

Scheduling of nurses using Constraint Satisfaction

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Abstract: Hospitals in India are short of nursing staffs. The scenario got even worse as the number of hospitals are not adequate to support the growing population of India. Usually, the hospitals treat more patients than its capacity. Nurses are the human resource that is essential for any hospitals for their daily procedures. In general, this human resource is scarce and needed to be utilized in optimal manner. The types of nurses and their working hours in India are regulated by Medical Council of India, New Delhi. Scheduling nurses is highly constraint and require a lot of effort to schedule manually. Since a lot of constraints are required to be checked, a constraint satisfaction problem approach is a natural choice. The Nurse Scheduling Problem (NSP) is formulated in this work as a Constraint Satisfaction Problem (CSP) so that scheduling can be automated using any object-oriented programming language.

Keywords: Nurse Scheduling Problem, NSP, constraint satisfaction problem, CSP, scheduling automation.

1. Introduction

The majority of the schedulers that are now in use for scheduling nurses in hospitals are based on facilities located outside of India. These schedulers are tailored to the operational needs of hospitals in the relevant nation. Many changes must be made to the current schedulers in order to use them for Indian Prospect. For example, the working hours for nursing staffs are 40 hours per week as per the regulations of Medical Council of India, New Delhi.

Hospitals usually have a number of departments like paediatrics, ENT, Neurology, Orthopaedics, Radiology etc. Specialized nurses cannot be assigned to each of these departments, and there is little variation in the nursing needs of the various departments. Therefore, departments with comparable nursing requirements are grouped together.

Nurses are categorized into four types, namely Auxiliary Nurse and Midwives (ANM), General Nurses and Midwives (GNM), Graduate Nurses, Masters in Nursing Graduate. A General Nursing Midwifery (GNM) nurse provides more comprehensive clinical care in hospitals, including helping with deliveries; a Graduate Nurse (BSc Nursing) has advanced clinical skills and can handle more complex patient care; and a Master's in Nursing graduate typically specializes in a particular area like critical care, education, or research, taking

on leadership roles and advanced practice responsibilities. The primary focus of an Auxiliary Nurse Midwife (ANM) is community-based basic healthcare, namely maternity and paediatrics.

Apart from this categorization, nurses are classified on the basis of their seniority. For example, at AIIMS, organization of nursing services from top to bottom is Chief Nursing Officer (CNO) -> Nursing Superintendent (NS) -> Deputy Nursing Superintendent (DNS) -> Assistant Nursing Superintendent (ANS) -> Senior Nursing Officer (SNO) -> Nursing Officer (NO).

Nurses are there for patient's medical care to support doctors. Patients at hospitals are categorized as inpatients and outpatients. Patients admitted in hospitals are termed as inpatients and patients that needed only medical consultation and does not require to get admitted are termed as outpatients. Out Patient Department (OPD) provides consultation to patients. Upon their consultation, a patient decides to be admitted or not to be admitted. For inpatients, different types of wards are needed where they are admitted like child ward, maternity ward, Intensive Care Unit (ICU) etc.

The job of nurses is to provides medical care to these in and out patients to support doctors. Allocating of nurses to OPD and wards are one of the major tasks for smooth functioning of hospitals.

Hospital nurses might choose between two different shift types: general duty and shift duty. Duty timing for a general duty is eight hours during the day. General duty hours at AIIMS are 9:30 AM to 5:15 PM, with a half-hour lunch break at 1:00 PM, For simplicity, we termed the General duty as GD. There are three types of shift duty: morning, evening, and night. The hours at AIIMS are as follows: 6:00 AM to 2:00 PM, 2:00 PM to 10:00 PM, and 10:00 PM to 6:00 AM. For the sake of simplicity, we termed these shifts as S1, S2 and S3 respectively. There are certain norms set up by government that needed to be followed by hospitals while allocating nurses. Like nursing staffs of shift duties are assigned equal numbers of morning, evening and night shifts and not more than two consecutive shifts can be allotted to a nursing staff. Total working hours of a nurse is 40 hours per week. Every nursing staff must do 22/23 shift duties in a month. Etc.

Apart from constraints on working shifts and working hours of nursing staffs, there are restrictions on the number of nursing staffs in a ward on the basis of specific ward and number of beds in the ward. For example, Normal wards require one nurse per 6 beds, special wards require one nurse per 4 beds, nursery requires one nurse per 2 beds, ICU needed one nurse per bed, Labour room requires one nurse per bed, Major Operation Table (OT) requires two nurses per OT, Minor OT requires one nurse per OT, OPD requires one nurse per 100 patients per day, etc.

The Nurse Scheduling Problem Statement:

The nurse scheduling problem is to assign available nurses to OPD's and different wards in a manner that the following constraints are satisfied:

1. A nurse can work 40 hours to 42.5 hours per week.
2. Each nurse will do both types of duty, General and Shift duty in a rational manner. If there are in total n_1, n_2, n_3, n_4 morning, evening, night and general duties and there are k nurses then approximately each nurse gets $n_1/k, n_2/k, n_3/k, n_4/k$ morning, evening, night and general duties.
3. Maximum two consecutive shift duty can be assigned to a nursing staff.

4. Domain specific nurses are allotted to their respective wards/OPDs.

5. Suppose there are r wards namely W_1, W_2, \dots, W_r with corresponding nurse requirements of N_1, N_2, \dots, N_r nurses. Then such requirements are needed to satisfied while scheduling.

6. Number of Senior nursing staff corresponding to respective number of junior nursing staffs.

2. Related Works

The NSP is an NP-Hard scheduling problem that, given restrictions, assigns a set of shifts to the group of nurses across the schedule period [1,2,3,4]. To address NSP, the majority of scholars have only thought about one aim, and very few look for several targets [5,6,7]. Nurses are assigned to shifts through NSP, with the primary goal being to do so while adhering to hospital policies. Mathematical programming models, heuristics, and meta-heuristics are used to solve the NSP [8,9,10]. To take advantage of the solution, Aickelin and Dowsland [11] employed a genetic algorithm framework with Tabu search as a local search. Burke et al. solved NSP and produced a key in the Pareto front using a simulated annealing multi-objective technique [12].

3. Design of Nurse Schedule Scheduler (NSS)

We use constraint satisfaction problem (CSP) technique to solve the Nurse Scheduling Problem (NSP). We reduce the NSP as a CSP, then using backtracking NSP can easily be solved. A CSP is considered as a 3 – tuple, (X, D, C) , where X represents the set of variables, D represents the set of respective domains of the variables and C represents the set of constraints on variables.

There are two types of requirements for nurse scheduling problem - Allocation of nurses to OPDs/Wards and equal number of S1, S2, S3 and GD to nursing staffs. We assume that GD are for OPDs only. The total shifts in a week are as under:

1. S1 – 7 per week
2. S2 – 7 per week
3. S3 – 7 per week
4. GD – 6 (Sundays are off for OPDs) per week

So, in total there are 21 shift duties per ward and 6 GD per OPD. If there are “X” number of wards (wards include general wards, special wards, OTs etc.) and “Y” number of OPDs then in a week there are $(21X + 6Y)$ shifts that needed to be allotted with nurses.

The working hours for the Hospital = $8(21X + 6Y)$ hours per week

Requirement of Nursing staff = $8(21X + 6Y)/40$ nurses = k nurses

What we want is to fill the following three types of tables. The first table provides the detail of engagement of a particular nurse N1 for a week. The entries in the table are the ward which is being allotted to the nurse in a particular shift in a particular day.

Nurse – N ₁	GD	S1	S2	S3
Monday				
Tuesday				
Wednesday				
Thursday				
Friday				
Saturday				
Sunday				

Output Table 1

The second table provides the details of assignment of nurses in a particular ward say W1. The entries in the table are the name of nurses in a particular day in a particular shift.

Ward – W ₁	S1	S2	S3
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			
Sunday			

Output Table 2

The third table provides the detail of engagement of nurses to various OPDs.

Ward – W ₁	OPD ₁	OPD ₂	---	OPD _Y
			-	
Monday				
Tuesday				
Wednesday				
Thursday				
Friday				
Saturday				
Sunday				

Output Table 3

We get the following tables as our database from which scheduling requirements will be considered.

Input Table 1: Contains details of each nursing staff

Serial Number	Name of Nursing Staff	Type of Nurse (ANM/GNM/Graduate/Master)	Seniority (CNO/NS/DNS/ANS/SNO/NO)	Code
1	N ₁	ANM	NO	1-ANM-NO
2	N ₂	GNM	NO	2-GNM-NO
...

Input Table 1

Coding Scheme: Serial-Type-Seniority

Input Table 2: Contains details of OPDs

Serial Number	1	2	...
Name of OPD	OPD ₁	OPD ₂	...

General/ Special	General	Special	...
Type of Nursing Requirement (ANM/GNM/Graduate/Master)	ANM	Graduate	...
Number of Required Nurses	2-ANM	1- Graduate, 2-ANM	...
Number of senior nursing staff	1-SNO	-	
Code	O1- GEN- ANM-2- SNO-1	O2-SPE- G-1- ANM-2	...

Input Table 2

Input Table 3: Contains details of Wards/OTs:

Serial Number	1	2	...
Name of WARD	W ₁	W ₂	...
General/ Special	General	Special	...
Type of Nursing Requirement (ANM/GNM/Graduate/Master)	ANM, GNM	ANM, Graduate	...

Number of Required Nurses	3- ANM, 2- GNM	1- Graduate, 2- ANM	...
Number of senior nursing staff	4- SNO, 1-ANS	-	
Code	W1- GEN- ANM- 3- GNM- 2- SNO- 4- ANS-1	W2- SPL-G- 1-ANM- 2	...

Input Table 3

Coding Scheme: (ward/OT/OPD number) - (GEN/SPL) - (nursing requirements).

For each ward/OT, the shift timings are coded as under: These tables are auto generated.

Ward/OT – W1/O1	S1	S2	S3
Monday	W1-1-1- ANM-3- GNM-2- SNO-4- ANS-1	W1-1-2- ANM-3- GNM-2- SNO-4- ANS-1	W1-1-3- ANM-3- GNM-2- SNO-4- ANS-1
Tuesday	W1-2-1- ANM-3- GNM-2- SNO-4- ANS-1	W1-2-2- ANM-3- GNM-2- SNO-4- ANS-1	W1-2-3- ANM-3- GNM-2- SNO-4- ANS-1
Wednesday	W1-3-1- ANM-3- GNM-2- SNO-4- ANS-1	W1-3-2- ANM-3- GNM-2- SNO-4- ANS-1	W1-3-3- ANM-3- GNM-2- SNO-4- ANS-1
Thursday	W1-4-1- ANM-3- GNM-2- SNO-4- ANS-1	W1-4-2- ANM-3- GNM-2- SNO-4- ANS-1	W1-4-3- ANM-3- GNM-2- SNO-4- ANS-1

Friday	W1-5-1- ANM-3- GNM-2- SNO-4- ANS-1	W1-5-2- ANM-3- GNM-2- SNO-4- ANS-1	W1-5-3- ANM-3- GNM-2- SNO-4- ANS-1
Saturday	W1-6-1- ANM-3- GNM-2- SNO-4- ANS-1	W1-6-2- ANM-3- GNM-2- SNO-4- ANS-1	W1-6-3- ANM-3- GNM-2- SNO-4- ANS-1
Sunday	W1-7-1- ANM-3- GNM-2- SNO-4- ANS-1	W1-7-2- ANM-3- GNM-2- SNO-4- ANS-1	W1-7-3- ANM-3- GNM-2- SNO-4- ANS-1

Table of timeslot codes of a ward

Coding Scheme: (Ward Number)-(day number)-(shift number)-(nursing requirement)

For each OPD, the GD timings are coded as under:

OPD – O1	S1
Monday	O1-1-1
Tuesday	O1-2-1
Wednesday	O1-3-1
Thursday	O1-4-1
Friday	O1-5-1
Saturday	O1-6-1
Sunday	O1-7-1

Table of timeslot codes of an OPD

Scheduling Strategy:

Since OPD time slots and ward/OT timeslots are to be assigned to nursing staffs so these timeslot codes are the values that needed to be assigned to nursing staffs. The OPDs and Wards/OTs different timeslots require a nurse to be assigned to them. So, nurse codes are the values for these Timeslots. It looks like it is a bijection from the set of timeslots to the set of nursing staffs, but it is not, as one nurse code can be assigned to more than one OPD or ward/OT timeslots.

Scheduling of nurses to the Wards/OTs and OPDs is of prime concern. So, Wards/OTs and OPDs

timeslots are the variables whose values are the nursing staff codes that needed to be assigned such that the scheduling constraints are satisfied. We assume that the timeslots can hold up to the number of requisite numbers of nurse codes and nurse codes can hold requisite number of timeslot codes. If all the Wards/OTs and OPDs timeslots gets their required number of the nursing staffs then the task of scheduling is completed.

Scheduling Constraints:

1. Each timeslot should get requisite number of nurses.
2. If more than one nurse is required at some timeslot, then one nurse code must be unique in the nurse codes allotted to the time slot.
3. Domain specific nurse needed to be allotted to specific timeslot.
4. A nursing staff is assigned less than or equal to 5 timeslots per week (which is 40 hours per week as a time slot is of 8 hours each).
5. One nurse cannot be allowed to do more than two consecutive duties.
6. Adequate number of senior nursing staffs be assigned with respect to junior nursing staffs allotted in a particular timeslot.

4. The scheduling model

Variables: There are two types of variables, namely timeslot variable and nurse code variables. If there are m number of total timeslots then there are m timeslot variables and if there are k number of nurses then there are k number of nurse variables. We create timeslot class and nurse class with the following specifications:

Timeslot Class: Object of timeslot class are instantiated with timeslot codes. As there are m number of timeslots, so m objects of timeslot class are to be created. Specification of timeslot class is as under:

Integer assignedLevel=0;	Do the instantiated object is assigned or not?
Integer requiredNurses;	Contains number of nurses

	required in this timeslot.
String NurseCodes[requiredNurses];	Array of NurseCodes to store allotted nurse codes.
Set and get functions for members of the class;	Use to set and get values of variables and functions of the class.

Timeslot class specification

Nurse Class: Object of nurse class are instantiated with nurse codes. As there are k number of nurses, k number of objects is to be created with nurse class. The specification of nurse class is as under:

Integer assignedLevel=0;	Do the instantiated object is assigned or not?
Integer requiredTimeslots;	Contains number of timeslots required to be allotted to the nurse.
String TimeslotCodes[requiredNurses];	Array of timeslotCodes to store allotted timeslot codes.
Set and get functions for members of the class;	Use to set and get values of variables and functions of the class.

Nurse class specification

Domains for the variables: Set of nurse codes is the common domain for timeslot variables and set of timeslot codes is the common domain for the nurse variables.

Two sets, Unassigned and assigned is to manage for both timeslot codes and nurse codes. Initially all the timeslot codes are in unassigned set as well as all the nurse codes are in another unassigned set. Once the quota of a timeslot or nurse codes are fulfilled, it is being removed from the set of unassigned to the set of their respective assigned set. When the set of unassigned set of timeslots is completed satisfying all the constraints, then the scheduler provides a solution of the NSP. Otherwise, the NSP is not solvable.

Constraints:

1. All assignment of string NurseCodes array in timeslot objects are to be made.
2. Domain specific nurse requirement must be made. For example, if ANM are required then we must choose nurse codes from ANM.
3. Nurse code is not repeated in the NurseCodes array of timeslot object. So, before assigning any nursecode to timeslot object, it is to be checked that whether the nursecode is already present in the nursecode array of the timeslot object or not?
4. Once a nursecode is choose to be allotted to a timeslot code then first, the timeslot code to which it is to be allotted, must be assigned to the nursecode object. At the same time, it is to verified that whether the nurse quota of timeslot is completed or not? Is its quota of timeslots is completed then it is to be removed from the set of unassigned nurse codes.
5. While choosing a nursecode from the unassigned set of nurse codes, it is to verify that the timeslot for which it is to be chosen must not be third consecutive shift for the same day. For this, suppose if a timeslot W1-6-2-ANM-3-GNM-2-SNO-4-ANS-1 is to be assigned to a nurse then the difference between first three component of this timeslot and first three component of any other timeslots that is already allotted to the nurse code must be less than two.
6. If a nurse is being considered for allotment, then its seniority would be checked with the requirement of the wards for which it is considered. A counter is maintained for number of senior and junior Nursing staffs.

5. Conclusion

The scheduling model presented here is robust and can be implemented in any hospital. The transformation of NSP into CSP is done with the care that the constraints that appeared, will be of unary in nature. Also, the model helps to provide schedule for both nurses as well as wards, which is tedious if only one schedule is available. The model lacks management of off days to nursing staffs but that can be done with addition of more constraints and adding extra nursing staff to accommodate the off days.

This scheduling design's ease of implementation in any object-oriented programming language is one of its main benefits. With a few small adjustments, any hospital in India may employ the concept.

To further cut down on the amount of time needed to find a workable solution, heuristics like local search, hill climbing, or ant colony optimization may be added in the future.

6. Competing Interests

No competing interests.

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