Constructive Nurse Scheduling Using Reinforcement Learning Considering Variations in Nurse Work Patterns

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Abstract

It is very difficult to create a work schedule that satisfies all the different requirements in nurse scheduling. For this reason, numerous studies have been conducted on the nurse scheduling problem. However, the created shift schedule is often not practical as it is, because adjustments including various constraints and evaluation criteria are required. Therefore, we have proposed a work revision method using reinforcement learning in a constructive nurse scheduling system. In this paper, we investigate the feasibility of creating a practical work schedule even when there are nurses with different work pattern evaluations, i.e., the feasibility of creating a practical work schedule that takes each nurse's life stage into consideration.

Keywords: nurse scheduling, reinforcement learning, constructive search, work patterns, life stages

1. Introduction

Various studies have been conducted on the nurse scheduling problem [1], which is the creation of a shift schedule for nurses. However, for practical use, adjustments including various constraints and evaluation values are required, and the created shift schedule is often not practical as it is, so many head nurses still feel burdened by creating shift schedules [2]. Therefore, we have proposed a work revision method [3] using reinforcement learning [4] on a constructive nurse scheduling system [5].

In this paper, we investigate the feasibility of creating a practical work schedule even when there are nurses with different work pattern evaluations, i.e., the feasibility of creating a practical work schedule that takes each nurse's life stage into consideration. In addition, the work pattern evaluations of the obtained modified work schedules are visualized. Furthermore, none of the previous studies on nurse scheduling considered the evaluation of different work patterns.

2. Constructive nurse scheduling system

2.1. *Features*

The features of the constructive nurse scheduling system [5] are as follows.

1. The system creates a schedule for each day, starting from the first day.
2. The priority calculation can be extended to consider detailed conditions.
3. It does not consider the evaluation value for the entire shift schedule for a month.

2.2. *Work Revisions*

The constructive scheduling system considers only the basic constraints that would be required in a hospital with many nurses, and the possibility exists that a feasible solution that does not satisfy the head nurse is obtained. For this reason, Kurashige et al. [5] describe the following two procedures for the actual modification.

(1) A work shift of the nurse in the case that does not satisfy the head nurse is manually exchanged with a work shift of another nurse.

(2) A work shift of the nurse in the case that do not satisfy the head nurse is exchanged to other work shift as designated work shift, and the rescheduling is done.

Next, we introduce our proposed system [3] that learns this exchange procedure using reinforcement learning.

3. Work Revision Method Using Reinforcement Learning

3.1. *Problem Setting for Reinforcement Learning*

The shift schedule created by the constructive nurse scheduling system, which is created in order from the first day, satisfies the shift constraints (such as the number of nurses required for each day). On the other hand, the shift schedule for the entire scheduling period (e.g., one month) is checked, there may be several cases in which the nurse constraints (such as the limited number of workdays) are not satisfied for each nurse.

Therefore, the number of violations Vnw of work shift w is calculated as the number of days exceeding $UTnw$, the upper limit of the number of assignments of work shift w to each nurse n, from the work schedule, and a revision is repeated according to the following:

$$min\ \sum_{\mathrm{n}} \sum_{\mathrm{v}} \mathrm{V_{nw}} \qquad (1)$$

The following procedure is to be used for one revision.

(1) Select a work shift w_0 that is the source of the exchange (usually the one with the most violations).

(2) Determine the nurse n_0 with the highest number of violations in the shift w_0.

(3) If the shift w_0 is the night shift, the shift w_0 with the highest number of violations, whether it is evening or late-night shift, is designated as w_0 for the nurse n_0.

(4) If there is a work shift that is below the lower limit of the number of assignments for the nurse n_0, that work shift w_1 is designated as a destination of the exchange shift. If not, day shift without the upper and lower limits of the number of assignments is used as the exchange.

(5) Determine the day d_0 with the highest priority among the days when the shift w_0 is exchanged to w_1 for nurse n_0.

(6) Deduce the group $g(j_0)$ in which the nurse n_0 is in charge of a job j_0, which is assigned as the shift w_0.

(7) Determine a nurse n_1 who belongs to group $g(j_0)$ and whose shift on the day d_0 is w_1. If there is more than one applicable nurse, determine the nurse n_1 with the highest priority among the nurses when the shift w_1 is exchanged to w_0 on d_0.

(8) The nurses n_0 and n_1 are exchanged their shifts on d_0.

In case there is no corresponding nurses in any of the procedures, the exchange is not valid. In addition, it is also not valid to undo a previous exchange.

Here, minimizing the number of violations is a very difficult problem, because the number of possible modifications depends on which work shift is being exchanged.

3.2. *RL Agent*

Q-learning [6] is applied to the proposed method to learn an appropriate exchange procedure. The state space of the RL agent consists of 4 dimensions: the previous exchange days (1 to 30), the total number of violations by all nurses for evening, late-night shift, and holiday: $\mathrm{V_{nw}}$ (w=1,2,3), to be a Markov decision process. The number of possible actions is 4, which is the exchange of evening, late-night, holiday, and night shift.

1 step is defined as 1 exchange including unsuccessful cases, 1 episode is defined as the time when the shift schedule reaches the target state, or 100 steps passed. Here, the target state is defined as the sum of violations for all nurses and shifts, $\sum_{\mathrm{n}} \sum_{\mathrm{v}} \mathrm{V_{nw}} = 0$ (excluding over-holiday violations). The positive reinforcement signal $r_t = 10$ (reward) is given only when the target state is reached and the reinforcement signal $r_t = 0$ is given at any other steps. At the start of each episode, the shift schedule will be in its initial state.

4. Computational Experiments

Table 1. Evaluations of work pattern for 2 days.

shift on previous day	shift on the day			
	day	evening	late-night	holiday
day	15	1	13	11
evening	0	5	0	12
late-night	0	8	5	4
holiday	23	3	0	17

Table 2. Evaluations of work pattern for 2 days allowing transitions from the evening shift to the late-night shift.

shift on previous day	shift on the day			
	day	evening	late-night	holiday
day	15	1	13	11
evening	0	2	8	7
late-night	0	8	5	4
holiday	23	3	0	17

Table 3. Parameters for experiments

Parameter	Value
α_{Q}	0.1
γ	0.9
τ	0.1

4.1. *Nurse Scheduling Problem*

The extended method is applied to a nurse scheduling problem like that of Kurashige et al. [5]. First, a threeshift system (day, evening, and late-night shift) is adopted, and the number of nurses is 23, including the head nurse. Furthermore, the number of positions is classified as 3 (head nurse, assistant head nurse, and general), the number of teams is 2 (A and B), and the skill level is 3 (experienced, mid-career, and new). The other constraints are outlined below.

- Restrictions on the number of nurses for each shift:
  (1) Required number of day shift on weekdays is greater than or equal to 10.
  (2) Required number of day shift for weekends and holidays is 5.
  (3) Required number of late-night shift is 5.
  (4) Required number of evening shift is 5.

Next, Table 1 shows the evaluation of work patterns for 2 days with M = 2. The evaluation of work patterns can be set using the current work schedule as a reference.

Here, we investigate the feasibility of creating a feasible modified work schedule in the situation where all nurses have the work pattern evaluations shown in Table 1 (Situation 1) and only Staff 6 and Staff 17, the experienced nurses of Team A and Team B, respectively, have the work pattern evaluations allowing transitions from the evening shift to the late-night shift shown in Table 2 (Situation 2).

4.2. *RL Agent*

In the state space of the RL agent, the total number of violations is assumed to be [0, 2] and can take 3 states.

The computational experiments have been done with parameters as shown in Table 3. In addition, all initial Q-values are set at 5.0 as the optimistic initial values.

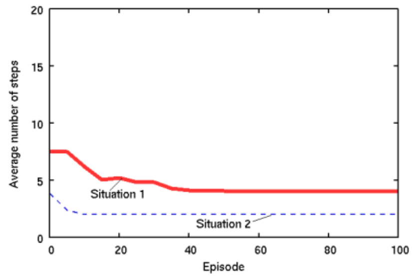

Fig. 1. Required steps for accomplishing the task.

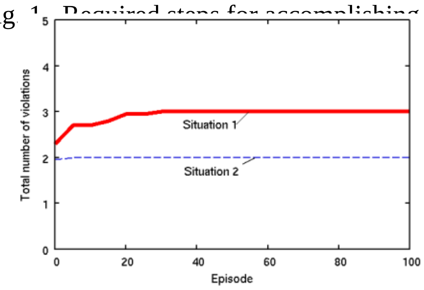

Fig. 2. Total number of violations when accomplishing the task.

4.3. *Results*

The average of the numbers of steps required for accomplishing the task and the average of the total number of violations when accomplishing the task in Situations 1 and 2 were observed during learning over 20 simulations, as described in Fig. 1 and Fig. 2, respectively.

It can be seen from Fig. 1 and Fig. 2 that (1) in Situation 1, the target state was reached in about 5 steps, and the number of violations was reached at 3, (2) in Situation 2, the target state was reached in about 2 steps, and the number of violations was reached at 2. Thus, we confirmed that a feasible modified work schedule could be created not only in Situation 1, but also in Situation 2, where nurses have different work pattern evaluations.

The average of each nurse's work pattern evaluations for each day (the average of the previous day's and the day's work pattern evaluation, and the day's and the next day's work pattern evaluation) and the total average of the work pattern evaluations on the modified work schedule for Situations 1 and 2, respectively, are shown in Figs. 3 and 4. In addition, the 24, 25, and 26 days of Staff 6, indicated by the red boxes in Fig. 4, represent the average of the pattern evaluation of the late-night shift, evening shift, and late-night shift, respectively, and the 7, 8, and 9 days of Staff 17 represent the average of the work pattern evaluation of the holiday, evening shift, and late-night shift, respectively.

It can be seen from Fig. 3 and Fig. 4 that (1) the total average of the work pattern evaluations is the same for Situation 1 and Situation 2.

Although additional experiments are needed, setting the work pattern evaluations to values that each nurse him/herself desires will enable him/her to realize a work style (work pattern) that suits him/her life stage and, in addition, will help him/her to understand the work schedule creation process.

Fig. 3 Average evaluations of work pattern in the revised work schedule in Situation 1.

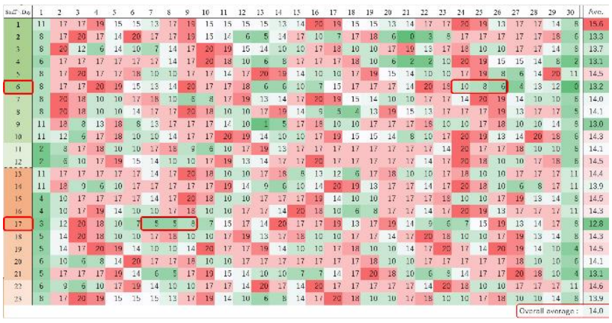

Fig. 4 Average evaluations of work pattern in the revised work schedule in Situation 2.

5. Conclusion

In this paper, we confirmed that the proposed method can create a feasible modified work schedule in a situation where there are nurses with different work pattern evaluations, specifically, where there are two nurses who can work from evening shift to late-night shift. In addition, the work pattern evaluations of the obtained modified work schedules were visualized and the total average of the work pattern evaluations in the situation was compared with the total average of the work pattern evaluations in the normal situation where evening shift to late-night shift is not possible, and we confirmed that the evaluation was equivalent to that in the normal situation.

Our future projects include to confirm the effectiveness of the proposed method in situations where nurses evaluate even more diverse work patterns, etc.

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Authors Introduction

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