A Goal Programming Model for Fairly Scheduling Medicine Residents

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***Abstract*—In this study we develop a goal programming model for scheduling the shifts of the residents in a Qatari health care clinic. In this facility, the residents are assigned for on-call shifts during their training (called first resident), as well as working during the regular day shifts (called helper) into different department. In addition to focus on the rules that must be strictly met, like the number of on-duty shifts and general coverage requirements, our model takes into consideration fair work balance between the residents which has been rarely addressed by the literature. We are able to solve problems of realistic size to optimality in a few seconds. We showed that the proposed formulation, which the department uses currently, has yielded substantial improvements and much better schedules are created with less effort.**

Keywords—Resident Scheduling; Goal Programming; Healthcare operation management; Mathematical programming.

1. Introduction

Medicine residency is a challenging graduate medical training during which residents must be exposed to all medical specialties. For instance, once the medical students finish their studies, they must join a hospital residency program to be able to practice medicine. During the residency program, the physicians are considered both learners and providers of medical services. They are involved in the patients care under the supervision of an experienced physician. And at the same time the resident is considered to be a student in training. Residency programs are established and conducted for some educational purposes. This study focusses on the resident scheduling problem in a cancer center formed by two departments (oncology and hematology) providing 24 h continuous service and the residents are part of the main providers of this service. During their training, the residents are mainly assigned to two main duties: (1) on-call shift which is a 24-hours shift also called first resident, as well as (2) working during the regular day shifts which around 15 hours shift called also helper. During their training the residents must spend half of their training period (two to three months) in the first department and second half in their second one. In addition to work rules and coverage requirements that will be detailed later, residents must be exposed to the same responsibilities and hence shall be assigned fairly to the same duties. We use goal programming framework to formulate and solve this scheduling problem and compare the obtained solution with the manual one.

The rest of the paper is organized as follows. Section 2 gives some literature review. In Section 3, we define the problem and give the GP model. We comment on the benefits and give some computational results in Section 4 and finally conclude in Section 5.

2. Literature Review

In the last few decades, personnel scheduling problems have been studied widely. The increase in research attention could be motivated by economic considerations. For many companies, labor cost is the major direct cost component. The healthcare industry has gave a lot of attention to workforce staffing and scheduling. We refer to [1] for a recent survey on personnel scheduling. In the following we focus on reviewing some studies relevant to the present work.

While this work aims at fairly allocating the different tasks among the residents in order to satisfy a batch of personnel and hospital constraints, there exist other studies ([2], [3]) which focus more on the work conditions and residents' moral and their effect on the quality of care service provided. Other studies [4], [5] have constructed a one week planning horizon resident schedule to meet the work rules and the shift requirement. The authors of [4] developed two kinds of schedules a Long Shift and Daily Admitting. Multi-criteria optimization techniques have been used by [5] to construct a residency schedule. The studies [6]-[7] were based on specific work rules and constraints while building the schedules mainly are focusing on the physician's ergonomic abilities, and how to raise the patients safety. Each study used different method, for instance in [6] the authors have designed an operations research algorithm called 80-Hour Work Week to be used in residents scheduling that would provide a rational solution and assign each resident to a total of 80 hours per week. The schedule was built for a health care center, based on the availability of resources. On the other hand, different resident scheduling criteria was used in

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[7], it was focusing only in two departments within a health care center the anesthesia and reanimation department. The schedule is prepared every month considering 2 shifts (day shift from 8:00am to 18:00pm and night from 18:00pm to 8:00am).The target of this study was to provide schedules that are able to match between the department demand and the residents' satisfaction and by taking the soft constraint into account and satisfying it. The programming model was used in order to generate a schedule for the residents for both night and weekend shifts. Moreover, the role of hospital and residents preference should be considered and taking it into account. By assigning residents who have shifts of Friday to Sunday shifts, the off days satisfaction will be achieved, and the objective is reached. The recommended formulation generated essential enhancements and provided schedules with less effort. Furthermore, additional features are gained such as: increasing number of off days during the weekends, decreasing tandem shifts, assigning the residents that are belongs to the same social group to the same shift. In addition to that, the required time to perform the scheduling is reduced significantly. Similarly in [8] the authors have addressed the resident scheduling problem (RSP) in order to assign residents to day and night shifts over a given planning horizon subject to various working rules and medical requirements. A constraint programming-based solution approach for medical resident scheduling problems was found by them. In fact, the need of meeting the commitment of the quality of resident education is connected to the well-being of residents themselves, the quality of care and medical services provided to the patients and also to the resident duty hours. For this reason, the authors developed a mixed-integer programming model to schedule residents to their duty hours including all the activities, the day-off, and the rest period, taking in considering the requirements of the residency program to be covered.

Both [6], [8] have listed some constraint to be followed while building the schedules. There are some conditions for the 80-Hour Work Week Problem, and the most important ones that can be considered as constraints are as following:

- Residents must have at least 1 day off (1 complete 24 hours) each 7 days.
- Residents must have at least 10 hours of rest between each consecutive duty periods.
- Residents physically cannot work more than 24 hours without stopping, even though an added 6 hours of time may be used for educational purposes or outpatient clinic activities.

The above constraints and more additional rules from Residency Review Committee (RRC) were formulated to have a schedule that complies with their requirements. The authors modeled that scheduling problem using OR and they concluded that it's a practical technique to schedule the medical residents and it's robust as well in accommodating changes in hospital service requirements and resident numbers [6].

Extending the previously mentioned rules and restrictions, [8] have considered certain rules provided by the Accreditation Council for Graduate Medical Education (ACGME) to guarantee the balancing between personal resident health, patient safety and the requirements of the residency educational program. The ACGME argued that long consecutive hours of working hours in residency training programs can lead to residents' stress, mood changes, and affect negatively the ability of delivering high quality medical care. Thus, the schedule should be built based on these rules to avoid the impact of resident fatigue that may have on the quality of the cares and services provided to the patients. The following lists the ACGME rules for scheduling the resident duty hours:

- Residents must not work for more than 80 hours per week.
- Residents must have at least 1 day out of 7 days, free of duties related to patient cares.
- Residents must schedule to in-house calls not more than 1 time every three nights, averaged over 4 weeks.
- The time on duty is restricted to 24 h with additional time up to 6 hours for educational purposes and without any responsibilities for new patients.
- Residents should have rest period of 10 hours minimum between the duty periods
- Whenever the residents are recalled into the hospital, the time spent in the hospital must be counted toward the 80 hours duty period per week.

Then the authors formulated the problem and developed an MIP model considering the above working regulations imposed by the ACGME as well as the residency program's clinical requirements and they could generate a fair optimal schedule. Finally, they argued that it is a highly complicated task to be done manually as it takes an excessive amount of time from the scheduler who is usually the chief resident to construct and revise the schedules, and the quality of the manual schedules is usually not at an optimal level as well.

Building a schedule for the emergency medicine residents is considered as a difficult task because of the many rules and constraints that must be respected such as the night shifts assigned to each resident, number of consecutive days and the number of weekends off. Therefore, preparing schedules that respect all the working rules especially for the emergency shifts is very important as it has a significant role in reducing the negative impact on emergency medicine residents psychologically, physiologically, and socially. For that reason, the author worked in this problem taking into account all the conflicting rules in this problem should be taken into account. Designing a goal programming (GP) model for one-month planning horizon that covers the problem from a multi-objective perspective and accommodates all the constraints was developed. And the model tested for a local hospital, the results show that the model can solve problems quickly, and save the chief resident time with very high qualities comparing to the schedules built manually [8]. In addition, [9] concentrated on the scheduling problem at hospitals for residents work-nights as emergency shifts and they took into consideration the needs and requirements of the department as well as the residents' preferences. They modeled the problem as a mixed-integer program using operations research technique to help in generating a wide solution covers different scheduling situations, which helps in saving effort and time.

There are several important real-world decision-making situations; sometimes it can be feasible, or preferable to shrink all the goals of an organization into one single objective. For instance, optimizing the profit of an organization could be the main target of an organization, however instead of focusing on that, the organization may simultaneously focusing in maintaining a constant work force, increasing the market share and controlling price increases. Goal programming is considered as an extension of the linear or nonlinear programming it involves an objective function with multiple objectives. During the development of a goal programming model, defining the decision variables of the model is a must. After that the managerial goals related to the problems need to be recorded and make a hierarchical order based on the priority. Ranking these goals on a cardinal scale is a challenging task; an ordinal ranking is usually applied to each of the goals [11].

Achieving every goal specified by the decision-maker may not always be possible to fully obtain. Therefore, goal programming is often referred to as a lexicographic procedure in which the multiple goals are satisfied in their priority order [12].

Goal programming is used to handle a decision problem with one goal and multiple sub-goals; also it is applicable for a problem with multiple goals and multiple sub-goals. The aim of applying the goal programming is to minimize the deviation between the goals and what can be obtained given a set of predefined constraints di^+, di^-.

General goal programming model can be mathematically expressed as:

$\sum_{i=1}^{m}\left(\sum_{i=1}^{m}\left(d_i^+ + d_i^-\right)\right)$

Subject to $Ax - Id_i^+ + Id_i^- = b$

$X, d_i^+, d_i^- \geq 0$

- m represent the number of goals.
- A is m*n matrix which represents the relationship between goals and sub-goals.
- x is the variables involved in the sub-goals (x1,x2,x3,…..xn)
- di+,di- are m component vector for variable representing deviations from goals
- I is an identity matrix in m dimensions [12].

3. Model description and formulation

Medicine residency is a challenging graduate medical training during which residents must be exposed to all medical specialties. The hospital we observed during this study is specialized on cancer treatment and mainly formed of two departments (oncology and hematology) providing 24 h continuous service and the residents are part of the main providers of this service. During their training, the residents are mainly assigned to two main duties: (1) on-call shift which is a 24-hours shift also called first resident, as well as (2) working during the regular day shifts which around 15 hours shift called also helper. During their training the residents must spend half of their training period (two to three months) in the first department and second half in their second one. In addition to work rules and coverage requirements that will be detailed later, residents must be exposed to the same responsibilities and hence shall be assigned fairly to the same duties. In the following we use mathematical programming to formulate the above described problem

3.1. Parameters

- R: Set of residents.
  R= {1,2,3, … … … … n} indexed by r
- D: Set of days
  D= {1,2,3, … … … … m} indexed by d
- WD: Set of weekend days
  WD = {1,2,3, … … … … f} indexed by wd
- Set of departments
  S= {O, H} = {s_1 ,s_2}
- Set of duties
  T= {RES, HLP} = {t_1 ,t_2}
- P: half of the set of days
  P= {1,2,3, … … … … p}
- Average number of assignments per duty per resident per department
  $$\alpha = \frac{number\ of\ days}{2 * number\ of\ residents}$$
- Average number of weekends assigned to each resident
  $$\gamma = \frac{number\ of\ weekend\ days}{number\ of\ residents}$$

Decision variables :

- $X_{rstd} = \begin{cases} 1, & \text{if resident r is assigned task t} \\ & \text{in department s on day d} \\ 0, & \text{otherwise} \end{cases}$
- $Y_r = \begin{cases} 1, & \text{if resident r is assigned to department 1} \\ 0, & otherwise \end{cases}$
- $\alpha_{r,s,t}^+$, $\alpha_{r,s,t}^-$: Positive real numbers representing the deviation or gap per resident per duty per department from the average target α
- γ_r^+, γ_r^- : Positive real numbers representing the deviation or gap per resident from the average worked weekend days γ.

3.2. Objective function

The main objective of the model is to generate a feasible resident schedule that satisfies a set of requirements (constraints) that are formulated in the next sub-section. These constraints need to be satisfied while minimizing the workload gaps between the residents in terms of duties assigned per department and per weekend days worked. This is referred to as fairness and equitability and is represented by minimizing the deviation gaps between residents.

$Min \sum_{r=1}^{n} \sum_{d=1}^{m} \sum_{s=1}^{2} \sum_{t=1}^{2} (\alpha_{r,s,t}^+ + \alpha_{r,s,t}^- + \gamma_r^+ + \gamma_r^-)$ (1)

3.3. Constraints

- Only one resident is assigned to only one duty per day and per department.

$$\sum_{r=1}^{n} \sum_{t=1}^{2} x_{r,s,t,d} = 1 \qquad \forall\ S, D \qquad (2)$$

- Each duty t, is performed once daily for both departments.

$$\sum_{r=1}^{n} \sum_{s=1}^{2} x_{r,s,t,d} = 1 \qquad \forall\ T, D \qquad (3)$$

- A resident cannot have two consecutive duties (a resident can be assigned at most once in 2 days).

$$\sum_{s=1}^{2} \sum_{t=1}^{2} (x_{r,s,t,d}+x_{r,s,t,d+1}) \leq 1 \quad \forall\, R, D \qquad (4)$$

- Each resident must perform all his duty in the same department for half of the planning period (P),(then he will be shifted to the second department in the other half of the period.)

$$\sum_{t=1}^{2} \sum_{d=1}^{p} x_{r,1,t,d} \leq p * \mathrm{Yr} \quad \forall\, R \qquad (5)$$

$$\sum_{t=1}^{2} \sum_{d=1}^{p} x_{r,1,t,d} \leq p * (1-\mathrm{Yr}) \quad \forall\, R \qquad (6)$$

$$\sum_{t=1}^{2} \sum_{d=p+1}^{d} x_{r,2,t,d} \leq p * (1-\mathrm{Yr}) \quad \forall\, R \qquad (7)$$

$$\sum_{t=1}^{2} \sum_{d=p+1}^{d} x_{r,2,t,d} \leq p * \mathrm{Yr} \quad \forall\, R \qquad (8)$$

3.3.1 Soft constraints

- Each resident can be assigned at most once in two consecutive weekends (means either consecutive Fridays, or consecutive Saturdays, or consecutive Friday and Saturdays (vice versa).

$$\sum_{t=1}^{2} (x_{r,s,t,wd} + x_{r,s,t,wd+1} + x_{r,s,t,wd+7} + x_{r,s,t,wd+8}) \leq 1 \quad \forall\, R, S, D \; (9)$$

3.3.2 Fairness constraints

- Fair distribution of duties per department among all residents.

$$\sum_{d=1}^{m} x_{r,s,t,d} - \alpha^{-}_{r,s,t} + \alpha^{+}_{r,s,t} = \alpha \quad \forall\, R, S, T \; (10)$$

- Fair distribution of worked weekends among all residents.

$$\sum_{wd=1}^{f} \sum_{s=1}^{2} \sum_{t=1}^{2} x_{r,s,t,d} - \gamma^{-}_{r} + \gamma^{+}_{r} = \gamma \quad \forall R \; (11)$$

4. Results and discussion

We solved the above described model using AMPL and CPLEX Solver. It took few seconds to generate optimal solutions for real world instance. Table 1 summarizes results of a schedule involving 8 residents over a two months period. As one can remark in addition to satisfying the work coverage requirements, the schedule promotes high fairness and workload equity between the residents which in practice increase their satisfaction and hence improve their learning process and work performance.

When comparing the automated solution we generate to the manual one used by the hospital, we noticed that in addition to the improvements in term of satisfying work coverage and constraints, the optimal solution is highly fair compared to the manual one. This observation can be better highlighted by Figure 1, where the assignment in the manual schedule is not balanced. This observation was also made for the other duty and department as well as for the number of weekend assigned to each resident.

Table 1. Summary of optimal solution for 8 residents over 2 months

Residents	Hematology		Oncology		$\sum$1st Res	$\sum$ HLP	$\sum$ weekend
	1st Res	HLP	1st Res	HLP			
R_1	4	3	4	4	8	7	4
R_2	4	4	4	4	8	8	4
R_3	4	4	3	4	7	8	5
R_4	4	4	4	4	8	8	4
R_5	4	4	4	3	8	7	4
R_6	4	4	4	4	8	8	5
R_7	3	4	4	4	7	8	4
R_8	4	4	4	4	8	8	4

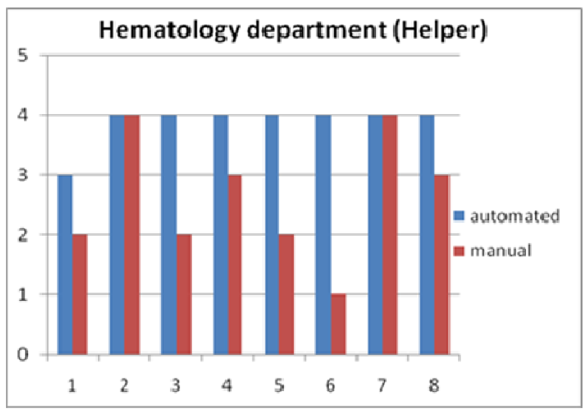

Figure 1. Duty 2 (helper) distributions in hematology department

5. Conclusion

In this paper we used goal programming to formulate a scheduling problem involving a number of residents that need to be exposed to two different departments within a hospital. In each department they can be assigned to either on call resident of regular daily shift. In addition to work constraints and coverage requirement, our model gave a lot of attention to the fact that the work load has to be fairly balanced between the residents. We showed that the proposed formulation, which the department uses currently, has yielded substantial improvements and much better schedules are created with less effort.

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