Extraction of Useful Knowledge for Making Roster by Analyzing Nurse Scheduling Data and Incident Data

Koichiro Okada[1], Masanori Akiyoshi[2], Yukie Majima[1], Hiroe Takahashi[3], Sayuri Tanaka[4], Misae Tanioka[4] and Miwako Hori[4]

[1]Department of Computing, Osaka Prefecture University, 1-1 Gakuencho, Naka-ku, 599-8531, Sakai-shi, Osaka, Japan
[2]Department of Computing, Kanagawa University, 3-27-1, Rokkakubashi, Kanagawa-ku, 221-8686, Yokohama-shi, Kanagawa, Japan
[3]Department of Planning Management, Japan Community Health care Organization (JCHO), Tokyo, Japan
[4]JCHO Osaka Hospital, Osaka, Japan

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Abstract: As described herein, we sought knowledge necessary to make a roster for nurses by analyzing nurse scheduling data and incident reports on the night shift. Even today, it is difficult to say that computers are used effectively producing nurse rosters. One reason is that algorithms suggested by researchers are not practical for nurses working at various sites because they are built without consideration of medical accidents known as “incidents”. Another reason is that the study of incidents from a team's perspective, which is the original mode of working as a nurse, is not available. Therefore, this study was conducted for discovery of knowledge to help produce a nursing roster by analyzing nurse scheduling data and incident data for night shifts from the viewpoint of teams, which is the original mode of working for nurses.

1 INTRODUCTION

When it is necessary to arrange staff during a day at institutions such as hospitals, managers usually adopt a shift-work system to fill a schedule, with shift staff working days and hours. This system demands a duty roster to show which duties are covered by which employee on which time shift. Therefore, this roster must be produced with consideration of the number of people needed for duties and various constraints such as workers’ requests and their respective capabilities. This scheduling invariably takes much time. Generally, an experienced expert who is familiar with the duties and personnel produces this roster over a long period of time. The problem of making such a roster entails "the necessity of assigning work as staff have requested as effectively as possible." This so-called shift scheduling problem can be resolved through mathematical programming. Producing a roster at a medical institution such as a hospital is a nurse scheduling problem.

Nurse scheduling problems are regarded as a difficult optimization problem. That is true because no matter how one might try to resolve the problem, it is difficult to define an optimum solution for any reason. If we define such a solution, then it is merely difficult to obtain the solution. A survey paper (Smith-Daniels et al., 1988) has presented that research of nurse scheduling problems began in the United States in 1976 (Miller et al., 1976). It declined thereafter, but became popular again from about 1998 (Dowsland, 1998; Miller, Kiragu, 1998). In recent years, many researchers engaged in the study of this problem (Burke et al., 2004; Ikegami, 2005; Ikegami, Tanaka, 2014; Tassopoulos et al., 2015). However, in spite of the fact that many researchers have developed the study and have suggested many algorithms for solving nurse scheduling problems, it remains difficult to say that computers are used for making rosters effectively. This fact is apparent from a survey (Ikegami et al., 1995) that found "the mean time of making roster is 6.8 hours." Moreover, nurses of a certain General Hospital, which provided data for our study, reported long preparation times. Apparently, hospitals have insufficient cost and technical knowledge to adopt scheduling software. Furthermore, the suggested algorithms are not practical for nurses working at a site because they are

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suggested without consideration of medical accidents known as “incidents.”

Table 1: Number of nurses per level.

Ladder level	Number of nurses
1	26
2	16
3	19
4	5
5	6
Temporary (0)	18

Studies of incidents (Bates et al., 1995; Onozawa et al., 2000) have been conducted by many researchers along with the nurse scheduling problem. Most depend on examinations of individual nurses to examine "What kind of nurses and circumstances cause incidents and what should we do for preventing those incidents." Research about incidents from a team perspective, the original mode of working for nurses, has not been conducted to date.

Therefore, this study was undertaken for discovery of knowledge to help produce a nursing roster by analyzing nurse scheduling data of 2009–2013 (5 years) and incident reports related to night-work provided by A General Hospital from the viewpoint of teams.

2 EXPERIMENTAL DATA DETAILS

Data we use are nurse scheduling data covering five years (April 1, 2009 – March 31, 2013) and incident date data on night shifts from the same period of time provided by A General Hospital (number of hospital beds, 68; mean number of hospital patients per day, 62; number of nurses, 89). The number of nurses includes temporary employees. Changing of nurses occurred during those five years.

Through research collaboration with A General Hospital, we received consent to use these data.

2.1 Details of Nurse Scheduling Data

These nurse scheduling data (e.g. see Appendix A) comprise seven items.

- Nurse ID
- Ladder level (Skill level)
- Date
- Day of the week
- Types of shift work
- Shift total of the month for each nurse (e.g. nurse A [day shift, 10; night shift, 5])
- Total number of nurses with each shift (e.g. Day 1 [day shift, 12; night shift, 6])

Nurse ID consists of five digit numbers. The ladder level has five stages of 1–5 (temporary nurse is 0, number of nurses per level is shown in Table 1) and Types of shift work consist of 11 items.

- Day shift
- Late shift
- Night shift
- Training
- Business trip
- Recreation
- Public holiday
- Holiday
- National holiday
- Substitute holiday
- Absence

2.2 Details of Incident Date Data

These incident date data on the night shift (e.g. see Appendix B) consist of two items as follows.

- Types of incidents
- Time and date of occurrence of each incident

Types of incidents consist of three items.

- Care: About fall occurrence
- Pharmacy: About wrong medication
- Tube: About removal of tube

This study was conducted for discovery of the knowledge to support the production of a nurse roster by analyzing these data from a team viewpoint.

3 EXPERIMENT

For this study, we conducted three experiments.

- Extraction of a shift pattern that all nurses meet working throughout the year
- Correlation of incidents and nurse group in the night shift
- Extraction of nurse pairs with no mutual work on a day or night shift during five years

Table 2: Time series database (Cited by Zaki, 2001).

SID	EID	Items
1	10	CD
1	15	ABC
1	20	ABF
1	25	ACDF

Table 2: Time series database (Cited by Zaki, 2001) (cont.).

2	15	ABF
2	20	E
3	10	ABF
4	10	DGH
4	20	BF
4	25	AGH

Table 3: Part of list coupling SID and TID per item.

A		B		…
SID	EID	SID	EID	…
1	15	1	15	…
1	20	1	20	…
1	25	2	15	…
2	15	3	10	…
2	15	4	20	…
3	10			…
4	25			…

Table 4: Lis obtained by combination of item A and B in Table 3.

A-B	
SID	EID
1	20

3.1 Extraction of Shift Patterns with All Nurses Working throughout the Year

3.1.1 Overview

Nurse replacement occurred in each year, but we specifically examined nurses who worked throughout the year and extracted shift patterns such that all nurses meet using a sequential pattern mining algorithm called SPADE (Sequential Pattern Discovery using Equivalence classes) algorithm (Zaki, 2001). Constraint conditions for making shifts are likely to be hidden in such shift patterns.

3.1.2 Spade Algorithm

Sequential pattern mining is extraction of pattern which have ordering. SPADE algorithm is the way of this mining. SPADE receives a time series database such as Table 2 as input, and this database consists of time series data. Time series data has Sequential ID (SID), Time ID (TID) and Items. SPADE combine SID and TID into list per item like Table 3 and find a new time series pattern by coupling these lists like Table 4.

3.2 Correlation of Incident and Nurse Groups on the Night Shift

3.2.1 Overview

On the night shift each day, we sorted nurse groups on shifts according to whether that group is likely to cause an incident or not based on the following definition of the group. Then we assess the correlation of the incident and that group.

Definition: when group work at night shift as hellows, we regard its group as "Risky group" that is likely to cause incident and other as "Non-risky group".

Group have over 2 nurses whose ladder level is under 3 and have no nurse whose level is over 3

3.2.2 Procedure

We make an experiment by following the steps described below.

1. We pick out all nurses as each night shift from scheduling data. Every nurse work at night shift are one group.
2. We distinguish these groups "Risky group" form "Non-risky group" using above definition.
3. We calculate the rate of each incident occurrence in the case of "Risky group" and "Non-risky group".

3.3 Extraction of Nurse Pairs with No Work Together on Day or Night Shifts during Five Years

3.3.1 Overview

Nurse work is team work related directly with the life and death of patients. Therefore, human relations must be considered, particularly excluding pairs that are more likely to cause incidents. In addition, human relations can cause resignation of freshly recruited nurses (Mizuta et al., 2004). Therefore, it is important to formalize such pairs without leaving it as tacit knowledge.

Table 5: Extracted shift pattern that has maximum length in each year.

Year	Extracted shift pattern that has maximum length
2009	<N,N,PH,D,D,N,N,PH,D>
〃	<N,N,PH,PH,D,D,N,N,PH>
〃	<N,N,PH,D,D,D,N,N,PH>
〃	<N,N,PH,D,D,N,N,PH,PH>

Table 5: Extracted shift pattern that has maximum length in each year (cont.).

Year	Extracted shift pattern that has maximum length
2010	<D,D,N,N,PH,D,D>
〃	<N,N,PH,PH,D,D,D>
2011	<D,N,N,PH,D,D,N,N>
2012	<D,D,N,N,PH,PH,D,D>
2013	<D,D,N,N,PH,PH,D,D>
〃	<D,N,N,PH,PH,D,D,D>
〃	<PH,PH,D,D,D,N,N,PH>
〃	<PH,D,D,D,N,N,PH,PH>

*D: Day Shift, N: Night Shift, PH: Public Holiday

Table 6: Combination of shift patterns of length 3.

<D,D,D>	<D,D,N>	<D,N,N>
<N,N,PH>	<N,PH,D>	<N,PH,PH>
<PH,D,D>	<PH,PH,D>	

*D: Day Shift, N: Night Shift, PH: Public Holiday

3.3.2 Procedure

We make an experiment by following the steps described below.

1. We acquire all nurse IDs from scheduling data and make pairs of IDs.
2. We make pairs of IDs at day shift and delete them form pairs created procedure 1. Similarly, we do at night shift.
3. After procedure 2, leftover pairs are regarded as nurse pairs with no work together on day or night shifts during five years.

4 RESULTS AND DISCUSSION

4.1 Extraction of Shift Patterns with All Nurses Working throughout a Year

Table 5 shows the extracted shift pattern that has maximum length in each year. The maximum lengths of shift patterns were high values such as 7–9, but a nurse actually making a roster considered these longest shift patterns only slightly when producing the roster. In other words, roster makers consider shorter shift patterns. Longer shift patterns result from combined constraints such as "Two consecutive night shifts are forbidden." Actually, these longer patterns are explainable by the combination of shift patterns of length 3, as shown in Table 6. In both Table 5 and 6, “D”, “N” and “PH” indicate “Day shift”, “Night shift” and “PH”, respectively. However, “Night shift” is a set of two “N” like <N,N>. Since, first “N” indicate “begin working” and second “N” indicate “finish working”.

4.1 Correlation of Incidents and Nurse Groups on the Night Shift

Tables 7 and 8 respectively show the rates of incident occurrence when nurses work in a "Risky group" or "Non-risky group". Figures 1, 2 and 3 show the rates of incident occurrence per incident type. According to Tables 7, 8 and Figures 1, 2 and 3, the rate as a "Risky group" was slightly higher than that of a "Non-risky group". Therefore, we investigated them using a *t*-test to clarify whether these results had significant differences. Results show no significant difference in any of the three kinds of incident. However, these results are dubious because we only use data for last 5 years. Accordingly, we are set to prepare data for more than 10 years and do significance test using that data.

Table 7: Rates of incident occurrence when nurses work in a "Risky group" (%).

Year	Care	Pharmacy	Tube
2009	21.2	13.6	3.4
2010	18.5	9.2	4.6
2011	19.7	10.6	2.3
2012	23.6	10.8	8.1
2013	13.6	12.6	5.5
Five years	22.2	13.1	5.8

Table 8: Rates of incident occurrence when nurses work in a "Non-risky group" (%).

Year	Care	Pharmacy	Tube
2009	19.4	10.1	1.6
2010	18.3	7.7	2.6
2011	20.6	9.9	3.0
2012	24.7	6.4	7.8
2013	18.1	18.1	7.8
Five years	20.3	10.0	4.3

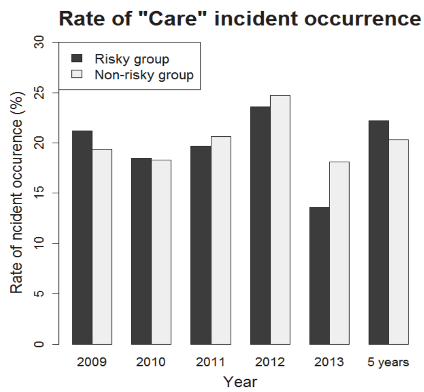

Figure 1: Rate of “Care” incident occurrence.

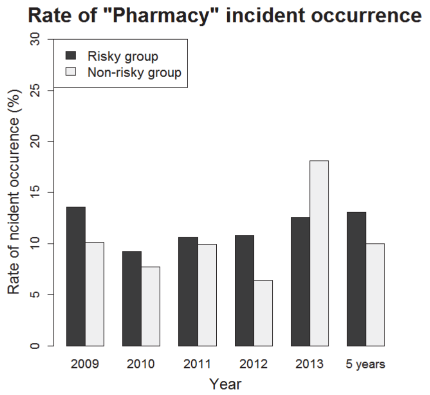

Figure 2: Rate of “Pharmacy” incident occurrence.

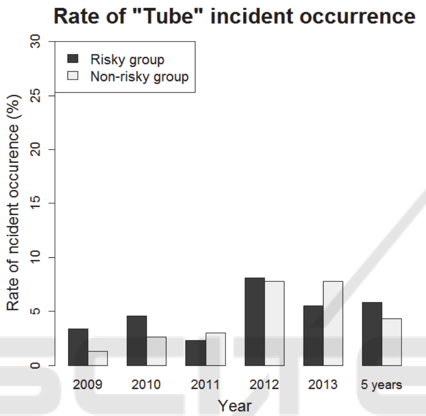

Figure 3: Rate of “Tube” incident occurrence.

Table 9: Nurse pairs who did not work together on day and night shifts during five years.

Type of shift	Number of pairs	Number of pairs between the nurses with ladder level lower than 2
day	117	58
night	34	26
both	24	18

4.2 Extraction of Nurse Pairs Who Did Not Work Together on Day and Night Shifts during Five Years

Table 9 shows the results. We gave a breakdown of the pair between the nurses with ladder level lower than 2 because the extracted pairs had high probabilities of causing incidents. We made a roster devoting attention to these pairs.

5 CONCLUSIONS

As described herein, we sought knowledge to support production of a nurse roster by analyzing nurse scheduling data and incident reports from night-work provided by A General Hospital from a team viewpoint, reflecting a nurse working style.

Accordingly, we conducted three experiments as follows from the viewpoint of a team.

- Extraction of shift patterns that all nurses meet working throughout a year
- Correlation of incidents and nurse groups on the night shift
- Extraction of nurse pairs with no mutual work on day and night shifts during five years

In shift pattern extraction, a limitation condition in roster making and a possible shift pattern were extracted. The maximum length in each year was explained using a combination of shift patterns of length 3. The real incident rate was judged from viewing 2 in a case of working in the dangerous nurse group, which was more likely to produce incidents. Although the rate of the dangerous group was slightly high, no significant difference was found. Pairs who did not take day and night duty together during five years were extracted.

Future studies should examine techniques to identify shift patterns that are most appropriate as constraints to roster making by analyzing extracted shift patterns and correlations with incidents.

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APPENDIX

Appendix A: Sample of nurse scheduling data.

2009/04		1	2	3	4	…	30		Shift total			
	NurseID - Ladder level	Wed.	Thurs.	Fri.	Sat.	…	Thurs.		Day	Night	…	Absence
	11111 - 2	PH	N	N	PH	…	N		10	7	…	0
	11122 - 1	N	PH	D	D	…	PH		12	4	…	0
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	44111 - 0	D	D	PH	N	N	PH		7	7	…	0
Shift total	Day	17	12	15	16		15					
	Night	7	7	8	6		7					
	⋮	⋮	⋮	⋮	⋮	⋮	⋮					
	Absence	0	0	0	0		0					

※ We define Temporary nurse's ladder level is 0

Appendix B: Sample of incident date data.

2009	Types of incident	Date							
	Care	04/01	04/03	04/10	04/21	05/09	05/13	…	03/12
	Pharmacy	05/12	05/27	06/22	06/28	07/05	07/18	…	02/22
	Tube	04/21	07/22	08/14	09/04	09/25	10/11	…	02/02