Nurse Rostering with Strategic Planning of Skills for Sick-Leave Robustness

Björn Morén[1 [0000−0001−7191−5206)]] and Elina Rönnberg[1 [0000−0002−2081−2888]]

Department of Mathematics, Linköping University, Linköping, Sweden
bjorn.moren@liu.se, elina.ronnberg@liu.se

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1 Introduction and contribution

In hospitals, nurse schedules are sensitive to disruptions such as sick leave since the absence of nurses with the right skills can have a severe impact on healthcare quality. The literature on the nurse rostering problem (NRP) is extensive and addresses a variety of aspects, such as minimizing the cost of schedules, meeting work regulations, and satisfying the preferences of the staff. The nurse rerostering problem (NRRP), which models rerostering of a schedule due to the absence of nurses, was first defined by Moz and Pato [2]. It has, for example, been studied in [4] where the aim is to do the rerostering with as few changes as possible while respecting staffing demand and hard constraints. They schedule shifts and tasks, and in the rerostering, nurses are allowed to change shifts or change free days to work days. Strategies to achieve robust and cost-efficient schedules are considered in [5], by using capacity buffers and reserve shifts, which can be changed to a working shift at a later stage. There are also general studies of staff rerostering, e.g. [3] that proposes a large neighbourhood search enhanced with machine learning for solving the problem.

We consider nurse rerostering from a strategic perspective and study the case of having multiple skills and varying staffing demand. Our aim is to design a decision support tool to be used on a strategic level to analyse how the distribution of skills affects the sick-leave robustness of schedules. As a first step, we here propose a scheme to both schedule and evaluate the schedule with respect to sick leave, similar to the work by Wickert *et al*. [5], and we evaluate it on real data from a case study. See Figure 1 for an illustration of our scheme.

We compare three approaches for handling the distribution of skills, denoted (i) `case`, (ii) `mix`, and (iii) `min`, where `case` allows the use of all available skills, `min` minimizes the available skills in a base schedule while scheduling with a capacity buffer. The approach `mix` is based on the same base schedule as `min`, but for each generated scenario, it is possible to add skills to cover understaffing.

For the scheduling part, the aim is to minimize understaffing and add an additional buffer per day, shift and task, while respecting the work time of the available nurses. A prerequisite for sick-leave robustness to be of interest is to have more nurses than what is required to meet the minimum demand. Our objective is then to spread out the additional nursing resources in such a way that the schedule is robust with respect to sick leave. To

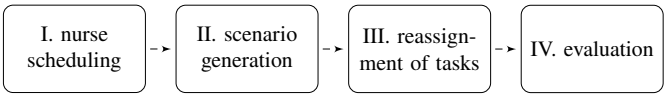

Fig. 1: Overview of the proposed scheme.

evaluate the robustness of a schedule with respect to sick leave, we generate scenarios. For each shift a nurse is assigned to, we assume that there is a probability that the nurse is absent and hence does not contribute to the staffing demand. This probability is based on one year of historical data of sick leave. For each scenario, we solve a restriction of the NRRP in which only tasks are reassigned. We impose this restriction as there are often limitations for changing a nurse's shift or a free day to a working day. For some understaffed shifts, it is possible to find a substitute nurse, but this is not known at the stage of scheduling. Hence, the only certain way to cover for an absent nurse is to reassign the tasks of the other nurses working that shift. If possible, the aim is to cover all the demands on tasks, or if not possible, at least cover the most important tasks. Finally, the updated schedule is evaluated with respect to understaffing.

2 Case study

Our case study is from a ward at a Swedish university hospital which has about 50 to 60 nurses and a scheduling period of 10 weeks. The ward requires nursing staff round the clock on both weekdays and weekends. There are three types of shifts—day, evening, and night—and for each shift, there is a task-based staffing demand. That is, a nurse is assigned a task for each scheduled shift. There are in total five tasks, requiring specified skills, except for one skill that is common for all nurses. The combination of skills is individual for each nurse and there is no general hierarchy between the skills. The demand varies over the scheduling period, for example, some tasks only appear every third week. The case can be classified as ASB|V3|LR based on the definitions from [1].

For the case study, we have formulated a straightforward mixed-integer programming model, based on binary variables indicating if to assign a nurse to a task at a specific shift, or not. There are additional variables concerning requirements of a task at a specific shift. They are used to model penalties for understaffing, lack of buffer, and presence of additional overstaffing. For the approaches including distribution of skills, there are binary variables for which tasks are available per nurse. The starting point is the skills of each nurse, and our approach tries to remove skills while still satisfying staffing demand, including a buffer. A summary of the included constraints is as follows.

- A nurse works at most one shift and is assigned at most one task per day.
- A nurse's maximum number of work days in a row is respected.
- A nurse's maximum number of night shifts is respected.
- The total work time of a nurse during the period is within an interval.
- A nurse works only according to permitted shift patterns, specifying which consecutive shifts that are allowed to work.
- On a weekend, a nurse is either free or works both Saturday and Sunday.

- A nurse works a specified number of weekends.
- A nurses should not work two weekends in a row and on-duty weekends should be spread out in the schedule.
- The work of different shift types is evenly distributed among the nurses.
- The staffing demand for each task at a specific shift is respected by either assigning a nurse to the task or by declaring a shortage.

3 Computational Experiments

Our evaluation is made on 100 simulated scenarios with a risk of absence of 6.4%, which is based on data from the ward. On average per scenario, there are absent nurses on 123 occasions. We show results for the three approaches `case`, `mix`, and `min`. The average understaffing for all shifts, weekdays, weekends is for approach `case` 72, 46, and 26, for approach `mix` 73, 46, 27, and for approach `min` 73, 46, 28. See Figure 2 for an illustration of understaffing per scenario. The computational times required for optimally solving the models for `case` and `min` are 1.5 h and 7 h, respectively.

Figure 3 shows the distribution of skills for the three approaches. Skill A is common among all nurses. It is clear that the number of nurses with skills C and D can be reduced to a large extent, while skill B and E appear to be more critical for the schedule and the sick-leave robustness. On average, the number of available skills (B-E) is 114, 69, and 67, for case, mix, and min, respectively.

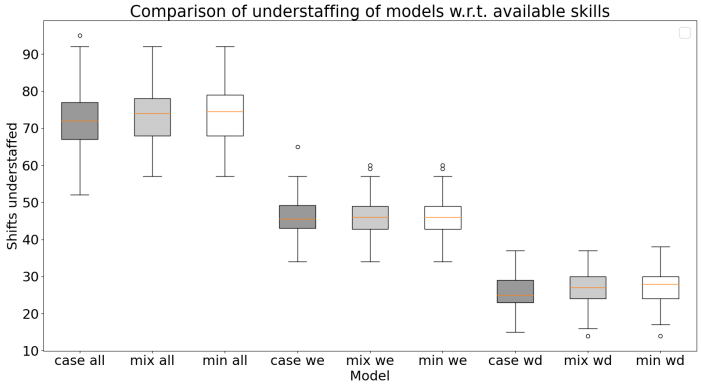

Fig. 2: Number of shifts understaffed per scenario for the three approaches, divided into all days (all), weekends (we), and weekdays (wd).

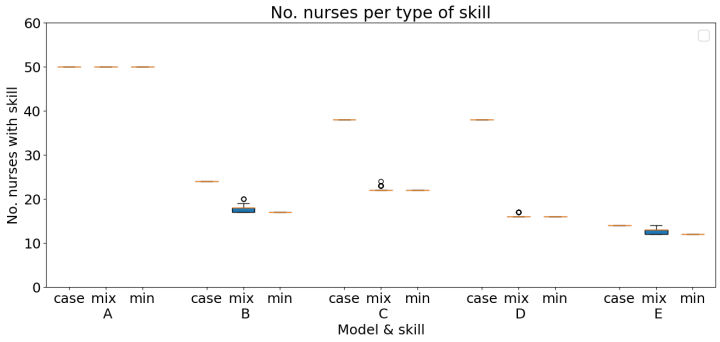

Fig. 3: Number of available skills of each type for the three approaches.

4 Discussion and conclusion

We have described a preliminary design for a decision support tool to plan the staff's distribution of skills. From our case study, we have shown that our tool can be used to indicate which of the available skills can be removed, with only a small impact on both the understaffing in the nominal scenario and scenarios with sick leave. These are results to be further discussed with the hospital.

There are simplifications in our approach, we consider a standard schedule period without individual nurse preferences, holidays, and vacation. The addition of nurse preferences could result in a less robust schedule and the presence of holidays and vacation would make more shifts understaffed in the initial schedule and also reduce the capacity to have buffers, limiting the possibilities to cover for sick leave.

References

1. De Causmaecker, P., Vanden Berghe, G.: A categorisation of nurse rostering problems. Journal of Scheduling **14**(1), 3–16 (2011)
2. Moz, M., Pato, M.V.: An integer multicommodity flow model applied to the rerostering of nurse schedules. Annals of Operations Research **119**(1-4), 285–301 (2003)
3. Oberweger, F.F., Raidl, G.R., Rönnberg, E., Huber, M.: A learning large neighborhood search for the staff rerostering problem. Lecture Notes in Computer Science **13292 LNCS**, 300–317 (2022)
4. Wickert, T.I., Smet, P., Vanden Berghe, G.: The nurse rerostering problem: Strategies for reconstructing disrupted schedules. Computers & Operations Research **104**, 319–337 (2019)
5. Wickert, T.I., Smet, P., Vanden Berghe, G.: Quantifying and enforcing robustness in staff rostering. Journal of Scheduling **24**(3), 347–366 (2021)