Incorporating Nurse Preferences in the Nurse Scheduling Problem

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Abstract. As the current healthcare labour market is volatile, due to employees having bad experiences with irregular shifts and unconventional working hours, it is important to make an effort to retain existing and attract new healthcare employees. This research explores the effect of scheduling decisions on job satisfaction of nurses in Dutch hospitals. We examine if nurse satisfaction can be improved using mathematical optimization, and at what cost. Incorporating results from interviews and a survey, this research presents a formulation of the nurse scheduling problem including both capacity coverage and nurse satisfaction in the problem's objective. The problem is solved using an exact (MIP) and a heuristic (VDS) approach. Using benchmark instances for the nurse scheduling problem, results show that nurse satisfaction can be improved without decreasing the capacity coverage.

Keywords: Nurse scheduling problem, Schedule satisfaction, Nurse job satisfaction, Mathematical programming, Variable depth search

1 Introduction

A recent study in The Netherlands reports an expected shortage of 140,000 healthcare employees by 2031 [4]. Two main reasons for this shortage are an increased demand for healthcare and a shortage on the healthcare labour market. The irregular shifts and unconventional working hours make nurses quit their profession and discourage others to apply. In order to keep nurses healthy and prevent burn-outs, their personal scheduling preferences should be incorporated in the scheduling process [3,6]. However, in practice, nurse preferences are complex and difficult to quantify in a single score per nurse per schedule. In this research, we combine the results of interviews and a survey to redesign the objective in the nurse scheduling problem. This particular combination of research methods is novel, as previous research has either focused on the quantitative solution methods, or used a qualitative approach to study nurse job (schedule) satisfaction, which mainly originates from human resources or social sciences fields.

2 Methodology

To gain an understanding of the preferences of nurses, we use a mixed-methods approach. This approach combines quantitative and qualitative methods to answer research questions on complex issues in the social sciences [5]. First, interviews were held at the

Martini Hospital (Groningen, The Netherlands) to gain an understanding of the most relevant preferences nurses have regarding the scheduling process. Based on the results, we cluster nurse preferences in five categories: incidental requests for (not) working a particular day or shift; preferences regarding the length of a consecutive series of shifts (consecutiveness); the shift types nurses are assigned to work; the scheduling of weekend shifts; and the scheduling of night shifts. Second, we designed a survey with closed questions on preferences for these five clusters. The survey concludes with a question asking participants to divide a total of 50 points across these five clusters to ask about the relative importance for each of these clusters. Results of the survey show that nurses find the adherence to their requests and their consecutiveness preferences most important for their schedule satisfaction. Also, consecutiveness preferences are correlated with the number of contract hours nurses are assigned to work. Part-time nurses typically prefer to work between 2 and 3 consecutive days on average whereas full-time nurses prefer to work a consecutive series of minimum 3 and maximum 4 shifts. Finally, we use the results of the interviews and surveys as input for our mathematical formulation. As there are multiple objectives, for both the planner and nurses, we make use of a weighted sum approach, as this is easy to interpret by the users and the weights can easily be adjusted to their preferences.

3 Mathematical formulation

Most nurses selected the requests and consecutiveness as their top two priorities. The consecutiveness penalty for a nurse ($i \in N$) is calculated based on the difference between the actual consecutiveness of the assigned blocks of shifts and the simulated preferences of the same nurse. Similarly, the request penalty for a nurse ($i \in N$) is calculated by counting the number of times the schedule fails to meet indicated preferences. An individual's satisfaction score will therefore be a weighted sum (with $0 \leq \alpha_i \leq 1$) of these two indicators of satisfaction:

$$P_i = \alpha_i \cdot \text{consecutivenessPenalty}_i + (1 - \alpha_i) \cdot \text{requestPenalty}_i \quad \forall\, i \in N \tag{1}$$

The individual satisfaction scores are aggregated using the worst-off score and the sum of all scores. These can be balanced using $\gamma_1, \gamma_2 \in \{0, 1\}$, respectively, depending on the scheduling policy. By setting $\gamma_1 > 0$, additional penalty is added for not dividing the total sum of satisfaction evenly across the employees which can be regarded as unfair. The objective function combines the satisfaction and coverage scores using the parameter $0 \leq \beta \leq 1$:

$$\min \quad \beta(\gamma_1 \max_{i \in N} P_i + \gamma_2 \sum_{i \in N} P_i) + (1 - \beta)(\sum_{d \in D} \sum_{t \in T} y_{dt} v^{min} + \sum_{d \in D} \sum_{t \in T} z_{dt} v^{max}) \tag{2}$$

with y_{dt} the total number of unassigned shifts, z_{dt} the total number of over-assigned shifts for day d and shift type t; v^{min} the penalty per unassigned shift, and v^{max} the penalty per over-assigned shift.

4 Computational results

Results are obtained using data from the nurse scheduling benchmark instances [2]. These instances contain data on the available employees, shift types, cover requirements and nurse requests. We will use *small instances* 1, 2 and 3, which have a scheduling period of two weeks and up to 20 employees, and *large instances* 11 and 12, which have a scheduling period of four weeks and up to 60 employees. These instances are solved for both the objective function without satisfaction (only coverage penalty, $\beta = 0$), and with the satisfaction scores $\beta = 0.5$, $\gamma_1 = 1$, and $\gamma_2 = 1$. Since we aim to optimize for nurse satisfaction using the consecutiveness preferences, we simulate these preferences based on the obtained probability distributions per contract type through our survey. The problem is modelled as a mixed integer programming model (MIP) and is solved using IBM ILOG CPLEX 22.1.0, on an Intel Core i7 2.8 GHz processor and 16GB RAM, and using a heuristic based on a Variable Depth Search (VDS) based on Burke et al. (2013) [1].

Table 1 shows the results obtained using the MIP with a maximum runtime of 1 hour, whereas Table 2 shows the results obtained using VDS with a runtime of 1 hour, using a fixed set of simulated preferences for the nurses. These results show that nurse satisfaction can be improved without decreasing the coverage by including satisfaction in the objective function of the nurse scheduling problem. To investigate the effect of the simulated preferences, we also run the instances with newly generated preferences for the nurses in every run. The MIP is run 100 times for small instances, and 5 times for large instances, due to the higher runtime. In all simulation runs, the results still hold, where the coverage stays the same and the nurse satisfaction is improved.

Table 1: MIP results with $\beta = 0$ and $\beta = 0.5$

	$\beta = 0$					$\beta = 0.5$				
instance	time (s)	gap	coverage	max P_i	$\sum P_i$	time (s)	gap	coverage	max P_i	$\sum P_i$
1	0.203	0	600	2	5.807	1.078	0	600	1	2.548
2	7.781	0	800	5	12.232	26.36	0	800	1	3.785
3	32.10	0	1000	4	21.371	490	0	1000	1.77	8.67
11	9.36	0	3423	4	60.432	3600	0.01	3423	4	33.163
12	3600	0.000	4001	9	82.062	3600	0.018	4000	9	70.872

5 Conclusion

The two most important indicators of nurse schedule satisfaction are the adherence to requests made by nurses to (not) work specific shifts and the consecutiveness of assigned shifts in the schedule. When nurses are assigned too many or too few consecutive shifts per block, their schedule satisfaction decreases as they cannot balance their workload with enough rest. However, the minimum and maximum number of preferred consecutive shifts differs per nurse because of personal differences. Additionally, the importance of

Table 2: VDS results with $\beta = 0$ and $\beta = 0.5$, runtime of 1 hour

	$\beta = 0$			$\beta = 0.5$		
instance	coverage	max P_i	$\sum P_i$	coverage	max P_i	$\sum P_i$
1	600	2	5.807	600	1	2.548
2	800	5	12.232	800	1	3.785
3	1000	4	21.371	1000	1.77	8.67
11	3827	5	27.36	3827	5	27.36
12	4900	6.025	38.386	4900	6.025	38.386

requests versus the consecutiveness of shifts differs per person. Therefore, including these personal preferences in the objective function of a nurse scheduling problem requires input from the nurses. The effect of including nurse satisfaction in the objective function shows that the satisfaction of the nurses can be improved without decreasing the coverage. Therefore, it does not cost anything in terms of coverage to improve the satisfaction of the nurse.

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