Iterated Local Search in Physician Scheduling problem

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Abstract

This paper presents how to solve Physician Scheduling at an Emergency Department over the real datasets of King Khalid University Hospital in Saudi Arabia. Due to the complexity of this problem, we propose Iterated Local Search that provides Physician schedules with improved efficiency and staff satisfaction. A comparison between proposed schedules and mathematical model shows on outperformance of the proposed one.

Keywords
Physician Scheduling, Iterated Local Search, A greedy algorithm, hard and soft constrain.

1. Introduction

Due to the continuously growing health care demands, health care is becoming increasingly expensive. A key issue for successful health care management is staff scheduling. The scheduling problem involves allocating suitably qualified staff to meet a time-dependent demand for different services. The problem of physician scheduling is one that affects most healthcare systems. So, building good work schedules can greatly influence physicians' working conditions, which is strongly reflected in the healthcare quality.

Emergency department (ER) is a very critical department in any hospital since it is the first line that faces emergency situations. Scheduling of ER stuff to handle patients' demands is highly required (Yang et al. 2009). ER is one of the most stressful place for physicians in hospitals. Thus, the quality as well as the efficiency of scheduling practices that at the same time matches economic needs, personnel's preferences and a higher level of care for the patients have a large contribution to the overall hospital performance. Unlike any other physicians, ED physicians do not determine, or control, the number of patients who are present for treatment. Preparing a schedule for physicians in the emergency department is a complex and time-consuming task, which requires taking into account a large number of rules, usually conflicting, respected to various aspects such as maximum number of consecutive shifts, night shifts and weekends rules, vacation periods, and physician's individual preferences. The problem is further complicated by such factors as: patient demand's variation, physician qualification and specialization, severity of patient illnesses, organizational characteristics (e.g., minimum required coverage and days off policies) and personal preferences and requests for vacations. In addition, some of these factors may conflict with others, such as physicians requests versus the need to balance workload.

The objectives in physician scheduling are multiple. These contain developing a methodical procedure for assigning physicians to work shifts and workdays ensuring a continuous and convenient service level of patient care, satisfying organizational scheduling policies such as specific work requirements while using minimum staffing to avoid wasted manpower, and satisfying appropriate physician preferences. Physician schedules are designed to ensure a reasonable fair for physicians. The most general form of a PSP can be described as: given a set of physicians, a set of shifts and a planning period, the scheduler seeks to maximize physicians' individual satisfaction through finding fair schedules for all physicians (Gendreau et al. 2007).

This papers is concerned with developing a Decision Support System (DSS) that provides optimized physician schedules for an Emergency Department (ED) at King Khalid University Hospital (KKUH). This automated tool will be designed using an Iterated Local Search (ILS) algorithm. This metaheuristic method is expected to provide good solutions within suitable computing time for physician scheduling problems.

This paper is organized as follows: section 2 presents literature review, section 3 presents the problem description and the related constraints of physician scheduling problems, section 3 presents the proposed algorithm used to solve the problem, experimental results and comparisons between manually schedules and our schedules are discussed in section 4 and conclusions are presented in section 5.

2. Literature review

To our knowledge, the main research on physician scheduling focused on a single type of duty, such as the emergency room (e.g (Beaulieu et al. 2000)) (M. Gendreau, J. Ferland, B. Gendron, N. Hail, B. Jaumard & Lapierre, G. Pesant 2007) (Puente et al. 2009)(Tontarski 2015) the operating room (e.g., (Testi et al. 2007) (Burke et al. 2004)) and the physiotherapy and rehabilitation services (e.g., (Ogulata et al. 2008)).

Several studies in the literature have utilized mathematical programming techniques to assist in finding efficient physician schedules. (Beaulieu et al. 2000) presented a mathematical programming technique for scheduling emergency room physicians over six-month, taking into consideration a large number of rules such night shifts and weekends. Their model can significantly reduce the time and the effort required to construct a six-month schedule. In addition, several techniques proposed by (M. Gendreau, J. Ferland, B. Gendron, N. Hail, B. Jaumard & Lapierre, G. Pesant 2007) (such as mathematical programming and constraint programming) to solve the physician scheduling problem in five different hospitals of the Montreal region. (Brunner et al. 2009) used mixed-integer program to develop model for flexible shift scheduling problem of physicians at a German university hospital to cover two week planning horizon.(Topaloglu 2006) used goal programming approach to model emergency medicine residents in a monthly planning horizon. This model is tested in the emergency room and the result showed that proposed model is capable of generating high-quality monthly schedules. The work in (Beliën 2007) presents some exact and heuristic methods for numerous scheduling problems encountered in hospitals. (Topaloglu 2009) proposed a multi-objective programming model for scheduling residents with different seniority levels. Accordingly, a monthly shift schedule is prepared to determine the shift duties of each resident considering shift coverage requirements, seniority-based workload rules, and resident work preferences.

(Carter & Lapierre 2001) introduced the problem of scheduling emergency room physicians. They used Tabu Search algorithm to minimize arising penalty costs in a cyclic schedule that violates fewer soft constraints compared to the one currently in use. According to (Gendreau et al. 2007), Tabu Search (TS) algorithm has been applied to the Physician scheduling problem as well as the nurse scheduling problem. Buzon 2001 applied Tabu search for physician scheduling. His model generated the cycle-schedule for physicians. In addition, they took into account the workload of each physician and his personal preferences. The algorithm spent around 3 hours of carputer time on a Sun Ultra '10 workstation to generate a good schedule. The period for this problem is 3 months and the number of staff is 22 physicians. (Rosocha et al. 2015) used Simulated Annealing (SA) to solve Emergency department scheduling problem. They dealt with two types of constrains: Hard and soft. Hard constrains are linked to legal and working regulation. Soft constraints were related to the quality of work, psychic, and work-life balance of staff. Moreover, nurses have been included in this schedule. The total number of staff at their department was around 60 physicians and nurses. They classified the level of doctors in three levels senior, novice, and intermediate. Fulfilling hard constraints were generated in the final schedule, while violation of soft constrains will be minimized. The monthly schedule has issued after 492 seconds (around 8 min) with best objective function value of 154 at iteration 403. Before this approach, the senior doctor has spent a few hours to issue a schedule.

While this literature review shows many related problems and solution approch, none of them focus on solving physician scheduling problems using Iterated Local Search (ILS). Thus, developing an efficient and effective DSS based on a ILS model is important to assess its competitiveness against the previous metaheuristics in terms of solution quality and computing time.

3. Problem Description

The KKUH Emergency Department provides emergency health services 24 hours a day. It has 3 an 8-hour shifts as follows: Morning shift (M) that starts at 7:30 and ends at 15:30, Afternoon shift (A) which starts at 15:30 and ends at 23:30, and Night shift (N) which starts at 23:30 and ends at 7:30.

The emergency department is currently composed of 23 physicians. Every single physician has to work a predefined number of 8-hour shifts each month. Physicians are classified into two types, based on the number of 8-hour shifts each month they take, as follows:

- Physicians type 1: 12 shifts of 8 hours each (96 hours)
- Physicians type 2: 13 to 15 shifts of 8 hours each (104 to 120 hours)

The number of physicians that is required depends on the shift type and the day (Ex. week-end). Currently, three physicians are required each morning shift while only 2 physicians are required in the week-end morning shifts. Two physicians are needed for each afternoon shift. Each night shift requires a minimum of 2 physicians, except the week-end night shifts which require only 1 physician.

At present, a physician manually produces the monthly schedules using an Excel sheet. He is spending one entire week each month to build the schedule.

3.1 Problem Constraints

There are a number of constraints on the problem that must be satisfied. These constraints can be split into hard and soft constraints, depending on whether they are essential or merely desirable, respectively.

- Hard Constraints that are generally related to hospital regulations and policies are listed below:
    1. Healthcare satisfaction by assigning to each shift of each day the least required number of physicians.
    2. High utilization of resources through assigning each physician the exact number of shifts he or she has to work.
    3. At most one shift per day per physician.
    4. At least 16 hours rest between two shifts.
    5. Night shifts are all assigned in successive days for each physician.
    6. Take into account the requested leaves.
    7. Each physician must have two weekends off during a month schedule.
    8. At most 5 afternoon or night shift per month per physician.
    9. At most 3 consecutive days on for each physician
- Soft Constraints which are related to physician goals and preferences:
    1. Minimum number of changes between shift types
    2. Satisfy requested days off.
    3. Satisfy requested morning shifts.
    4. Satisfy requested afternoon shifts.
    5. Satisfy requested night shifts.
    6. No separated days off.
    7. No separated days on.
    8. An equal number of weekends off for all physicians, except seniority reasons, or other priority rule.
    9. An equal number of night shifts for all physicians, except seniority reasons, or other priority rule.

4. Proposed method

This section describes our proposed iterated local search (ILS) algorithm for solving the Physician scheduling problems. ILS is a simple metaheuristic approach for solving combinatorial optimization problems. It helps a traditional Local Search method to avoid getting stuck in a local optimum by applying some simple modifications to it. The main elements of ILS are initial solution, perturbation, local search and acceptance criterion. In the following subsections, the main steps of our ILS proposed algorithm are described in detail.

4.1 Generating an initial solution

The quality of the local optima obtained by a local search method depends on the initial solution(Talbi, 2009). An initial solution may be specified randomly or by a given greedy heuristic. In this study, a greedy construction algorithm was used to generate the initial solution s_i by satisfying all hard constraints and the assignments of days were random. This process continues until a feasible solution is obtained. This procedure is repeated until all shifts are assigned, each day and each week. A general procedure for the greedy heuristic to generate initial solution is described in the following steps:

1- Set the order of days in random basis. The sort of solution will be sorted in random sequence.

2- Start to fill the N shifts by checking all hard constrains in each step

3- Avoid to fill 3 consecutive shift for any type of shifts

4- Check if each physician has at least two weekend off

5- Each physician must have two weekends off during a month

if N has fail to satisfy any hard constrain

Go back to set order

If N success

Do the same for A

Then do the same for M

End

4.2 Perturbation

The first motivation of the ILS algorithm is based on the fact that the perturbation method must be more effective than a random restart approach, where an independent initial solution is regenerated randomly. A perturbation mechanism is used to clear the assignment of shifts to some physician and to create a new feasible schedule. The perturbation step makes it possible to create a suitable new starting point for the local search and to get out of the local optimum. The number of physician whose schedule is cleared is chosen randomly, between 5 and 7. A number of 5 to 7 random swaps are performed in this step.

4.3 Local Search

As we can generate local optimum with high variability, iterated local search may be used to improve the quality of successive local optima (Ahuja, Orlin, & Sharma, 1998) . In this process, we use a swap between three physicians on randomly selected day to find a local optimal solution. A number of feasible solutions are obtained within a predefined time and select the best.

4.4 acceptance criterion

The acceptance criterion specifies the rules by which the new local optimum must satisfy to replace the current solution. It is used to control the intensification and the diversification search strategy. In the intensification search, the role is to accept only improving solutions in terms of the objective function. In the case of diversification, any solution will be accepted regardless of its quality.

To validate whether the new solution s*' obtained by LOCAL_SEARCH is better than current best solution s*, the ACCEPTANCE_CRITERION is implemented. In this procedure, the new obtained solution s*' value is compared with the previous best solution s* value. If the new solution s*' value is better than s*, it is kept as the current solution if it improves the objective function and if it is not in the history set. Otherwise, s* is kept as the current solution. This acceptance criterion is called the Better Acceptance Criterion or the Intensification Acceptance Criterion. the acceptance test is represented below(Singh Cheema, 2016):

$$Better\ (s^*, s^{*\prime}, history) = \begin{cases} s^{*\prime}\ if\ f(s^{*\prime}) < f(s^*) \\ s^*\ \ elsewhere \end{cases} \qquad (1)$$

5. Results

Table 1 shows the summary of the proposed schedule and the hospital schedule, respectively, in terms of satisfying hard and soft constraints. A clear outperformance of the proposed schedule can be observed in all aspects. The detailed manual and optimized schedules are displayed in Tables 2 and 3, respectively.

Table 1. Comparison between the hospital and the optimized schedules

Criteria	Hospital Schedule	proposed Schedule
Assign the required staff for each shift type of each day	89%	100%
Number of quick changes between shifts	20	0
No morning/afternoon shift between night shifts	56%	100%
Each physician must have two weekend off during a month schedule.	74%	100%
The maximum number of afternoon shifts is respected	82%	100%
The maximum number of night shifts is respected	87%	100%
No physicians have more than 3 consecutive days on	82%	100%
Number of isolated days off	21	4
Number of isolated days on	62	18
Time to prepare the schedule	1 hour	5 sec

6. Conclusion

In this paper, we have dealt with a real-world physicians scheduling problem from The KKUH Emergency Department in KSA. This problem is computationally hard to solve and constitutes a time-consuming task for the scheduler. The Iterated Local Search has been proposed to solve it. The results demonstrate that the proposed schedule outperforms the manual one in several aspects. Moreover, the results indicate that high-quality schedules can be obtained within a few seconds.

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