2011 International Conference on Information and Electronics Engineering
IPCSIT vol.6 (2011) © (2011) IACSIT Press, Singapore

Innovative Neighbor Generations In Tabu Search Technique For A Nurse Rostering Problem

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Abstract. The problem of rostering nurses to shift duties and off days with several hard organizational and soft preferences constraints was studied. Many previous studies have been carried out to solve similar problems but there is no one solution technique that can be considered as the best. Thus, the study explores the use of Tabu Search (TS) technique to solve a particular nurse rostering problem (NRP). A TS algorithm with special representation and innovative neighborhood generations was constructed. Two variations of the neighbor were introduced. The solution is in the form of work schedule or roster which is able to assign effective and efficient shift duties.

Keywords: artificial intelligence, tabu search heuristics, nurse rostering problem, manpower scheduling

1. Introduction

Nurse rostering or the scheduling process is in essence the allocation of nurses to execute nursing services per shift and per day in a certain duration of time. Through this rostering, nursing services can work out as anticipated. [1] stated that the nurse scheduling problem (NSP) or nurse rostering problem (NRP) consists of assigning varying shift types to hospital personnel with different skills and at the same time, considering certain work regulations. The nurse roster must ensure that there are enough nurses working at all times that is, 24 hours a day and seven days a week.

Nursing is a high risk job due to its difficulties, tiring nature, and also because it involves patients safety and health care. The current working schedules of nurses are not just inconvenient with long work stretches, but also with improper allocation of days off that disturb family and social lives. Thus, the assigning of nursing staff to shift duties is a crucial task in a hospital management.

Most hospital wards have head nurses or nurse managers, who are regularly responsible for constructing nurse schedules, which usually are manually done. Nurse managers usually spend a substantial amount of time developing schedules, especially when there are many requests. There is even much time consumed in handling the ad hoc changes to current duty rosters [2]. Thus, manual procedures turn out to be inefficient because it requires a large amount of effort and hence, a time-consuming task.

Nurse scheduling needs to fulfill many objectives including hard and soft constraints. Hard constraints must be respected at all costs while soft ones are only desirable [3]. Hard constraints that must be satisfied are such as mandatory workdays constraints, ordering constraints and night shift constraints. At the same time soft constraints such as individual nurse preferences and special requests are considered as much as possible. This is a way of providing job satisfaction to the nurses. Thus, this problem is complex and a challenging combinatorial problem, which is also known to be NP-hard.

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A number of studies ([2], [4], [5], [6], [7], [8], [9]) have been carried out previously to solve similar problems but there is no one solution technique that can be considered as the best [10]. Hence, this paper explores the problem and suggests a promising solution approach. It discusses how a Tabu Search (TS) approach is utilized. The TS is quite established because of its solution quality and its efficient algorithm [11]. Various cases that were explored, among others, consist of control mechanism for the tabu tenure of TS, objective function with the automatic control mechanism based on weight, and the enlargement of the search neighborhood [12].

In the following section, a nurse scheduling problem is briefly presented, with the objectives of the study. The TS procedure is described in Section 3, while Section 4 discusses the experimental result. Section 5 concludes the paper and outlines possibilities of further work.

2. The Nurse Rostering Problem

The main objective is to develop a scheduling model to solve a particular NRP, which satisfy all the hard constraints, and such that nurse preference regarding the days off is maximized. This nurse preference is considered as one of the soft constraints and is realized in the form of a sub-objective of the model. The sub-objective attempts to generate longer consecutive days off for each nurse in the roster. Another sub-objective is equivalent shifts assignment among nurses. The whole problem environment for the NRP is described through relevant hard and soft constraints as excerpted from [13] and are listed below.

2.1. Hard Constraints

The hard constraints must be satisfied at all costs.

1. As a general rule, nurses are required to work 6 days a week. That is the reason for the entitlement of one off day (WO) in each week.
2. Consecutive work days must not exceed 6 days and must not be less than 2 days. Hence, split of days off or single work day is disallowed.
3. There must be at least 3 nurses assigned for each shift type, for each nurse skill level on each day.
4. A nurse is allowed to work only one shift that is morning (M), evening (E) or night (N) shift in a day.
5. N shifts are assigned in blocks of 3 shifts according to turn and rotation.
6. Two days off (NO) must follow the third N shift of the block.
7. For each nurse, it is forbidden to have a formation of N-M shifts in any adjacent work shifts.
8. The assigning of shifts must respect the forward clockwise direction rule or circadian rhythm, i.e. the M→E→N.

2.2. Soft Constraints

The followings are soft constraints of the NRP that have been translated into specific statements. They are incorporated in the model and can be violated whenever situations do not permit.

1. Days off are strongly preferred to be consecutive in the arrangement.
2. In a stretch of six work days with no N shifts, it is preferred that the combination of M's and E's be four M's two E's, three M's three E's or two M's four E's. Therefore, the maximum number of M is two. It is vice versa with E. That is, $2 \leq M \leq 4$ and $2 \leq E \leq 4$.
3. Similarly, for 5 days work stretch the preferred combinations of M and E are $2 \leq M \leq 3$ and $2 \leq E \leq 3$.
4. It is also preferred that for a 4 days stretch, the combination be 2M's and 2E's.
5. For 2 and 3 days stretch, it is preferred that it either be 2M's or 2E's and 3M's or 3E's, respectively.
6. The total number of M and E shifts in a personal roster of the nurses (the row) should roughly be equivalent. The acceptable criteria is $((M + E) / 2) \pm (1 \text{ or } 2)$.

3. Tabu Search Methodology

Data for the modeling of the NRP is in terms of constraints regarding the problem environment as described in sections 2.1 and 2.2. Other information needed is the user input data before the model can generate solutions: i) total number of nurses in a particular ward or unit with the break up number for the senior and junior levels, ii) number of days needed to be scheduled, and iii) number of certain off-day being considered. A solution or roster for the NRP is represented in a 2-dimensional array or matrix of size *m* row for nurse by *n* column for day. The scheduling period is two weeks which, is normally practiced.

3.1. Fitness Function

The computation of fitness function incorporates the evaluation of both hard and soft constraints. Thus, the fitness function for the NRP model is given below.

$$f(s) = \sum_{k=1}^{t} w_k c_k(s) \quad \text{where,}$$

w_k penalty associated with constraint-type *k*

$c_k(s)$ number of constraint violation of type *k* in schedule, *s*

3.2. Tabu Search Architecture

A framework on the development of the TS for the NRP is given in Figure 1, which shows major tasks in the search for a solution. An initial feasible schedule is obtained heuristically satisfying all the hard constraints in the initialization of solution step.

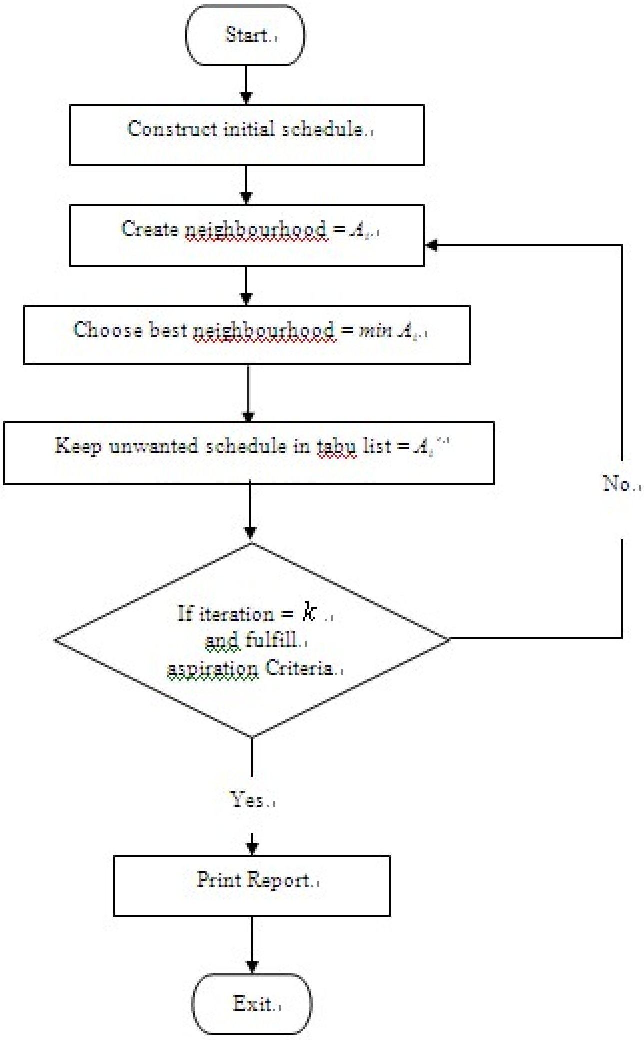

Fig. 1: TS development for the NRP

The next task is to create neighbor solutions. The third task is to generate the tabu list, which is just an empty list that will contain unwanted solutions created before. Tabu list keeps the search from revisiting the unwanted solutions in certain duration of time.

The fourth task is to choose the best-so-far solution in relative to the initial and other neighbor solutions. At this point, the current local optimum roster is replaced with the best-so-far roster. This procedure is repeated for a certain number of iterations as requested at the start of the process. After a certain duration of time, we introduce an aspiration function to check on the solutions in the tabu list if any can be "untabued". Another criterion for stopping the iterations that we adopt is when there is no improvement to the current local optimum roster in ten consecutive iterations.

3.3. Innovative Neighborhood Generation

In our study, we introduce special neighborhood generation methods which are considered as innovative and are utilized in the second task of the TS architecture mentioned above. Two different swapping heuristics specific to the NRP are suggested to generate two different neighbor solutions. The swapping heuristics are based on: (i) night shift pattern for nurses from different skill levels, and (ii) other work shifts pattern for different nurses.

In the first swapping heuristics w(l), two rows with same night shift patterns were identified with each one represents different skill levels, and then swapped. In the second heuristics w(p), work shifts pattern other than night with equivalent length in different rows were swapped.

4. Tabu Search Result

In the experiment, we started the search with an initial roster solution at fitness value 1230. The initial solution has been improved through the neighborhood generation process after a number of iterations. Until there is no more improvement at iteration 111, the 'best so far' roster is achieved with fitness value at 1040. The performance of the proposed TS technique is shown the graph as in Figure 2.

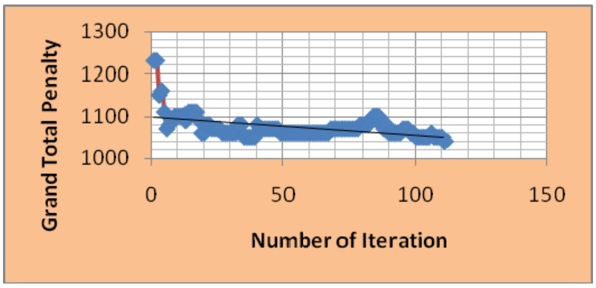

Fig. 2: Performance graph of the proposed TS technique

A sample of an effective and efficient roster satisfying all the hard constraints and fulfilling all the soft constraints as much as possible is exhibited in Table 1. In this case, the roster presents shift duties for day view in half of the scheduling period only.

Table 1. A Sample of an Effective and Efficient Roster

Nurse	Mon	Tue	Wed	Thu	Fri	Sat	Sun
m_1	N	N	N	NO	NO	WO	E
m_2	E	N	N	N	NO	NO	M
m_3	M	M	N	N	N	NO	NO

5. Conclusions

A prototype for the nurse rostering solution with the proposed TS methodology is established as part of the objective of the study. The adoption of the innovative neighbor generation heuristics has helped in the diversification of solution search. The rostering process took a short time to generate effective and efficient rosters satisfying both hard and soft constraints relevant to the problem. The prototype is able to fulfill circadian rhythm ordering when generating rosters thus, satisfying the body clock requirement which helps to avoid body fatigue. Another ability of the prototype is to schedule shift work within the policy day limit which in turn promotes fairness to nurses.

The prototype can be used to assist nurse managers in generating shift work rosters for nurses in a hospital unit. This systematic and computerized roster would certainly be able to help nurse managers in their time-consuming tasks. Consequently, they can use the time saved to do other important nursing duties. The rostering prototype is efficient and able to properly utilize the nursing manpower. Thus, it is able to minimize cost in term of idle staff. At the same time, nurse preference regarding longer rest periods could also be achieved. As a result, nurses would feel happy and satisfied with their jobs. Consequently, the increase of job satisfaction among nursing staff would give a great impact on health care quality as a whole. Overall, rosters produced through the proposed TS technique are of high quality and without bias. In this sense, it is certainly better than the manually constructed rosters.

6. Acknowledgement

The authors would like to thank the Ministry of Science, Technology and Innovation, Malaysia (MOSTI) which has partially funded this research and helps make it possible.

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