# A dynamic nurse scheduling using reinforcement learning: Dealing with various sudden absences of a nurse

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**Abstract**

In nurse scheduling, whereby work schedules for nurses are created, it is very difficult to create a work schedule that satisfies all the various requirements. Hence, various studies have been conducted on the nurse scheduling problem. However, for practical use, adjustments including various constraints and evaluation values are required, as the created shift schedule is often not practical as it is. Therefore, we have proposed a work revision method using reinforcement learning on a constructive nurse scheduling system. In this paper, we extend the proposed method to dynamic nurse scheduling, in which the work schedule is revised or rescheduled when an absence occurs. Furthermore, we confirm whether or not the extended method can be used to create a work schedule that is feasible in various sudden absences of a nurse.

*Keywords*: dynamic nurse scheduling, reinforcement learning, constructive search, sudden absence

## 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 extend the proposed method to dynamic nurse scheduling, in which the work schedule is revised or rescheduled when an absence occurs. Furthermore, we confirm whether or not the extended method can be used to create a work schedule that is feasible in various sudden absences of a nurse.

## 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 take into account detailed conditions.
3. It does not take into account the evaluation value for the entire shift schedule for a month.
4. Based on the priority of job *j* for nurse *n*, the problem is transformed into a $\mathrm{N} \times \mathrm{N}$ assignment problem and can be solved efficiently using the Hungarian method. Note that jobs are prepared for

the number of nurses by dividing work shift $w$, including holiday, by the group $g$ to which the nurses belong.

### 2.2. *Work Revisions*

The constructive scheduling system considers only the basic constraints that would be required in a hospital with a large number of 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. In this case, it is important that the constraints are satisfied by the exchange. If an exchange is made that does not satisfy the constraints, a warning message is displayed.

(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. Of course, the next solution displayed is not necessarily a satisfactory solution, but the above procedure is repeated in a timely manner until a satisfactory solution is obtained.

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:

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

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 considered to be 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: $\mathrm{V}_{\mathrm{nw}}$ ($w$=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, $\sum_{\mathrm{n}} \sum_{\mathrm{v}} \mathrm{V}_{\mathrm{nw}} = 0$ (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 before a sudden absence occurs.

## 4. Dynamic Nurse Scheduling Using Reinforcement Learning

When an assignment of work shift has to be changed suddenly due to an absence, etc., an alternative nurse is first secured according to the following procedure. In the case that a change of day shift is unavoidable, a change to the night shift (evening or late-night shift) may be considered, but only holiday is considered in this paper.

(1) Designate the work shift $w_0$ of the absent nurse $n_0$ on the day of the absence $d_A$ as the source of the exchange, and designate the destination work shift $w_1$ as holiday.

(2) Deduce the group $g(j_0)$ in which the absent nurse $n_0$ is in charge of a job $j_0$, which is assigned as the shift $w_0$ on the day $d_A$.

(3) Determine a nurse $n_1$ who belongs to group $g(j_0)$ and whose shift on the day $d_A$ 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 $d_A$. there is no applicable nurse, determine the nurse $n_1$ by changing the source work shift $w_0$ to day shift, late-night shift, and evening shift, in that order.

(4) The nurses $n_0$ and $n_1$ are exchanged their shifts on the day $d_A$. Then, change the work shift of the nurse $n_0$ to a designated work shift so that the work shift of the nurse $n_0$ will not be exchanged any more.

Next, the exchange procedure is obtained by reinforcement learning in the same way as the procedure described in Section 3.1 after the occurrence of an absence. However, the day with the highest priority is determined after the absence occurrence date $d_A$.

## 5. Computational Experiments

### 5.1. *Nurse Scheduling Problem*

The extended method is applied to a nurse scheduling problem similar to that of Kurashige et al.[5]. First, a three-shift 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 shift patterns for 2 days with M = 2.

Table 1. Evaluation of shift 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. Parameters for experiments

| Parameter | Value |
|---|---|
| $\alpha_Q$ | 0.1 |
| $\gamma$ | 0.9 |
| $\tau$ | 0.1 |

### 5.2. *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 arameters as shown in Table 2. In addition, all initial Q-values are set at 5.0 as the optimistic initial values.

### 5.3. *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 the occurrence of a sudden absence on day, evening and late-night shift were observed during learning over 50 simulations, as described in Fig. 1 and Fig. 2, respectively. Here, a day of the absence and an absent nurse were determined by random numbers.

It can be seen from Fig. 1 and Fig. 2 that (1) in day and late-night shift absences, the target state was reached in a few steps, (2) required steps for accomplishing the task was 100 only once in evening shift absence, because the target state could not be reached, (3) the number of violations has not increased much from the initial number of 2.

In evening shift, where the target state could not be reached, no alternative nurse could be found for the 17th nurse absence on 28th day. This situation could not be adjusted without increasing the number of violations excluding over-holiday violations in the current month only, since this absence occurred late in the month. In practice, it is thought that an alternative nurse is secured in consideration of the work shift schedule for the following month.

Thus, we confirmed that the extended method can deal with absences other than designated work shift except at the end of the month in this task.

## 6. Conclusion

In this paper, we extend the proposed method to dynamic nurse scheduling, in which the work schedule is revised or rescheduled when an absence occurs. Through computational experiments, we confirmed that the extended method can deal with absences other than designated work shift except at the end of the month.

Our future projects include to respond to a sudden absence of a designated work shift and to clarify the rules for creating shift schedules, etc.

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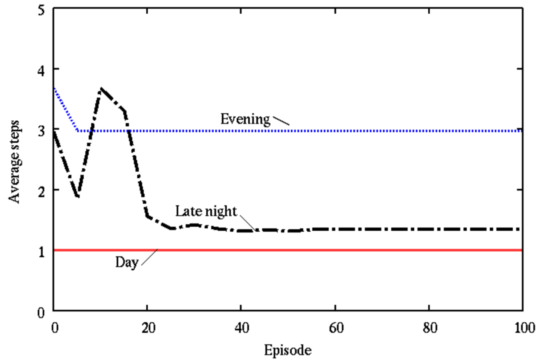


Fig. 1. Required steps for accomplishing the task.

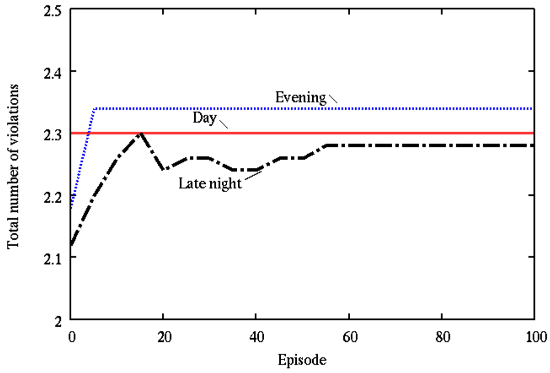


Fig. 2. Total number of violations when accomplishing the task.

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## Authors Introduction

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