Computers & Operations Research 38 (2011) 246–255

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

A constraint programming-based solution approach for medical resident scheduling problems

Seyda Topaloglu [a,*], Irem Ozkarahan [b]

[a] Dokuz Eylul University, Department of Industrial Engineering, Tinaztepe Yerleskesi, 35160 Izmir, Turkey
[b] Troy University - Montgomery, Department of Computer Science, P.O. Drawer 4419, Montgomery, AL 36104, USA

ARTICLE INFO

Available online 15 May 2010

Keywords:
Medical resident scheduling
Mixed-integer programming
Constraint programming
Accreditation Council for Graduate Medical Education
Duty hours

ABSTRACT

Persistent calls come from within the graduate medical education community and from external sources for regulating the resident duty hours in order to meet the obligations about the quality of resident education, the well-being of residents themselves, and the quality of patient care services. The report of the Accreditation Council for Graduate Medical Education (ACGME) proposes common program requirements for resident hours. In this paper, we first develop a mixed-integer programming model for scheduling residents' duty hours considering the on-call night, day-off, rest period, and total work-hour ACGME regulations as well as the demand coverage requirements of the residency program. Subsequently, we propose a column generation model that consists of a master problem and an auxiliary problem. The master problem finds a configuration of individual schedules that minimizes the sum of deviations from the desired service levels for the day and night periods. The formulation of this problem is possible by representing the feasible schedules using column variables, whereas the auxiliary problem finds the whole set of feasible schedules using constraint programming. The proposed approach has been tested on a series of problems using real data obtained from a hospital. The results indicate that high-quality schedules can be obtained within a few seconds.

1. Introduction

Postgraduate residency education is required of all medical school graduates seeking full license in one of the specialties of medicine. This phase of medical education is conducted primarily in clinical settings and requires direct participation by residents in the delivery of patient care services. The residents have a unique position both, as learners who have to attend educational activities and as providers of services working long duty hours.

Residents' duty schedules should be prepared keeping in mind the potentially adverse impact that resident fatigue may have on the quality of patient care provided and the resident physical and emotional well-being. The scientific literature has consistently demonstrated that the long hours of intense clinical work seen in residency training programs raise concerns about residents' stress, mood changes, and capacity to deliver high quality medical care [1–3]. Much data supports that for many residents, fatigue cultivates anger, resentment, bitterness, and depression rather than kindness, compassion, or empathy [4,5]. It also leads to cognitive impairment that results in higher rates of medical error, motor vehicle accidents, and pregnancy complications [6–9]. These societal concerns have prompted the Accreditation Council for Graduate Medical Education (ACGME) to apply certain rules for regulating the duty hours of residents in order to strike a balance between educational requirements, personal well-being, and patient safety. The ACGME is a private, non-profit council that evaluates and accredits medical residency programs in the United States. The mission of the ACGME is to improve health care by assessing and advancing the quality of residents' education through accreditation.

The following lists the proposed ACGME common program requirements for resident duty hours [10]:

- Residents must not be scheduled for more than 80 h per week, averaged over a 4-week period, with the provision that individual programs may apply to their sponsoring institution's Graduate Medical Education Committee for an increase in this limit of up to 10 percent if they can provide a sound educational rationale.
- Residents must have at least one full (24-h) day out of 7, free of patient care duties, averaged over 4 weeks.
- Residents must not be assigned in-house calls more often than every third night, averaged over 4 weeks.
- Continuous time on duty is limited to 24 h, with additional time up to 6 h for inpatient and outpatient continuity, transfer

* Corresponding author. Tel.: +90 232 4127611.
E-mail addresses: seyda.topaloglu@deu.edu.tr (S. Topaloglu), iozkarahan@troy.edu (I. Ozkarahan).

0305-0548/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cor.2010.04.018

of care, educational debriefing and formal didactic activities. Residents may not assume responsibility for new patients after 24 h.
- Residents should have a minimum rest period of 10 h between duty periods.
- When residents take calls from home and are recalled into the hospital, the time spent in the hospital must be counted toward the weekly duty hour limit.

In this paper, we address the resident scheduling problem (RSP) that involves assigning residents to day and night shifts over a given planning horizon subject to numerous working regulations and staffing requirements. The RSP acquires notable differences and variances from other personnel scheduling problems, which need to be dealt with specifically. While the resident is a provider of medical services, he or she is also a student in training. This situation implies a variety of working rules to ensure an optimal learning environment and to provide a good balance between education and patient care activities. The residents are usually grouped according to their seniority levels and the working rules may change for different resident groups. The critical issue is to allocate the desired number of residents from each seniority level to the shifts and to assign a certain designated number of day and night shifts to the residents considering the seniority rules. Since resident fatigue deteriorates the quality of patient care provided, it is also required to regulate consecutive shift assignments. There is little work about the RSP. The first study belongs to Ozkarahan [11] that proposes a goal programming model considering the requirements of the residency program and the desires of residents as to days off, weekends, on-call nights for a 1-week planning horizon. Sherali et al. [12] addressed the night allocation problem of residents while considering departmental staffing and skill requirements as well as residents' preferences. The relevant problem was modeled as a mixed-integer program and heuristic solution procedures were developed for different scheduling scenarios. Franz and Miller [13] dealt with the allocation of residents to training rotations and associated clinics. This is actually the first phase of the RSP. Each residency program, depending on the specialty and the year in the residency program, requires rotation of residents to different departments on a monthly basis. Preparing rotation schedules is easy compared to shift schedules since there are master plans and the chief resident makes the assignments. Once the number of residents is known in a department, monthly schedules should be prepared for the residents as in our case. Recently, Topaloglu [14] developed a goal programming model for scheduling emergency medicine residents. The proposed model is an abstract representation of the rules in the emergency room. Day et al. [15] formulated an integer programming model for scheduling the weekly work hours of residents considering the 80-h work limit of the ACGME and institution-specific constraints of the surgery residency program. However, long computing times were a major issue with this model. Topaloglu [16] 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.

The foregoing literature review has revealed a number of RSPs and models dealing with specific scheduling contexts. One should easily notice the urgent need for a new generalized model that incorporates the ACGME requirements for residents' duty hours. On the other hand, Agraval and Joshua [17] draw attention to the provisions of the ACGME that allow residency programs to average the weekly duty hours and on-call nights over a 4-week period. They criticize that under such a system, residents theoretically could be scheduled to work an excessive number of hours in any given week and be assigned to on-call nights more often than every third night. For this reason, it is required to impose rules regulating the number of weekly work hours and on-call night assignments. The fact that residents have different seniority levels, and thereby different working rules and staffing requirements should also be taken into account. As a result, apart from the ACGME requirements, additional constraints related with the maximum number of allowable weekly duty hours, minimum and maximum number of consecutive work days, minimum number of nights off between consecutively scheduled on-call nights, minimum and maximum number of on-call nights specific to seniority levels, seniority-based staffing requirements and off-day regulations should also be considered.

This paper is the first study that models the RSP considering the ACGME requirements and other required constraints needed to generate acceptable schedules for a 4-week planning period. The developed model is a general one that can be implemented in any resident scheduling environment that stipulates the ACGME common program requirements. With this characteristic, it is different from the other contributions in the literature that only consider the specific scheduling context. The models in [11,14,16] consist of mainly soft constraints that allow deviations from the working rules of the relevant scheduling environment. On the other hand, the proposed model imposes the ACGME duty hour regulations without any deviations to provide a common working standard for all residents in different residency programs. For this reason, it consists of mainly hard constraints, except the ones related to staffing levels.

This study first presents a mixed-integer programming (MIP) model. Since the direct solution of the MIP model is possible only for small resident numbers, a column generation (CG) approach is proposed for solving larger problem instances. The proposed CG approach considers a model consisting of a master problem and an auxiliary problem. The master problem finds a configuration of individual schedules that minimizes the sum of deviations from the desired service levels for the day and night periods. The formulation of this problem uses column variables to represent feasible schedules, which are generated using an auxiliary problem solved via constraint programming (CP). In the real-life clinical setting we are considering, it is possible to generate all the columns a priori and solve the master problem optimally in just a few seconds.

The remainder of the paper is structured as follows. A detailed presentation of the MIP model for the RSP is given in Section 2. The CP based column generation method is presented in Section 3. In Section 4, the performances of MIP and CG approaches are compared and the experimental results are given. Finally, concluding remarks are presented in Section 5.

2. Model development

2.1. Notation

The following notation is used to specify the model which is referred to as the MIP_1 model.

Indices and sets

i *index for the residents;*
j *index for the work days;*
k index for the shift types that can be assigned to the residents, $k = 1$ and $k = 2$ for the day (7 a.m.–7 p.m.) and night (7 p.m.–7 a.m.) shifts, respectively, $k=3$ for a 24-h shift;