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Nurse Scheduling Model in Saudi Arabia Hospitals[1]

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Abstract: The nurse-scheduling problem (NSP) is a critical issue in the healthcare sector. Hospitals must provide an effective, efficient, and high-quality service to their patients, where the aim of the hospital is to ensure that business is continuously with an appropriate number of staff in possession of the right skills; to achieve this, a suitable number of nurses need to be active. NSP is a very complex problem. In this paper, a model developed that can be applied in the future studies to create an algorithm to solve the nursing schedule problem in Saudi Arabian hospitals. In addition, mathematical formulations are proposed. In this work, an algorithm has been created to calculate the yearly vacation. In order to approve the schedule, it need to take into account the nurses' preferences, which are based on general preferences, weekend preferences constraints, and yearly vacation preferences. The overall aim of this study is to automate nurse schedules, as well as maximize nurse preferences in Saudi hospitals.

Keywords: Nurse Scheduling Problem, Scheduling, Health Services

1. INTRODUCTION

The nurse-scheduling problem (NSP) is also known as the nurse rostering problem. The main challenge of NSP is to determine the nurse roster during a specific period where NSP is NP-hard [1]. [2] have defined NSP, as an operation research issue that requires the identification of an optimal solution that assigns a set of available nurses to the required shifts. Another definition of the nurse-scheduling problem is given in [3], which it is described as the task of assigning shifts to a personal member who is responsible for qualification categories required for the jobs that need to be done. In other words, the objective of scheduling is to structure the work and activities of nurses in a timely manner, without any interruption [3].

NSP is a very complex schedule problem that has to be solved to provide work schedules for nurses. The challenge in solving the NSP is that there are many constraints; these constraints can be divided into hard and soft constraints, which refer to the regulations of the institution and preferences of the nurses, respectively. If NSP perfectly solved, this will increase the quality of the provided healthcare that provided. Typically, the head of the nurses is the responsible for creating the schedule in each hospital. In order to be have a good schedule, the preferences of the nurse should be considered it needs to consider the preferences of the nurse [4]. The NSP is the biggest scheduling issue facing many hospitals around the globe [5].

In Saudi Arabian hospitals, the head of the nurses is responsible for manually assigning shifts to nurses. This head spends most of his/her time working on the schedule; and carrying out this task manually is inefficient, because the manual process is very time consuming and requires a lot of effort. In addition, the head nurse will try to arrive at a solution without focusing on optimality. As such, as part of this study, a visit was carried out to one government hospital in Saudi Arabia, where information was collected relating to nursing staff and how the scheduler (head) assigns shift and workload.

2. LITERATURE REVIEW

Much of the literature in this field discusses NSP, and this section will present some of these studies. A review of the literature on personal scheduling problem is presented in [6] that begins by discussing the classification methods applied in pervious review papers. The main contribution of the review is in facilitating the tracing of published research and identifying gaps for future work. In addition, the paper evaluates the literature in various fields. Some of the objectives considered in this research are replacing manual scheduling, and maximizing nurse preferences.

An approach to scheduling that was implemented in over 40 hospitals in Belgium is described in [7]. The main aim of the study was to more accurately model the real-world situation than had been done in previous works, as well as to present a sufficient Tabu Search. The paper

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focuses on providing an innovative representation of common personal constraints in healthcare organizations, and presents an algorithmic approach to handling new formulations.

A solution to the nursed scheduling problem at Hong Kong Hospital based on an Excel spreadsheet was proposed in [8]. However, the research investigated NSP in an emergency department only, which is a particularly dynamic work environment. Alternatively, [9] proposed a scatter search approach, which can be used across a number of issue domains, and is able to create nurse schedules automatically. The algorithm was tested and compared with previous works. A mathematical programming model also proposed in [10] to solve the nurse scheduling problem. The main aim of this approach was to minimize the number of idle waiting nurses. The proposed model used numerous examples and Lingo8.0 software, in order to ensure that the global optimum solution was reached.

A study conducted in [11] used constructive heuristics, alongside several genetic algorithms based on custom encoding and operators of sequence issues. In this approach, each individual in the population is connected with a pair of chromosomes, to denote rearrangements of duties and nurses. When one or more of the nurses is unable to attend a shift that has already been approved, then the nurse rostering issue has to be applied.

A study conducted by [12] focused on a French public hospital, and attempted to resolve an anesthesiology nurse scheduling problem at this hospital. The proposed model was compared with their previous results obtained. A new evaluation function was created, which is able to ensure minimum unfair assignments among the nurses.

An autoregressive integrated moving average classic was proposed [13], in order to forecast the number of patients to use as an input to determine the number of nurses that need to be scheduled. In addition, the study established several shifts that can be used as comprehensive integer-programming classics, considering nurse layers and their preferences. Also, the authors designed a heuristic algorithm with several rules, in order to achieve near optimal scheduling. The greatest advantage of this approach is the ability to adapt the number of nurses assigned to the shift dynamically, as well as to control patient waiting time effectively. In [14] a new integrative nurse staffing and shift scheduling approach was introduced, which was tested and assessed in a real-life environment. The impact of several personnel policies on staffing decisions was evaluated.

3. PROBLEM STATEMENT AND METHODS

A visit to one government hospital in Saudi Arabia was carried out, and information related to nursing staff and the way in which the scheduler assigns shifts, and workloads was collected. The total workload should be distributed equally between nurses. For this study, a questionnaire was prepared, which concerned the work involved in scheduling nurses. All the data that collected was provided by the director of the nursing department; the information concerned departments, number of nurses, shifts, days off, emergencies, and nurse preferences.

A. Departments

A department is denoted by d, assuming that there are n departments. Thus $d \in \{1, .., n\}$. The department types are: surgery, internal, children's, and general departments. The below are overall descriptions of all four hospital departments are given below:

1) Surgery

The surgical department is important, and practices operative physical and involved techniques on a patient to treat a pathological condition, such as disease or injury, to help improve bodily function or appearance, or to repair unwanted ruptures. The surgical department implements a widespread range of tasks, including general surgery.

2) Internal

Internal medicine is one of the main medical specialties, and encompasses a wide range of other specialties. It is the medical field responsible for the full disclosure of patient health, including health alertness, and supervision of related diseases. This department is accountable for the follow-up of illnesses such as diabetes, high blood pressure, colds and flu, as well as diseases of the liver and digestive system.

3) Children

The children's department is primarily focusing on the various aspects of children's physical and psychological health. The department is responsible for the diagnosis and treatment of numerous childhood diseases and disabilities, from birth to youth. In addition, it extends to defensive healthcare.

4) General

This department is involved in distinguishing and recognizing the symptoms communal among persons, and medical analysis. The general department focuses on diseases of the human body and the symptoms associated with these diseases, as well as methods to improve human health. In addition, it is the duty of the general department to refer to specialist consultants when necessary.

B. Number of nurses

1) Nurses in department d

The required number of nurses required depends strongly on the number of patients in each department. Each service in the hospital has a maximum number of patients, and thus required nurses. For the sake of clarity, the following notations will be adopted:

- $N_{th\_p}^{d}$ is the number of patients required to have one nurse in the department d. This number is the threshold, which is denoted by th.

- $N_{\mathrm{p}}^{\mathrm{d}}$ is the number of patients in department d.
- NR_{nurse}^{d} The number of nurses required in department d. To determine the number of nurse required in department d , one must calculate N_{nurse}^{d}, as follows:

$$NR_{nurse}^{d} = \frac{\mathrm{N_p^d}}{N_{th\_p}^{d}} \quad (1)$$

Distributing nurses to the various shifts is one of the tasks of the scheduler. Every four patients should have one nurse; this for patient who sandman (admitted) to the hospital. In this case, $N_{th\_p}^{d} = 4$ however, in intensive care, every patient should have a dedicated nurse, thus$N_{th_p}^{d} = 1$

2) Head nurses

The maximum number of the nurses under one head nurse is six nurses, to ensure the head nurse is able to manage his/her staff. The number of head nurses depends on the department and the shift. Therefore, it is necessary to introduce d and j in the following equation:

$$NH_{nurse}^{d,j} = \frac{N_{nurse}^{d,j}}{6} \quad (2)$$

3) Shifts

There are three shifts over 24 hours. The first shift starts at $8{:}00$ in the morning and finishes at $4{:}00$ in the afternoon. The second shift starts at $4{:}00$ in the afternoon and finishes at $12{:}00$ at night. The third shift starts at $12{:}00$ at night and finishes at $8{:}00$ in the morning. The total time of each shift is eight hours, and on each shift, there is a fixed number of nurses (16). The shifts are denoted as follows:

$$j = \begin{cases} 1 \text{ for the first shift} \\ 2 \text{ for the second shift} \\ 3 \text{ for the third shift} \end{cases}$$

$N_{nurse}^{d,j}$ denotes the number of nurses on shift j and in department d.

4) Days off

a) Extra day off

An extra day off will be calculated by cumulating the score for each nurse. This resultant score is expressed as points. Each hour of overtime corresponds to two points. If the score reaches eight points, the relevant nurse will be entitled to one day off. To calculate the score, the notation below can be used.

- SC_{d_off} is the score to calculate the number of days off.
- N_{oh} is the number of overtime hours.
- $N_{d\_off}^{EX}$ is the number of extra days off.

$$SC_{d\_off} = 2{\cdot}N_{oh} \quad (3)$$

$$N_{d\_off}^{EX} = \frac{SC_{d\_off}}{8} \quad (4)$$

b) Yearly vacation

For yearly vacations, some constraints must be taken into account. Yearly vacations require expressions of year (y), month (m), and day (d). Below, denotes the yearly vacation in terms of years (y), months (m) and days (d). For each nurse $Nurse_i$ a corresponding yearly vacation needed to be fixed:

$$YV_{m,y}^{d}(Nurse_i)$$

$$YV_{m,y}^{d}(Nurse_i) \begin{cases} 0 \text{ if day is not chosen} \\ 1 \text{ if day is chosen} \end{cases}$$

It was necessary to count the number of successive days of yearly vacation in a fixed year (Y). This calculation will be done into the variable $count$. The table $TabYV$ will contain 1 if the nurse has a vacation day, 0 otherwise. The variable $ndays$ indicates the number of days in the fixed year. The following algorithm explains the calculation of $count$:

```
i = 1;
ndays = 0;
Count = 0;
For m = 1 to 12
{
      md = day_month(Y, m);
       For j = 1 to md
       {
             ndays ++;
             If (YV == 1)
                  { TabYV[i] = 1;
                   count ++;
                   }
                 else
             TabYV[i] = 0;
          i ++;
           }
       }
```

```
int day_month(int Y; int m)
{
        switch(m)
        {
          case 1:
          case 3:
          case 5:
          case 7:
          case 8:
          case 10:
          case 12:
                md=31;
                break;
            case 4:
          case 6:
          case 9:
          case 11:
                md=30;
                break;
        case 2:
                md=Leap(int Y)
                break;
        return md;
        }
}
```

```
i = ndays
While(tab[i] == 0 and i >= 1)
i − −;
end = i
```

```
        int Leap(int Y)
        {
              if(Y%4 == 0)
                {
                   if(Y%100 == 0)
                   {
                      if (Y%400 == 0)
                         md=29;
                      else
                         md=28;
                   }
                   else
                      md=29;
                }
                else
                   md=28;
              return md;
        }
```

The variable $Begin$ contains the index of the first case in table $tabYV$, which is equal to 1.

```
i = 1
Begin = 0;
While (tab[i] == 0 and i <= ndays)
i + +;
if (i! = ndays + 1)
Begin = i;
```

The variable end contains the index of the last case in table $tabYV$, which is equal to 1.

Now it is possible to calculate, using the variable nc, the value of the number of cases between end and begin calculated previously.

$if\,(begin! = 0)$

$nc = end - begin + 1$

It is important that to test the successively of yearly vacation days. Only one condition is the following:

$$count == nc$$

The time between two yearly vacation must be one year.

5) Emergencies

It is important to be able to detect emergency states, which will require additional nurses. For this reason, denotes the emergency test, which will return the number of nurses required to cover what is needed.

$$E_m = \sum_{d=1}^{n} NR_{nurse}^{d} - \sum_{d=1}^{n}\sum_{j=1}^{3} N_{nurse}^{d,j} \tag{5}$$

$$E_m = \begin{cases} > 0 \text{ there is an emergency state, and the value is the number of nurses needed} \\ \leq 0 \text{ there is no emergency state} \end{cases}$$

In an emergency where there are not enough nurses (> 0), the hospital is prepared for this by activating an alert at nurses' accommodation. If any nurses are required, the bell will ring. This means that there is an emergency, with not enough nurses on shift.

6) Nurse preferences

a) General preferences

The scheduler should ask nurses for their preferences. These preferences include desired days off, or working days. The scheduler should try to accommodate nurses' preferences as far as possible.

$Day = \{1,2,3,4,5,6,7\}$ denotes the days per week indexed, as follows:

1: Sunday

2: Monday

3: Tuesday

4: Wednesday

5: Thursday

6: Friday

7: Saturday

Denoted by the two variables function Dop , which will return 0 if the day off preference of nurse i is not selected, and 1 if the day off preference of nurse i is selected. Thus, this function depends on the first variable and the second variable Day.

Each nurse receives 6 days off per month. For this reason, the index m denotes the month, and the index k denotes the day in each month. Thus, md denotes the number of days per month:

$$k = \{1..,md\}$$

$$m = \{1,..,12\}$$

The following denotes the day preferences for the nurse i, the month m:

$$Dop_m^k(Nurse_i) = \begin{cases} 0 \text{ if the day not chosen} \\ 1 \text{ if the day is chosen} \end{cases}$$

For each nurse in each month, the maximum number of days off is six days. Therefore, for the nurse the following constraint applies:

$$\sum_{k=1}^{md} Dop_m^k(Nurse_i) \leq 6 \qquad (6)$$

Example: $Dop_4^3(Nurse_{17}) = 0$: the nurse indexed 17 prefers to work on the third day of the month of April.

b) Weekend preferences constraints

Every nurse prefers to have the weekend off; this situation is dealt with by staff working alternate weekends.

For weekends, which consist a special case of day off, the days are Friday: $Day = 6$ and Saturday: $Day = 7$. For the day indexed 6 the nurse has to choose between one of two consecutive weekends. In the notation, the week for the month m is denoted by k, so the consecutive week will be k and $k + 1$ for the month m with $k \leq 3$.

When choosing one of two consecutive weekends, if the value of is equal to 1, then the preferred day off for the next week denoted by must be equal to 0, and vice versa. Thus, the following constraint appears:

$$Dop_m^k(Nurse_i, 6) + Dop_m^{k+1}(Nurse_i, 6) \leq 1$$

The same reasoning will be applied for the Saturday: $Day\ = 7$

$$Dop_m^k(Nurse_i, 7) + Dop_m^{k+1}(Nurse_i, 7) \leq 1$$

c) Yearly vacation preferences

When the scheduler makes the schedule, they must take yearly vacations into account. The scheduler should have all of the information about yearly vacations. The length of yearly vacations must not exceed 30 days. Therefore, any preferred dates regarding yearly vacation must be less than 30 days. Nurses can take 30 days as a yearly vacation, which can be spread across two months: m and $m + 1$, for example from 15 July to 14 August. For this reason, vacations are denoted as m and $m + 1$ for a fixed year, as follows:

$$\sum_{k=1}^{4} \sum_{Day=1}^{7} Dop_m^k(Nurse_i, Day) + \sum_{k=1}^{4} \sum_{Day=1}^{7} Dop_{m+1}^k(Nurse_i, Day) \leq 30 \qquad (7)$$

For example, when a nurse last had a vacation, and the dates of the next.

4. NURSING MODULE

Based on all information presented in the previous section (Section3), the model proposed in this paper is presented in Fig. 1 below, and consists of the following components: department, shifts, general nurse preferences, weekend preference constraints, yearly vacation preferences, days off. The process for this model are:

Each department has its own shifts, where each shift has general nurse preferences (each nurse belong to the department has its preferences in each shift). The nurse preferences divided into two components which yearly vacation preferences and weekend preferences constrains. Extra day and yearly vacation components can feed up the day off for the nurse, which reflect to yearly vacation preferences and weekend preferences constrains. Finally, the result for this model should reflect nurse preference that setting from the begging, otherwise nurse preferences must change. This test is generated in Scheduling According component.

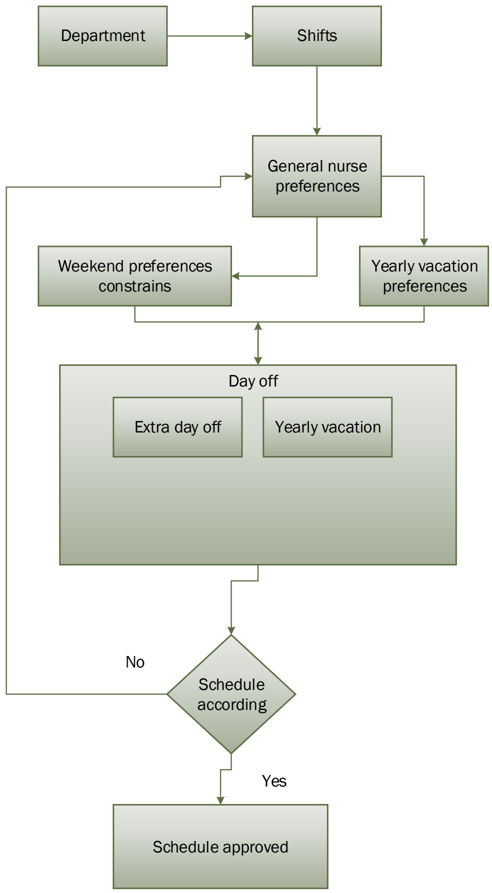

Figure 1. Proposal model for nurse scheduling

5. CONCLUSION

The nurse scheduling problem is solved by assigning a set of existing nurses to the required shifts. In general, the NSP is a very complex scheduling problem. This paper began by reviewing existing research and literature on the nurse scheduling problem. Referring to existing literature on this issue, it can be seen that the issue has been widely studied. However, to the best of the author's knowledge, there have been no studies of the NSP in Saudi hospital as yet. This research has proposed a model for nurse scheduling in Saudi hospitals, which aims to automate nurse scheduling as well maximizing the accommodation of nurse preferences. The model used to schedule nurses' shifts has been described in depth. This model can be used in future studies to help create an algorithm able to solve the nurse scheduling problem. An algorithm was created in the present study to calculate yearly vacations, based on the model described previously. In addition, in order for the schedules to be approved, the model takes nurse preferences into account, including general preferences, weekend preferences constraints, and yearly vacation preferences.

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