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The Robust Nurse Scheduling Problem

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Abstract — In hospitals, nurse scheduling and assignment is a major issue. In order to keep hospital expenses down and respect the preferences of the nurses, a well-planned schedule is needed. For the nurse scheduling problem (NSP), we provide a novel mathematical formulation that incorporates certain additional restrictions. For coping with uncertainty, we also present a resilient equivalent to the deterministic model, which is based on the worst-case scenario A future project will focus on developing a solution and putting it into action.

Keywords — nurse scheduling problem, robust optimization, worst case criterion, nurse preferences

I. INTRODUCTION

Many publications in the literature have dealt with scheduling issues in recent years, owing to its efficiency in maximising an organization's profitability and productivity.

In terms of health care, nurses have a lot of obligations in hospitals since they care for patients to boost their happiness. This may lead to overtime work and job discontent, both of which can significantly effect hospital quality of service.

To satisfy working contracts and hospital demand, the NSP entails arranging cyclic schedules (daily, weekly, or monthly) for nursing staff by allocating various nurses to several shifts.

The NSP may maximise a variety of goals, such as hospital costs, nurse preferences, and so on.

On the one hand, a novel formulation for the NSP is offered, and on the other hand, a robust optimization model for the nurse scheduling issue is presented for coping with uncertainty in the number of nurses in each period is presented in this paper. We consider the total hospital cost as well as the cost of overtime each day. The horizon, shifts, and the day off, which marks the holiday, are all factors in the planning.

The planning horizon is a period of time (usually considered as a week). A day is divided into 12 shifts, each of which lasts two hours. Each day consists of four morning shifts, four afternoon shifts, and four night shifts. Furthermore, multiple nurses must be pleased throughout each shift.

Normal nurses (grade 1), specialised nurses (grade 2), and head nurses (grade 3) are the three types of nurses examined (grade 3). Many restrictions must be considered as a result of hospital policy:

- Nurses have set working hours that must be adhered to.
- The nurses are required to take a day off.
- If nurses perform night shifts on a day, they have no work hours the following morning.
- If the nurses performed morning/afternoon shifts on the same day, they must not work all night shifts on the same day.

The goal of this research is to provide a novel NSP formulation that takes into consideration nurse availability on each shift. Using the worst-case criteria and the uncertainty in nurse demand in each shift, we offer a robust counterpart model.

II. LITERATURE REVIEW

Researchers employed many methodologies to solve the NSP in several literatures; we mention precise and approximant strategies. For accurate approaches, a fuzzy approach was given for the NSP. They took into account the unpredictability of nurses' preferences as well as the demand for nurses on any given day. For the NSP, I presented a mathematical model that reduced nurses' idle waiting time. They used optimization software to solve the issue after including certain limits. In cancer clinics, an optimization technique was presented to reduce nurse overtime and overall patient waiting time. The suggested optimization method was split into two multi-objective models: one for primary care delivery and the other for functional care delivery. Developed a strategy to assist hospital administrators and prevent manual scheduling, which might raise costs. For two types of nurses, they developed a heuristic and a mathematical model for the NSP. The NSP was solved using a multi-commodity network flow model and an integer linear programming (ILP) paradigm. Approximant techniques have been employed by several writers to solve the NSP. For the downgrade issue, I presented a strategy to enable nurse scheduling and preferences. The authors used an ILP model to address the issue and used the column-generation method to solve it. Developed a mathematical model to meet the needs of hospital administration and nurses. They employed a commercial optimizer and added limitations such as hospital policy and nursing preferences. At a large United Kingdom (UK) hospital, I presented a genetic algorithm method to solving the NSP. Because of the multi-objective character of the challenge, a method for integrating certain competing goals and constraints for the NSP was proposed. The column-generation technique and other heuristics were used to address the challenge. Introduced a method for maximising the preferences of nurses. A heuristic derived from a multi-agent system was used in their method. Developed a deterministic heuristic technique with the goal of meeting nurses' preferences while lowering the cost of soft constraint violations. There were two stages to the algorithm. A solution to the issue of nurse scheduling was proposed. They introduced an ant colony algorithm that takes numerous hard and soft limitations into consideration. Only a few papers have addressed the robust NSP. Considered two approaches to addressing the NSP goal: ensuring that each shift has an adequate number of nurses. SAWing and noising are compared to see which procedure produces the greatest results. A hyper-heuristic strategy was presented for an NSP that occurred at a prominent UK hospital. To demonstrate the efficacy of their method, they compared it to certain metaheuristics.

The following is a breakdown of the paper's structure. The deterministic mathematical model is provided and discussed in Section III. The robust formulation of the nurse scheduling issue is presented in Section IV. Section V concludes with some recommendations for further research.

III. PROBLEM FORMULATION

The suggested mathematical model (P1) is given and explored further down. Its goal is to cut costs as much as possible.

Normal nurses (grade1)$\{1,2,3,\dots,H\}$, specialised nurses (grade 2) $\{H+1,\dots,L\}$, and head nurses (grade 3)$\{L+1,\dots,I\}$ are the three types of nurses.

A day is split into 12 shifts: four in the morning, four in the afternoon, and four in the evening.

A. Parameters

c_i : The price of a grad I nurse i ($i \in \{1,2,3\}$)

c_4 : Nurses' overtime costs (all grades)

W_i: A nurse's maximum number of shifts is i

Z_i: Nursing shifts that must be performed by i

M_j: The number of nurses that are required to perform shifts j

C: Indicated number of mandatory afternoon shifts

D: Night shifts that must be completed

Q: Grade 3 nurses are required to perform a certain number of shifts.

M: A huge number of people

B. Decision variables

$$x_{ij} = \begin{cases} 1 \text{ if nurse i is assigned to shift j} \\ 0 \text{ else} \end{cases}$$

$$\alpha_{ih} = \begin{cases} 1 \text{ if nurse i works at least one morning or afternoon shift on the day h} \\ 0 \quad \text{else} \end{cases}$$

$$\beta_{ih} = \begin{cases} 1 \text{ if nurse i works at least one night shift on the day h} \\ 0 \quad \text{else} \end{cases}$$

C. Objective function

$$\min \sum_{i=1}^{H}\sum_{j=1}^{J}(c_1 \times x_{ij}) + \sum_{i=1+H}^{L}\sum_{j=1}^{J}(c_2 \times x_{ij}) + \sum_{i=L+1}^{I}\sum_{j=1}^{J}(c_3 \times x_{ij}) + c_4(\sum_{i=1}^{I}(\sum_{j=1}^{J} x_{ij} - Z_i)) + \sum_{h=0}^{\frac{J}{12}-1}\sum_{i=1}^{I} \tau_{ih}$$

The goal of the objective function is to reduce cost, which is divided into five components. The expenses of nurses' grade 1, grade 2, and grade 3 are shown in the first three portions. The fourth point is about overtime. Finally, the fifth indicates the cost of doing more work on a given day.

D. ROBUST FORMULATION

When it comes to identifying solutions before uncertainties are realised, the worst-case criteria might be called the robust optimization benchmark. In general, it identifies the best solution in the worst-case situation when applied to an unknown issue. The provided solution is robust since it provides a guarantee for all possible outcomes. The demand for nurses throughout each shift is affected by unknowns and is generally evaluated using a mean figure. (P1) can be thought of as a programme with interval numbers on the right-hand side. We'll have a look at the strategy presented in the next section.

We investigate the issue (P1) and assume that the first constraint's right-hand side M_j ($j \in J$) fluctuates inside the interval [M_j, M_j].

Except for the first restriction, (*) reflects all of the constraints of the issue (P1).

Consider the following polyhedron, which specifies the solutions that are possible (P1):

$$X^{M_j} = \{x_{ij} \in \{0,1\}: (*) \ \& \sum_{i=1}^{I} x_{ij} \geq M_j\}$$

IV. CONCLUSION

In this research, we provide a novel mathematical formulation for the NSP that intended to reduce overall hospital costs while taking nurses' preferences and hospital demand into account. Furthermore, when the number of necessary nurses in each shift is unclear, the robust counterpart model was established utilising the worst-case criteria. In the future, we'll use the tabu search method to solve the issue. Our approach will also be tested in a real-life case study at a French hospital.

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