AUTOMATED SYSTEM FOR NURSE SHEDULING USING GRAPH COLORING

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Abstract

The research work presented in this paper aims to provide effective method for solving Nurse scheduling problem (NSP) by satisfying the nurses, patients and hospital requirements. NSP is a major problem faced by many hospitals all over the world. That is a subclass of scheduling problems that are hard to solve. After analyzing the existing method, it was revealed that there are many drawbacks in the method. The goal is to produce automated system which is using for the creation of a monthly nurse roster. To minimize the complexity of the problem graph coloring techniques was applied.

Keywords: *NR- Nurse Roster, NSP-Nurse Scheduling Problem*

1. Introduction

In any Organization that operates continuously, daily work is divided into shifts to minimize the complexity and to carry on the work in an easy manner. In such a context, the scheduling problem consists in assigning a schedule to each worker, which involves building a timetable for a specified period. Scheduling can be thought of as a decision making process which involves the allocation of limited resources to tasks over time. One of the definitions of scheduling is given by Wren[1], who stated that "Scheduling is the arrangement of objects into pattern in time or space in such a way that some goals are achieved, or nearly achieved". Wren has been described about the rostering problem also. Rostering is the placing of resources into slots in a pattern. Hospital is one example for above mentioned type of organization. In a hospital there are various kinds of employers like doctors, nurses, attendants, etc. and they must assign to shifts to do their work. In this study mainly considered about the nurse shifts which is given for nurses named as nurse roster.

Hospital care units must provide twenty four hour nursing coverage at levels to match patient demand while adhering to organizational policies designed to protect the health and welfare of patients and staff. The already difficult scheduling problem is further compounded by a shortage of nurses. The schedule has to determine the day-to-day shift assignments of each nurse for a specified period of time in a way that satisfies the given requirements as much as possible, taking into account the wishes of nurses as closely as possible.

2. Problem Definition

Scheduling nurses to staff shifts is usually made by a head or chief nurse by manually in Sri Lanka. Head nurse has the responsibility to construct the nurse roster by monthly and should be published before the new month. Head nurse initiate the nurse roster for the next month by close to fifteenth of the current month. Manual made table is used by the head nurse with days of month along the columns and, in the rows all nurses names. Shift types are hospital tasks with a well-defined start and end time. The hospital management can set

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the details of the shift types in order to make them match the activities. Conventionally a nurse can work three shifts because nursing is shift work: Morning shift - Form 7.00 am to 1.00pm, Evening shift - Form 1.00pm to 7.00pm and Night shift - Form 7.00 pm to 7.00am. The responsible person whom we considered as head nurse will fill the table with **due- nights** for each and every nurse. This is normally filled by identifying a pattern among the number of nurses and the required number of nurses. After the night shift the following day is the awaiting **day-off.** Other than these day-offs the number of Sundays in a month is also giving as leave for each nurse. Head nurse is trying to assign more OT for nurses to get rid of the conflicts in the nurse roster. Anyone can have mutual exchanges in these OT under some constraints in the hospital. To properly care for patients, each shift requires the right number of nurses and a nursing staff with the right combination of healthcare skills. Budgets are a vital concern, where staffing requirements must always be weighed against budgets. But this is the minimum satisfied point when preparing the nurse-roster. But OT rates cannot be over reached the basic of each individual. And working too much overtime makes for an overworked staff that is more prone to error. Need to put the concentration whether staff members are happy with the scheduling process. Process should provide the flexibility that the staff need.

In Patient perception how sick patients are and how much care they need is another important consideration. On a ward with patients who require complex treatments, patients' needs can vary greatly depending on how sick they become; more nurses may be needed at different times, and scheduling becomes still more complicated.

In this problem head nurse is searching for a solution satisfying as many wishes as possible while not compromising the needs of the hospital also. Some examples of constraints are:

- A nurse doesn't work the morning shift, evening shift and night shift on the same day
- A nurse may go on a holiday and will not work shifts during this time
- A nurse doesn't work the next day after a night shift
- Minimum/Maximum number of successive days
- Minimum/Maximum number of hours worked
- Minimum/Maximum number of successive free days
- Maximum number of assignments per day of the week
- Maximum number of assignments for each shift type
- Maximum number of a shift type per week
- Assign identical shift types during the weekend
- Balancing the workload among personnel

By considering all these stuff head nurse is preparing the roster. But in some situations need to talk with the other nurses because conflicts are occurring. For an example same day has been requested as a leave by more nurses. So head nurse will request for someone not urgent to change the leave for another day. Head nurse continue with the roster while assigning the morning and evening shifts. In these two shifts personal requests of the nurses is concerned in less manner. Generally same shift is continuously allocated maximally for about three times. Also number of nurses for each shift should be considered in the preparation of the schedule. But these constraints will be taken into less awareness according to the completeness of the nurse roster. Below table 1 is a part of nurse-roster that shows the continuation of the same shift. Columns are the days of the month and the rows are the names of the nurses. In this chart in front of the name head nurse has been specified whether the individual is a senior or junior nurse. N is denoting night shift, M for morning shift, E for evening shift and DO for day-off for the night shift.

Table 1. Sample table in manual nurse roster

	1	2	3	4	5	6	7	8	9
Nimala-S	N	DO	M	M	M	E	E	N	DO
Kamala-S	E	N	DO	E	E	M	M	M	N
Aruni-J	N	DO	M	M	M	E	E	N	DO
Amali-J	M	N	DO	E	E	M	M	M	N
Chathu-J	M	M	N	DO	E	E	E	M	M
Sulo-S	E	E	E	N	DO	M	M	M	E

Making sure that each shift is properly staffed is one of the hardest challenges that head nurse face. In general, staff members prefer to have more input and flexibility in their scheduling, but the more flexible scheduling is, the harder it is for a head nurse to supervise scheduling and make sure that the unit is correctly staffed. According to the above reasons manual way of making the nurse roster is really a trouble for the head nurse as well as result of the roster is highly affecting nurses as well as for the patients.

3. Methods and Materials

As described in above, to solve NSP need to assign nurses into shifts. In the proposed solution for the NSP, first divided nurses into shift groups and then nurses in one shift group were assigned to one shift. When creating the shifts, nurses from those different shift groups were not jointly used for a one shift. This is a kind of scheduling problem. Major problem of scheduling problem is allocation of recourses in an effective way. Graph coloring has been used in creating the shift groups

Because of NSP is a CSP, constraints analysis is very important in solving this problem. During the requirements analysis several constraints were identified. After analyzing those constraints, divided them into two groups according to the affect of those constraints to the final solution. Violating of some constraints will be affected to the solution directly and violating of some constraints will be affected to the quality of the solution. Similar to other studies which were carried out to solve NSP, in here also two groups were named as Hard Constraints and Soft Constraint. Hard constraints are the constraints, which must be satisfied to get feasible solution for use in practice and Soft constraints the constraints, which are used to evaluate the quality of the solution. So SC are not compulsory but are desired to be satisfied as much as possible.

3.1 Applying graph theory for the NSP

To solve most scheduling problem Graph Theory was used. In scheduling problem Graph coloring in Graph theory can use to avoid conflicts and to allocate resources effectively.

In this problem when considering the constraints, nurses with different skills levels can be in same shift. But only the junior or senior nurses can't be in same shift. And also there some nurses, they don't like to work together. So they must put in to different groups. Sometimes hospital management also wants to put some nurses in to different shifts to create high quality roster. As well as when creating the roster patients requirements also have to consider. They also may ask to put some nurses in to different shifts.

To solve NSP, ward with fifteen nurses were considered. They were named as N1,N2,N3, ….. , N15. Considering seniority most senior three nurses were put into a one group called a. Then most junior three nurses were put in to another group called c. Like that by considering nurse requirements, hospital management requirements, patients requirements, etc; nurses were grouped as following table 2 given below.

Table 2. Example for the groups

Group	Nurses
a	N1,N3,N4
c	N6,N15,N8
d	N14,N15
e	N14,N1
f	N14,N9

By using above data a matrix was created for the nurses. It was a 15 X 15 matrix. In that matrix nurse's names take as i and j .Then ij-th entry is put according to the above table 2, If any two nurses are in same group, then ij-th entry is put as '1' otherwise put it as '0'. Following figure 1 shows the relevant matrix.

	$N1$	$N2$	$N3$	$N4$	$N5$	$N6$	$N7$	$N8$	$N9$	$N10$	$N11$	$N12$	$N13$	$N14$	$N15$
$N1$	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0
$N2$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$N3$	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
$N4$	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
$N5$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$N6$	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
$N7$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$N8$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
$N9$	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
$N10$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$N11$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$N12$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$N13$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$N14$	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1
$N15$	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0

Fig: 1. Adjacency matrix for the nurses

Using above matrix, a graph was constructed by taking nurses as vertices. If two nurses are in same group according to the above table 2 corresponding vertices are combine using edges. According to the graph theory above matrix can named as adjacency matrix. It is a **n x n** matrix whose ij-th entry is the number of edges joining vertex i and vertex j. As the next part vertices in graph were colored. If two vertices are adjacent, they were colored using two different colors. Below figure 2 shows the resulting graph.

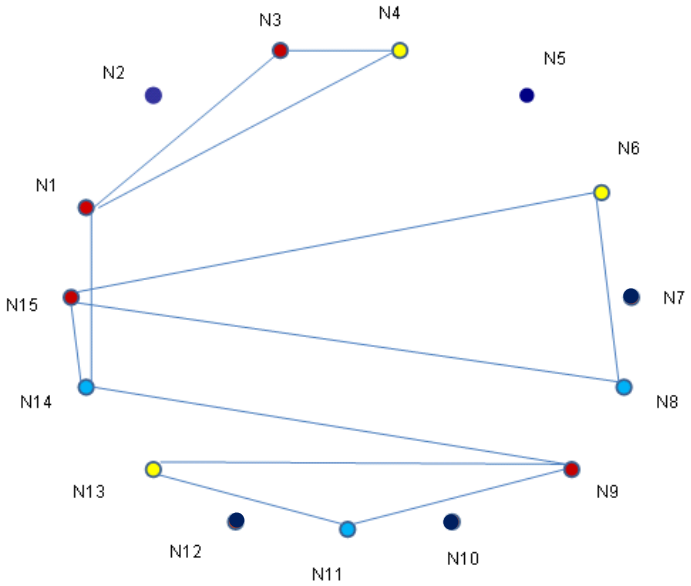


Fig: 2 Colored Graph

Then using vertices colors again nurses were grouped. In grouping, nurses with same color were put in to one group. Normally in graph coloring if any vertices were not adjacent with any other vertices, as an example here N2 and N5, it is colored using existing color. That is using another vertices color in the graph that has

already colored. But in this study those are also colored using a new color and put them into to a different group called bench group (B). Following table 3 shows the group details after applying the graph coloring techniques.

Table 3. Nurse's group after applying graph coloring

Group	Nurses
G1	N3,N9,N15,N1
G2	N14,N11,N8
G3	N13,N4,N6
Bench(B)	N2,N5,N5,N10,N12,N7

According to the above table 3 Nurses in group G1, G2 and G3 could be in same shift only if they are in same group. That's mean N3 and N9 can be in same shift and can work together because N3 and N9 are members of same group G1. But N3 and N11 can't work together because they are in different groups G1 and G2. To be presented in the same shift, nurses must be in same group otherwise some constraints may be violated. But there is special group; Bench group or group B. Members in group B has special facility. They can work together with any nurses in any group. There is no any restriction. So members in group B can work in any shift with anyone.

3.2 Programming Language and Algorithms

To construct shift groups for the nurses following algorithm was used.

Get word_number from the user
Retire matched word_number array according to the word_number
Get size of the array array_size_word_No
Find the square root of array_size_word_No to sq(array_size_word_No)

```
I=0
Do {
        Create new variable call nurse
        Nurse = I
        Construct one way array call new
        J=0
        Do{

                k=0
                Do{
                        If(element of J^th position of word_number array ==1 )
                                k^th position of new array =J

                 next k
                } Until k = array_size_word_No


        Go to next J
        } Until J = sq(array_size_word_No)

        Group =1
        Do {
                Take group array
                Take intercept between group array and new array
                If (group ∩new == NULL)
                        Assign I element to group array
```

```
        Else
                Go to next group
        } Until group = 8

Go to next I
}Until I = sq(array_size_word_No)
```

After groups have been created, following algorithm was used to assign the night shift for the nurses.

```
Start EMPTY_NURSE_NO_Day :

        Create new variable -both- {emptyi – integer & emptyj - integer}

        Take i=0 and j=0

        Do {
                Do {
                        If (i^th j^th position of NURSESSHIFTS array == NULL )
                        {
                                both.emptyi=i
                                both.emptyj=j
                                return both
                                break loop
                        }
                        Else
                                Go to next j
                } until j=9
                                Go to next i
        } until i =29

End EMPTY_NURSE_NO_Day :

Start SEARCH_ PREVIOUS-DAY :

        Take the values send from main in to previousDay , Nurse

        Take i=0 & found =0

        Do{
                If (i^th previousDay^th position of NURSESSHIFTS array == Nurse)
                        found=1
                Next i
        } until i=9

        Return found

End SEARCH_ SAME_DAY :

Take the values send from main in to sameDay

        Take i=0 & sum =0
```

Do{
If (i^{th} sameDayth position of NURSESSHIFTS array != NULL)
sum=sum+1
Next i
} until i=9

Return sum

End SEARCH_SAME_DAY :

Start FIND_GROUP :

Take the values send from main in to symbol
Take i=0

Do{
If (i^{th} position's Nurse_No of CATEGORY array == symbol)
Return CATEGORY.Group_Symbol

Next i
} until i=9

End FIND_GROUP :

Start MACH_WITH_OTHERS :
Take the values send from main in to currentDay

Take i=0

Do{
If (i^{th} position's Nurse_No of CATEGORY array == ithcurrentDayth position of NURSESSHIFTS array)
Return CATEGORY.Group_Symbol
Else
Return N

Next i
} until i=9

End MACH_WITH_OTHERS :

Start MAIN :

Create 2 way integer array {NURSESSHIFTS / column – nurses_No & row - day}
Create new variable –group- {nurse_No – Integer Group_Symbol - characters }
Create one way –group- array {CATEGORY}

Assign one of the nurses for $0^{th}0^{th}$ position of NURSESSHIFTS array randomly.

n=0 & d=0

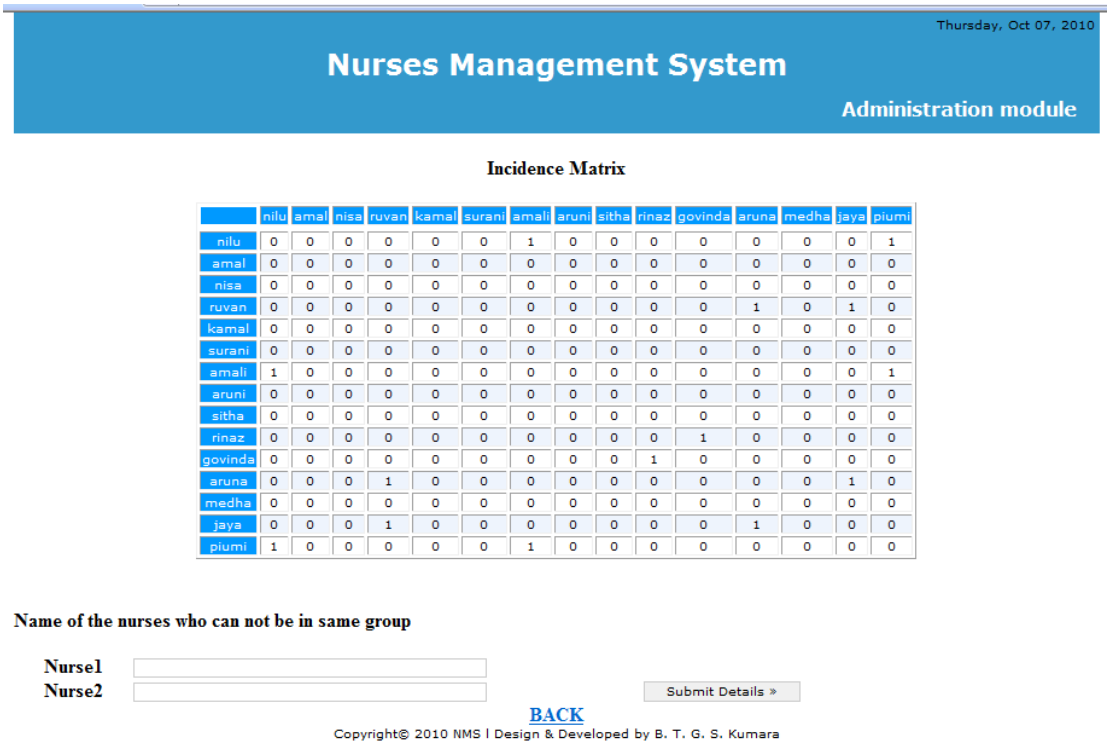
```
Do{
        Do {

Go Label EMPTY_NURSE_NO
NurseNO= return from the EMPTY_NURSE_NO (both.emptyi)
Day= return from the EMPTY_NURSE_NO (both.emptyj)

Send (Day -1) and NurseNO to Label SEARCH_ PREVIOUS-DAY
numberOfDay = return from the SEARCH_ PREVIOUS-DAY (found)

if (found ==1)
        go to next n
else
        Send Day to label SEARCH_SAME_DAY
        NursesPerDay = return from the SEARCH_SAME_DAY
        If (NursesPerDay >=2)
                Go to next d
        Else
                Send NurseNO to label FIND_GROUP
                Group= return from the FIND_GROUP
                Send Day to label MACH_WITH_OTHERS :
                storedNurse= return from the MACH_WITH_OTHERS :
                if (Group ==storedNurse )
                        assign n^th d^th slot as 1
                else if (storedNurse==”N”)
                        assign n^th d^th slot as 1
                else if(storedNurse=E)
                        assign n^th d^th slot as 1
                else if(Group=E)
                        assign n^th d^th slot as 1

                go to next n
 } until n=9
                Go to next d
} until d=29

End MAIN :
```

As the programming language PHP was used. As backend MySQL was used. MySQL is an open source and it is a relational database management system. Because of this system is web a based system , to manage access to files, folders and other resources and to handle permission, execute program, keep track of directories and files and communicate with client web server is needed. Most popular Apache web server was used as the web server.

4. Results

Proposed system was run on 1.2 GHz system with 256 MB RAM and windows 2000 operating system and core 2 Duo 2.8 GHz system with 2GB RAM and windows vista operating system. Output was a feasible NR.

This study was basically divided into two major parts. As the first part, division of nurses into shift groups using graph theory was completed. An algorithm was implemented to create NR in the second part. In graph theory part, first adjacency matrix was created for data of fifteen nurses. Following figure 3 shows the resulting adjacency matrix.



	nilu	amal	nisa	ruvan	kamal	surani	amali	aruni	sitha	rinaz	govinda	aruna	medha	jaya	piumi
nilu	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
amal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nisa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ruvan	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
kamal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
surani	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
amali	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
aruni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
sitha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
rinaz	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
govinda	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
aruna	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
medha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
jaya	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
piumi	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Fig: 3. System Interface-adjacency matrixes

After creating the matrix, divided nurses into shift groups using grouping algorithm. That algorithm was given the best result in the study. Following figure 4 shows the system interface relevant to nurse groups.

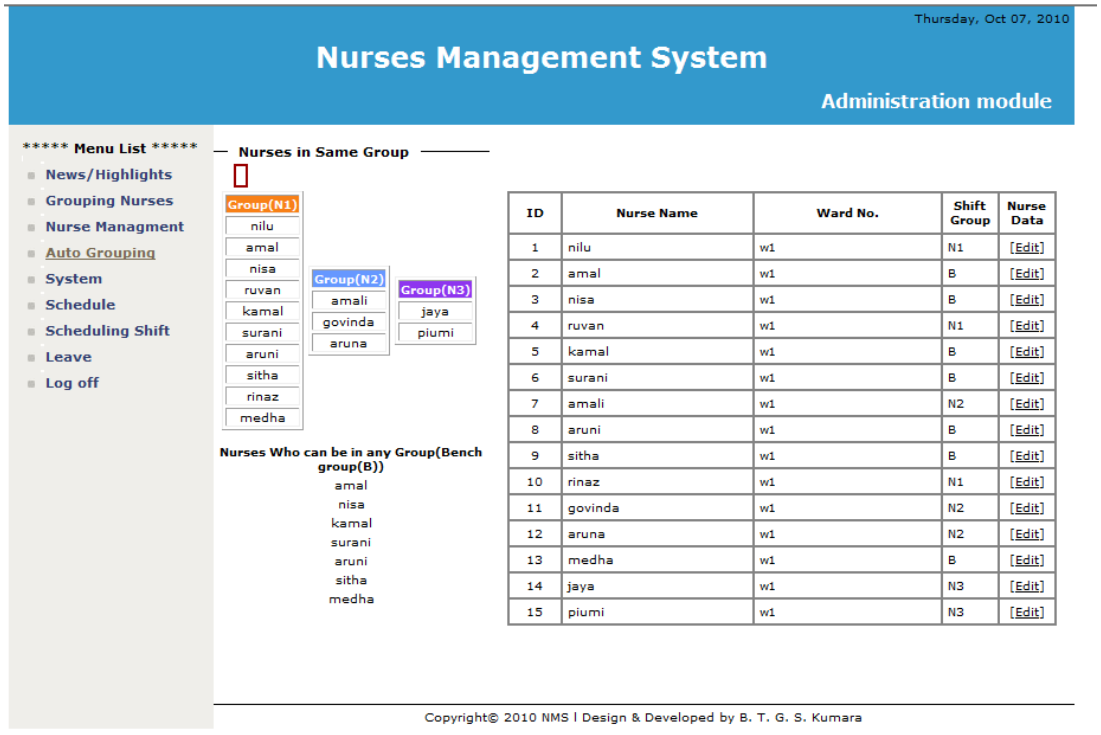
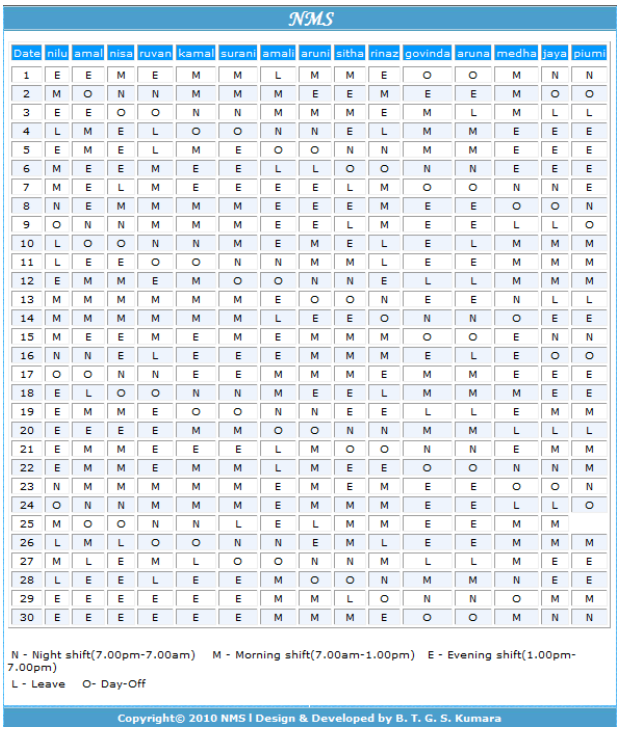


Fig: 4. System interface - nurses groups

After creating the shift groups, first part of the study was finished. Because of this shift groups when assigning the shift to the nurses some constraints will not be violated.

Following figure 5 shows the resulting interface of the system after creating the nurse scheduling timetable for first 19 days of the month.



NMS

Date	nilu	amal	nisa	ruvan	kamal	surani	amali	aruni	sitha	rinaz	govinda	aruna	medha	jaya	piumi
1	E	E	M	E	M	M	L	M	M	E	O	O	M	N	N
2	M	O	N	N	M	M	M	E	E	M	E	E	M	O	O
3	E	E	O	O	N	N	M	M	M	E	M	L	M	L	L
4	L	M	E	L	O	O	N	N	E	L	M	M	E	E	E
5	E	M	E	L	M	E	O	O	N	N	M	M	E	E	E
6	M	E	E	M	E	E	L	L	O	O	N	N	E	E	E
7	M	E	L	M	E	E	E	E	L	M	O	O	N	N	E
8	N	E	M	M	M	M	E	E	E	M	E	E	O	O	N
9	O	N	N	M	M	M	E	E	L	M	E	E	L	L	O
10	L	O	O	N	N	M	E	M	E	L	E	L	M	M	M
11	L	E	E	O	O	N	N	M	M	L	E	E	M	M	M
12	E	M	M	E	M	O	O	N	N	E	L	L	M	M	M
13	M	M	M	M	M	M	E	O	O	N	E	E	N	L	L
14	M	M	M	M	M	M	L	E	E	O	N	N	O	E	E
15	M	E	E	M	E	M	E	M	M	M	O	O	E	N	N
16	N	N	E	L	E	E	E	M	M	M	E	L	E	O	O
17	O	O	N	N	E	E	M	M	M	E	M	M	E	E	E
18	E	L	O	O	N	N	M	E	E	L	M	M	M	E	E
19	E	M	M	E	O	O	N	N	E	E	L	L	E	M	M
20	E	E	E	E	M	M	O	O	N	N	M	M	L	L	L
21	E	M	M	E	E	E	L	M	O	O	N	N	E	M	M
22	E	M	M	E	M	M	L	M	E	E	O	O	N	N	M
23	N	M	M	M	M	M	E	M	E	M	E	E	O	O	N
24	O	N	N	M	M	M	E	M	M	M	E	E	L	L	O
25	M	O	O	N	N	L	E	L	M	M	E	E	M	M	
26	L	M	L	O	O	N	N	E	M	L	E	E	M	M	M
27	M	L	E	M	L	O	O	N	N	M	L	L	M	E	E
28	L	E	E	L	E	E	M	O	O	N	M	M	N	E	E
29	E	E	E	E	E	E	M	M	L	O	N	N	O	M	M
30	E	E	E	E	E	E	M	M	M	E	O	O	M	N	N

N - Night shift(7.00pm-7.00am) M - Morning shift(7.00am-1.00pm) E - Evening shift(1.00pm-7.00pm)
L - Leave O- Day-Off

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Fig: 5. Nurse Roster

5. Conclusions

When consider the NSP it is a real world problem. And also it is a very complex problem with so many constrains. When solving NSP in this study it is not considered about all the soft constraints. But all the hard constraints were considered. So results show a feasible solution for the problem. That means this study ends with a solution, which can be used in real world.

By using graph coloring could reduce the complexity of the NSP problem. So applying graph coloring for the problem like NSP can get better solution.

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