-27, 17/22 (2006) in Japanese

(15) H.I. Ozaku, A. Abe, N. Kuwahara, F. Naya, K. Kogure, and K. Sagara, Building Dialogue Corpora for Nursing Activity Analysis, Proceedings of the 6th International Workshop on Linguistically Interpreted Corpora (LINK-2005), 41/48 (2005)

(16) H.I. Ozaku, A. Abe, K. Sagara, N. Kuwahara, and K. Kogure, A Task Analysis of Nursing Activities Using Spoken Corpora, Advances in Natural Language Processing, Research in Computing Science, **18**, 125/136 (2006)

(17) R. Ohmura, F. Naya, H. Noma, T. Toriyama, and K. Kogure, Towards a system for recording and analyzing nursing activities based on sensor data, Proceedings of the 21st Annual Conference of the Japanese Society for Artificial Intelligenct, 3F6-4 (2007) in Japanese

(18) A. L Tucker and S. J. Spear, Operational failures and interruptions in hospital nursing, Health Services Research, **41**-3Pt1, 643/662 (2006)

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