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# Fair optimization of fortnightly physician schedules with flexible shifts

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ABSTRACT

This research addresses a shift scheduling problem in which physicians are assigned to demand periods. We develop a reduced set covering approach that requires shift templates to be generated for a single day and compare it to an implicit modeling technique where shift-building rules are implemented as constraints. Both techniques allow full flexibility in terms of different shift starting times and lengths as well as break placements. The objective is to minimize the paid out hours under the restrictions given by the labor agreement. Furthermore, we integrate physician preferences and fairness aspects into the scheduling model. Computational results show the efficiency of the reduced set covering formulation in comparison to the implicit modeling approach.



## 1. Introduction

During the last decades, hospitals face a mounting pressure to reduce costs. Particular attention is paid to personnel costs since these put a high burden on the budgets of the facilities (Thungjaroenkul et al., 2007). In 2007, almost 30% of German hospitals suffered a financial loss and hence went into bankruptcy (see Blum, 2008). The challenge for the hospitals is to provide high quality care at reduced costs. Therefore, hospital management takes a great interest in improved scheduling procedures to reduce staffing costs.

This article deals with the flexible shift scheduling problem of physicians at hospitals. Physician scheduling is much more complex than for example nurse scheduling. The demand varies widely within a day and from one day to the next. Demand coverage has to be provided by 100% either by inhouse staff or outside resources that incur very high costs. Furthermore, on top of regular shifts physicians have to provide on-call service to handle emergencies in off hours at night or during weekend periods. In addition, physicians can negotiate favorable labor contracts with the government or the hospitals, resulting in detailed labor agreements that vary, among others, by region and/or governing authority.

The task of the considered tour scheduling problem is to assign shifts and days-off to a given number of physicians, such that the demand is completely covered and all labor regulations are satisfied. In particular, using overtime is a costly option for service organizations. For instance, the efficient use of overtime at the British Post Office is investigated in Mc Manus (1977). As is often the case, we consider regular time as a fixed cost block which is determined by labor contracts. Therefore, we minimize the number of overtime hours required to meet the time varying demand. In our model we do not consider long term decisions like hiring and planning for vacations. We assume a fixed number of available inhouse physicians as an input and, if gaps in coverage occur, we allow calling in outside physicians at very high cost. Summarizing, our major concern is to minimize operating cost, which is in our case the cost incurred due to overtime. Alternative or additional objective function criteria for staff scheduling are employee preferences, fair assignments of employees to schedules, and consistent employee workloads (see Alfares, 2004). Preferences include aspects as for example the length of the workstretch, days-on and days-off patterns, preferred partners working together (see Bard and Purnomo, 2005a; Burke et al., 2004). Fairness can be seen as how violations to preferences are balanced over all employees.

The work has two key contributions to the research community. The first is the formulation of the flexible shift scheduling problem of physicians in hospitals as a reduced set covering model that allows to solve it to optimality for real-world data with standard-software. This formulation provides much better results with respect to runtimes and solution quality than other known formulations for that problem. The second contribution is the consideration of fairness aspects in the scheduling procedure. Based on interviews with our collaborating hospital, the most important fairness aspects that should be considered are a fair distribution of on-call services and fair assignment of working hours. We study the impact of fairness integration on the schedules using real-world data.

The remainder is organized as follows. The most relevant literature for our work is presented in Section 2 followed by problem description in Section 3. The reduced set covering formulation is

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developed in Section 4. Section 4.1 describes the necessary preprocessing to incorporate breaks and on-call services in the reduced set covering formulation. The mixed-integer program (MIP) is described in Section 4.2. A comparison of this modeling approach to the implicit modeling technique based on computational investigations using real-world data is presented in Section 4.3. The impact of fairness objectives on the rosters and the objective function is analyzed in Section 5. Finally, we give some concluding remarks.

## 2. Literature

There is a lot of literature on research in the area of personnel scheduling. According to the classification scheme introduced by Ernst et al. (2004) a personnel scheduling problem can be characterized by one or more of six modules that address demand forecasting, days-off scheduling, shift scheduling, line-of-work construction (tour scheduling), task assignment and staff assignment. The first module, demand forecasting, determines the requirements per period or per shift. Days-off scheduling (second module) deals with how rest days are interspersed between work days. Shift scheduling determines shifts to cover the demand over a certain planning horizon according to general and individual work regulations. The line-of-work construction module combines days-off scheduling with shift scheduling and uses the results to build feasible work patterns (tours) over the planning horizon. The task assignment module then assigns tasks to shifts. The last module, staff assignment, involves the assignment of staff to lines-of-work. Normally, these modules are considered sequentially by planners.

The focus of this paper is on fortnightly tour scheduling. There are many different approaches to solve tour scheduling problems (see the comprehensive reviews in Ernst et al. (2004), and Alfares (2004)). Optimization approaches are often based on set covering or on implicit formulations. Stolletz (2010) introduces a reduced set covering formulation, which requires a daily tour matrix (similar to set covering formulations) but implicitly models the tour-building constraints. This formulation is able to handle flexible shifts but does not take into account breaks, on-call services, and fairness. Within these restrictions, it enables optimal solutions and outperforms other mathematical programming formulations.

Most research on tour scheduling in health care organizations concentrate on scheduling nurses (e.g., see Burke et al., 2004; Cheang et al., 2003; Ernst et al., 2004). In the following we review heuristic solutions on scheduling emergency room physicians or medical residents. Beaulieu et al. (2000) present a model for scheduling emergency room physicians for a six month planning period which is solved by decomposition. The formulation uses three 8-hours shifts to cover a specific day and incorporates several kinds of requests for days-off as well as preferred shifts. Scheduling hospital rounds by specialty for teams containing senior, junior, and resident physicians is considered by White and White (2003). Their tabu search and logic constraint algorithm provides monthly assignments. The investigation of several scheduling procedures for emergency physicians currently in use at six different hospitals is given in Carter and Lapierre (2001). Brunner et al. (2009) introduce an implicit formulation for the flexible shift scheduling problem of physicians in hospitals as considered in this paper. Rather than starting with a predefined set of shifts, their model formulates all rules for shift- and tour-building as constraints. They use a heuristic decomposition strategy to find feasible solutions. Rousseau et al. (2002) tackled a physician scheduling problem with a combination of three approaches that includes constraint programming, local search and genetic algorithms. Topaloglu (2006) uses goal programming techniques for a monthly tour scheduling problem for emergency medical residents. In a subsequent work he presents more insights into the underlying problem and gives a real implementation at a pulmonary unit of a local hospital (see Topaloglu, 2009).

Literature considering fairness and preferences is for example about nurse scheduling (see literature reviews by Cheang et al. (2003) and Burke et al. (2004)). Warner (1976) refers to the quality of a schedule as a measure of the schedule's desirability as judged by the employee who will have to work it. Bard and Purnomo (2007) distinguish three approaches to consider such preferences and fairness aspects in rostering: cyclic staffing, self-scheduling, and preference scheduling. In cyclic scheduling, fixed tours are established and the staff is rotated continuously through them. This results in even distribution of undesirable tours but does not take into account individual preferences. In self-scheduling the staff is asked to sign-up for shifts they wish to work. This procedure is based on individual preferences but may lead to conflicts which have to be solved by the unit manager. Preference scheduling balances the staff satisfaction and economic consequences through quantifying the violation of preferred requests. This can be done by assigning (employee-specific) penalties to shifts or tours (e.g., see Cheang et al., 2003; Bard and Purnomo, 2005a; Trilling et al., 2006) or by penalizing the number of violations for each employee with exponential factors (see Bard and Purnomo, 2007). Besides the minimization of the sum of those penalties, the difference between minimum and maximum realized penalties could be used as a measure of fairness (see Trilling et al., 2006).

To the best of our knowledge, no tour scheduling formulation described in literature treats all features of the considered flexible shift scheduling problem of physicians with fairness aspects and allows to solve it to optimality with a standard solver.

## 3. Problem description

The problem consists of a fixed number of identical physicians $\mathcal{I}$ who are scheduled over a planning horizon of $\mathcal{D}$ days, where each day consists of $\mathcal{T}$ periods, stated in 1-hour increments. We consider a midterm scheduling problem where rosters up to several weeks are generated. Shifts cannot spill over to the next planning day. In this discontinuous planning problem at most one shift start per day is allowed. The physicians have some defining characteristics, such as minimum shift length, maximum shift length, minimum rest duration between consecutive shifts, working time and overtime restrictions per week. All labor rules are stated either in the general labor agreement or in individual arrangements with the hospital. According to the contracts regular time is a fixed cost block and hence it is not relevant for optimization. We consider over- and undertime as deviations from the regular working time per week. In the considered bi-weekly planning problem the overtime during the first week could be compensated by undertime during the second week. Otherwise, the (not compensated) overtime in the first week is paid out time. From this it follows that we minimize the paid out time and the overtime during each week of the planning horizon according to different cost parameters. It is not possible to compensate for assigned overtime during the current week by assigning the same amount of undertime during the previous week.

According to the general labor rules, each shift has to be assigned a lunch break within some time span. This time span is characterized by the minimum time on duty before and after the break takes place.

Furthermore, to take individual or general preferences into account, all the shifts assigned to one or all physicians might fulfill a relative starting time window. Such starting time windows defined in relative terms force that the difference between the earliest and the latest starting period for several shifts within a week is less than a fixed period of time.