Implications for Developing Information System on Nursing Administration – Case Study on Nurse Scheduling System –

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Abstract. This research was focused on the nurse scheduling system as the supporting system for the nursing administration. In this research as a case study, the nurse scheduling system was developed by applying the human centered design process. The head nurses claimed that it was a higher workload for them to rearrange the imperfect roster of the first automated scheduling system than to make the roster from the beginning because the mathematical solution for the system cannot always propose the roster which has no violation. The nurse required the scheduling support system which supported her heuristic scheduling instead of the automated system. The nurse scheduling support system was developed and the other nurses were more satisfied with the system than with the conventional popular automated scheduling system. From the results of this research, the approach of the development of the supporting system for administration was discussed.

Keywords: nurse scheduling, human centered design, usability, administration system.

1 Introduction

Japanese government has been promoting the development and implementation of information systems and networks for the administration of health services these last 10 years in order to realize the supply of the high quality, efficient, and low cost medical services [1]. The situation in some western countries might be similar [2].

The electric health care card system is a kind of medical information system and the system has been gradually implemented from the large hospitals in Japan and about 20% of the large hospitals, which have more than 400 beds, had implemented the system in 2005 [3]. The nurse scheduling system was the popular supporting system for nursing administration in Japan because the scheduling system tended to be included in the electric health care card system. The nurse scheduling problem has been researched in Operational Research field since 1970s [4] and many system developers have supplied the automated nurse scheduling systems to hospitals.

M.J. Smith and G. Salvendy (Eds.): Human Interface, Part II, HCII 2009, LNCS 5618, pp. 529–538, 2009.

However, few of the researches and the developments of the nurse scheduling system have been focused on the usability of the systems. In this research, as a case study, the nurse scheduling system is developed by applying the human centered design process [5] in order to increase the usability of the nurse scheduling system.

Generally the system development approach for the nurse scheduling problem aimed the automated scheduling solution as previously stated. On the other hand, the head nurses had adopted heuristic scheduling approach on the paper. There was the other approach of the system development which aimed to support their heuristic scheduling. In this research, through the development of the nurse scheduling system, it was discussed that the system development approach influenced to the usability of the supporting system for administration.

2 Methods

This research project was carried out as the case study in the period between 1999 and 2003. The project was designed that consisted of the steps, the research for the context of use for the nurse scheduling system, the definition of the nurses' requirements for the system, the development of the system, and the estimation of the system by the nurses, and the repetition of this circular steps according to the human centered design process in ISO13407 [5].

Step1: The questionnaire about the constraints, the methods of the nurse scheduling to a head nurse was held in a public hospital in northern Japan. The questionnaire also asked the experience of the nurse scheduling. The questionnaire was consisted of items as follow;

- The profile of the head nurse who solves the nurse scheduling problem.
  - Age, position, experience of nurse scheduling, and time spent in scheduling per month.
- The constraints of the nurse scheduling in the section which depend on the nursing administration regulation of government or hospital regulation.
  - The number of the nurses who belong to the section.
  - The minimum required number of the nurses per night shift, per semi-night shift and per day
  - The number of the teams in the section
  - The existence of the classification of the nurses
  - The night shift time, the semi-night shift time, and the day time
  - The maximum times of the night shift and the semi-night shift in a month
  - The maximum number of the continuous days
  - The permission of the continuous night shifts and semi-night shifts
  - The minimum interval between night shifts and semi-night shifts
  - The number of the holiday in a week, in four weeks, and in a month
  - The continuous weekend holidays
  - The nurse service patterned order about holiday, working day, working night shift, and working semi-night shift.

- The constraints which depend on each nurse's personal preferences and conditions.
  - Holiday, Annual paid leave, Required working night shift, Required working semi-night shift, Required working day, consumption rate of annual paid leaves, and the satisfaction of the requirements of the last month.
- The four degrees of the priority which each constraint is kept.
  - Grade 1: the constraint has to be kept strictly.
  - Grade2: the constraint should be kept as much as possible.
  - Grade3: the constraint had better be kept if possible.
  - Grade4: the constraint does not need to be kept.
- The rules of the nurse scheduling.
  - The patterned order about holiday, working day, working night shift, and working semi-night shift.
  - The adjusting methods for conflicting constraints.
  - The adjusting methods for conflicting requirements with the nurses.
- The devices for the nurse scheduling.
  - The supported equipments
  - The estimation of the outcome of the nurse scheduling
- The experience of the nurse scheduling
  - The problem of the present nurse scheduling, the experience of the nurse scheduling system, the problem of the system, the necessity of the system, and the requirements of the system

The observation of her behaviors of the paper based nurse scheduling was held in the public hospital in northern Japan. She was required to schedule a set of day, night shift, and semi-night shift nurses within a month and make a roster as usual. She was required to think loud during scheduling. Her behaviors and utterance were recorded by two video cameras and the characteristic behaviors and utterance were measured by the event sampling method.

Step2: The requirements for the nurse scheduling system were discussed from the results of both the questionnaire and the observation.

Step3: The nurse scheduling system was developed based on the requirements.

Step4: The head nurse of the hospital was required to schedule a set of nurses within a month and to make a roster by using the nurse scheduling system. She was required to think loud during scheduling. Her behaviors and utterance were recorded by two video cameras and the characteristic behaviors and utterance were measured by the event sampling method. She was required to answer the satisfaction of the roster by the system and the usability of the system in comparison with the paper based nurse scheduling.

As the repetition of the steps, the functional and usability problems of the proposed system and the new requirements of the officer were extracted by the results of the former step. The system itself changed from the scheduling system to the scheduling support system according to the officer's requirements. The officers of the other

private hospital in the central area of Japan were required to estimate the roster by the support system and the usability of the system through scheduling a set of nurses within a month for two months.

3 Automated Approach

3.1 Mathematical Model of Nurse Scheduling

In this section, we present the nurse scheduling model. This model is categorized as the mathematical programming approach [6]. This model is built up by three stages, nurse preferences, night shift working, semi-night shift working, and day and holiday working scheduling. On the first stage, all the preferences of all the nurses are input the system. On the second stage, night shift working and semi-night shift working schedule is arranged. On the last stage, day working and holiday working is arranged. On each stage of both the second and third, the former arranged schedule might be modified if the value of the fitness function could decrease. The fitness function evaluates the degree of constraint violation. The model adopts the greedy algorithm for a combinatorial optimization problem which can be formulated as Integer programming. The arranged schedule is the approximate optimal schedule when the value of the fitness function is the minimum.

The fitness function is consisted of three kinds of the variables (X_i, Y_j, Z_k) of the constraints and their own weighted parameters (α_i, β_j, δ_k) as Eq. (1) shows. Eq. (2) shows the total number of violation which is counted by the unit of the nurse. N is the set of the nurses. If the constraint was satisfied in the case of constraint "*i*" and nurse "*l*", X_{il} equals 0, and if not, X_{il} equals 1. Eq. (3) shows the total number of violation which is counted by the unit of the day. T is the set of dates in the scheduling period. If the constraint is satisfied in the case of constraint "j" and date "*t*", Y_{jt} equals 0, and if not, Y_{jt} equals 1. Eq. (4) shows the total number of violation which is counted by the unit of the nurse and the day. If the constraint is satisfied in the case of constraint "*k*", nurse "*l*", and date "*t*", Z_{ktl} equals 0, and if not, Z_{ktl} equals 1.If all the constraints are satisfied, the value of the function "P" equals zero. All the variables of the constraints are chosen and all the parameters are decided by the results of the questionnaire. Table 1 shows all the variables and all the weighted parameters.

$$P = \sum \alpha_i X_i + \sum \beta_j Y_j + \sum \delta_k Z_k \tag{1}$$

$$X_i = \sum_{l \in N} X_{il} \tag{2}$$

$$Y_j = \sum_{t \in T} Y_{jt} \tag{3}$$

$$Z_k = \sum_{l \in N, t \in T} Z_{klt} \tag{4}$$

Table 1. Weighted parameters for the penalties of the violations

Variables	Constraints	Weighted parameters
X_i	Keep the number of night or semi-night shift working under 10 nights per month	100
	Keep the working hours under 160 hours per 4 weeks	100
	Keep the number of holidays	50
	Keep the deviation of plus or minus 1 day from the averaged holiday-working number	2
	Keep consecutive holidays more than once	2
	Keep consecutive holidays more than three days including weekend	0.03
	Keep consecutive holidays more than three days	0.03
Y_j	Keep required number of nurses per day	100
	Keep required number of nurses per night shift	100
	Keep required number of nurses per semi-night shift	100
Z_k	Avoid the team which consists of only novice nurses	100
	Avoid the team which consists of only practical nurses	100
	Avoid the team which does not keep the regulation	100
	Avoid working consecutively in day, semi-night shift, and night shift	100
	Keep the nurse service patterned order 1	0.7
	Keep the nurse service patterned order 2	10
	Keep the nurse service patterned order 3	10
	Keep the night shift or semi-night shift working interval more than 3 nights	0.8
	Arrange the high skilled nurses to the special sections	5
	Avoid consecutive day workings more than 5 days	0.05
	Avoid consecutive day, semi-night shift, or night shift workings more than 6 days	4
	Keep the same nurse as the leader between weekdays	0.5
	Satisfy the nurse preferences	15

3.2 User Interface of the Nurse Scheduling System

In this section, we present the interfaces of the nurse scheduling system. The interfaces for input are designed as satisfying the requirements from the questionnaire and the observation. Every information input can be done by pushing the command button with mouse device. The interface for output is designed which has the same layout as the paper based roster.

The procedure of the usage of the system is as follows. The head nurse is required to choose the month scheduled on the start screen. Next, if she wants to change the staff information, add, or delete staffs, the head nurse pushes the staffs' personal information command and can modify the staff information. If she wants to change the constraints' conditions for scheduling, she pushes the initial condition command and can change the value of the constraints and the value of their weighted parameters. Next if there are some staffs' preferences, she pushes the preference scheduling command and can enter their preferences. Then if the head nurse pushes the schedule command of a ward, the system starts the scheduling process and makes the month's scheduled sheet of the ward.

3.3 Results from User Testing

The user test for the proposed nurse scheduling system was held. The head nurse was required to schedule a set of nurses within a month and to make a roster by using the nurse scheduling system. Her behaviors and utterance were recorded by the event sampling method. By the event sampling method it was confirmed that the system could be used without any problem. It revealed that the usability of the system was sufficient.

On the other hand, the roster was not the optimal schedule but the approximate optimal schedule with which some constraints were not satisfied, because the nurse scheduling problem is NP-hard [7] that the number of the constraints was huge and

the optimal solution for scheduling might not exit. She was not satisfied with the roster by the scheduling system. The reason of her dissatisfaction was because it was so difficult for her to re-arrange the proposed schedule without more violations when she wanted to change the part of the imperfect roster. She reported her feeling that it was easier to make the roster from the beginning than to re-arrange it. Finally she estimated the proposed nurse scheduling system was not useful. She wanted the support system for her heuristic scheduling. And she wanted the support system to supply her with the input patterns, which reflected the nurse service pattern and the nursing administration regulation, and to supply her with the important information on the constraints. So we analyzed the observation records again.

4 Heuristic Support Approach

4.1 Support System for Heuristic Nurse Scheduling

The requirements for the scheduling support system were discussed from the results of both the questionnaire and the observation. The support system for heuristic scheduling was developed in consideration of many requirements the system should satisfy. Through the usage of the proposed system by three head nurses, the functional and usability problems were clarified. The system was improved in consideration of the problems.

4.2 User Interface of the Support System

The proposed system for nurse scheduling supported the heuristic scheduling of the head nurse. The system was made on Microsoft Excel2000. The system supplied the officer the real time information how the roster satisfied the constraints, such as the number of staffs in each day working, the number of staffs in each night shift working, the number of staffs in each semi-night shift working, the number of day workings in each staff, the number of night shift workings in each staff, the number of semi-night shift workings in each staff, the number of holidays and their excess and deficiency in each staff, the number of annual paid leaves in each staff, and so on. The value of the constraints for the regulations of the hospital and the government could be controlled on the system. The officer could make scheduling of each staff in each date and, of course, she could also input the scheduling pattern which were predetermined and registered. By using this support system, the head nurse can do heuristic scheduling while checking how the constraints were satisfied.

The interface of this system for making the roster was designed in order to be able to make scheduling in the same way the head nurses made the roster on paper. The procedure of the usage of the system is as follows. The methods to use the start screen and the screen for modifying the nurse information are the same as the former system. If the head nurse wants to change the constraints' conditions for scheduling, she pushes the nurse information command and the night shift and semi-night shift command, and changes the value of the constraints. Next she can make scheduling of each staff in each date by choosing the item of the list in the combobox in the scheduling sheet. She can also make scheduling by pushing working type command

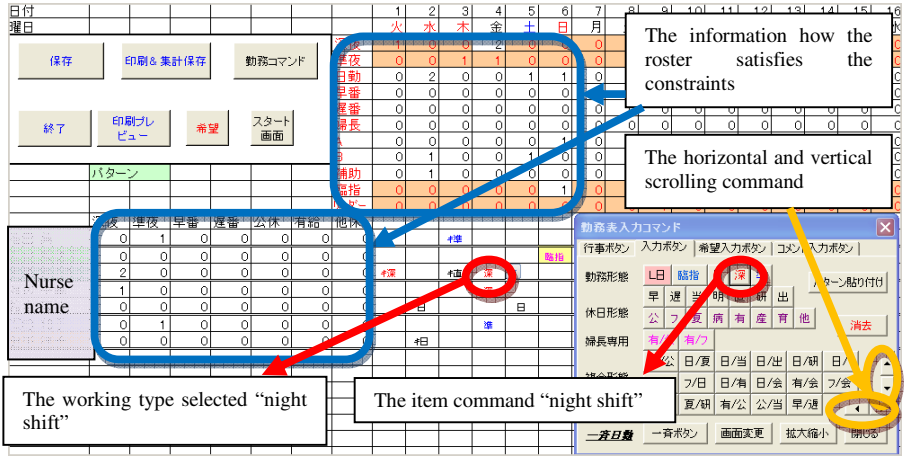

Fig. 1. Scheduling screen of proposed scheduling support system

and the item command in the working type screen as figure 1 shown. The scheduling sheet can be scrolled by horizontal and vertical scrolling commands. The system supplied the officer the real time information how the roster satisfied the constraints. The scheduling sheet can change to the styles for output or for full screen.

4.3 Result from User Testing

The user test for the proposed nurse scheduling support system was held in comparison with the popular automated scheduling system in Japan. Two head nurses, who were the expert and the beginner computer users, were required to schedule a set of nurses within a month and to make a roster by using the nurse scheduling support system for two months. Their behaviors and utterance were recorded by the event sampling method. The several nurses were required to answer the questionnaire and the interview for estimating the usability of the system in comparison with their daily used conventional automated system. By the event sampling method it was confirmed that both of the expert and beginner could use the system without any problem. The results of the questionnaire and the interview revealed that the usability of the system was sufficient and they were more satisfied with the system than the conventional automated system as table 2 shows.

Table 2. Two way mixed-design ANOVA with Qeustions and Systems

Source	*SS*	*DF*	*MS*	*F*	
Question	27.0125	49	0.5513	1.5526	P<0.05
System	58.1405	1	58.1405	16.5011	P<0.01
Question×System	22.2845	49	0.4548	1.2808	p>0.10
Total	107.4375	99			

5 Discussions

Through the development of the support system for the nurse scheduling, it was clarified that the head nurses were not always satisfied with the automated nurse scheduling system by the mathematical programming approach because the automated system could not propose the perfect solution to a large number of constraints and the nurses had to rearrange the roster. It was so hard work for the nurses to rearrange the imperfect roster without more violations to match the roster with their actual feelings about the priority of the constraints. The more the nurses consider the staffs' preferences, the more difficult it might be for them to rearrange the roster. It might be impossible to improve the automated system to match the proposed solution with their feelings because there might not be the perfect solution satisfying a lot of constraints. Furthermore the nurses could not be conscious of the priority of the constraints correctly in order to propose the approximate optimal solution satisfying their feelings. The results of this research revealed that the nurses required the support system for their heuristic scheduling rather than the improved automated system.

Of course, if the number of constraints was not large or the head nurse did not need to consider staffs' preferences sufficiently, the head nurse might be satisfied with the automated scheduling system because the system could propose the optimal solution.

The results of this research suggested that the supporting system for the administration should not always set goal to the automated solution system (automated system). When the administration belongs to the loose management type, the approach of the development of the automated system would be not appropriate because the system developed would not propose the optimal solution and the system would be not used by the users. The loose management type means that the number of the constraints is large or the management considers the staffs' preferences sufficiently. In these situations the supporting system should set goal to the supporting system for heuristic solution (heuristic system). On the other hand, when the administration belongs to the rigorous management type, the approach of the development of the automated system would be appropriate because the system might propose the optimal solution. The rigorous management type means that the constraints are only the government and workplace regulations and the management does not need to consider the staffs' preferences. Figure 2 shows the concept of this relationship between the management types and the system development approach on the usability view.

As mention above, the direction of the system development approach depends on the management type. In order to set the direction correctly, the actual task supported by the system should be analyzed in details, and the context of use of the supporting system and the influence of the supporting system to the business and the organization should be researched. The deep understandings of the task and the influence of the system implementation would lead the supporting system in the correct direction. For these understandings, the human centered design approach, the contextual design [8], and the socio-technical design approach [9] would be effective.

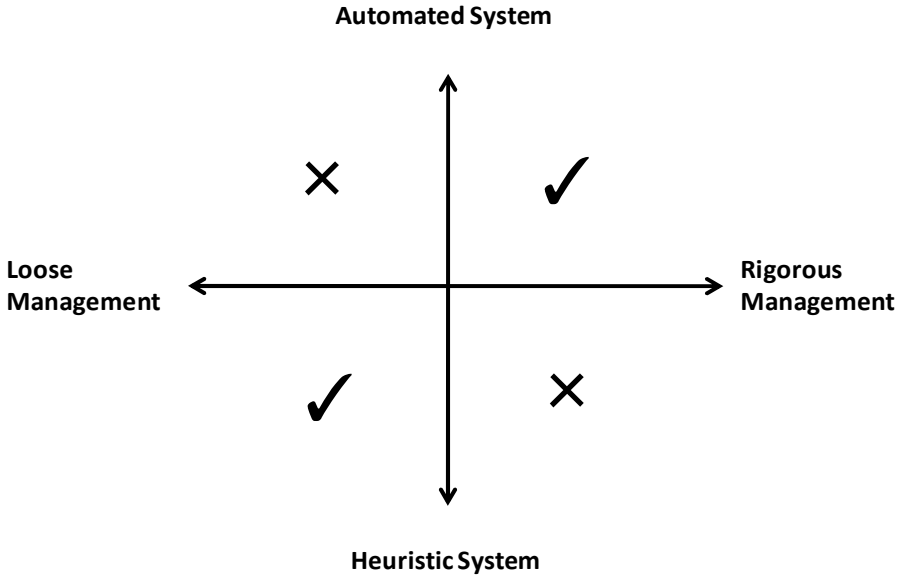

Fig. 2. Concept of relationship between management type and system development approach on usability view

6 Conclusions

This research was focused on the nurse scheduling system as the supporting system for the nursing administration. In this research as a case study, the nurse scheduling system was developed by applying the human centered design process. The head nurses claimed that it was higher workload for them to rearrange the imperfect roster of the first scheduling system than to make the roster from the beginning because the mathematical solution for the nurse scheduling system cannot always propose the roster which has no violation. The nurse required the scheduling support system which supported their heuristic scheduling instead of the mathematical programming approach. The nurse scheduling support system was developed and the two other nurses were higher satisfied with the system than with the conventional popular scheduling system in Japan by the mathematical programming approach.

From the results of this research, it was suggested that the approach of the development of the automated system was not always correct direction of the development of the supporting system for administration. The concept of the relationship between the management type and the system development approach on the usability view was proposed. It was also proposed that the deep understanding of the task supported by the system and the influence of the system implementation would lead the supporting system for an administration in the correct direction and that the human centered design approach, the contextual design approach, and the socio-technical design approach would be effective.

References

1. Japanese Ministry of Health, Labour, and Welfare (in Japanese), http://www.mhlw.go.jp/shingi/0112/s1226-1.html
2. Ludwick, D.A., Doucette, J.: Adopting electronic medical records in primary care: Lessons learned from health information systems implementation experience in seven countries. International Journal of Medical Informatics 78, 22–31 (2009)
3. Japanese Ministry of Health, Labour, and Welfare (in Japanese), http://www.mhlw.go.jp/toukei/saikin/hw/iryosd/05/kekka1-3.html
4. Vanhoucke, M., Maenhout, B.: On the characterization and generation of nurse scheduling problem instances. European Journal of Operational Research 196, 457–467 (2009)
5. ISO13407: Human-Centered Design Process for Interactive Systems (1999)
6. Smith, L.D., Wiggins, A.: A computer-based nurse scheduling system. Computer and Operations Research 4, 195–212 (1997)
7. Osogami, T., Imai, H.: Classification of various neighbourhood operations for the nurse scheduling problem. In: Lee, D.T., Teng, S.-H. (eds.) ISAAC 2000. LNCS, vol. 1969, pp. 72–83. Springer, Heidelberg (2000)
8. Holtzblatt, K., Wendell, J.B., Wood, S.: Rabid contextual design. Morgan Kaufmann, San Francisco (2005)
9. Eason, K.: Understanding the Organisational Ramifications of Implementing Information Technology Systems, completely revised. In: Helander, M., Landawer, T.K., Probhu, P. (eds.) Handbook of Human Computer Interaction Second, pp. 1475–1495. Elsevier, Amsterdam (1997)