Computers & Operations Research 40 (2013) 2450–2465

Contents lists available at SciVerse ScienceDirect

Computers & Operations Research

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

A constraint-based approach for the shift design personnel task scheduling problem with equity

Tanguy Lapègue *, Odile Bellenguez-Morineau, Damien Prot

Ecole des Mines de Nantes, IRCCyN UMR CNRS 6597 (Institut de Recherche en Communication et en Cybernétique de Nantes), LUNAM Université, 4 rue Alfred Kastler, La Chantrerie, BP20722, 44307 Nantes Cedex 3, France

ARTICLE INFO

Available online 12 April 2013

Keywords:
Personnel task scheduling problem
Fixed job scheduling problem
Task assignment
Shift design
Equity
Constraint programming

ABSTRACT

This paper presents an industrial problem which arises in a company specialized in drug evaluation and pharmacology research. The aim is to build employee timetables covering the demand given by a set of fixed tasks. The optimality criterion concerns the equity of the workload sharing. A solution to this problem is the assignment of all tasks whose resulting working shifts respect tasks requirements as well as legal and organizational constraints. Scheduling problems usually consider a fixed set of shifts which have to be assigned to a given number of employees whereas in our problem shifts are not fixed and are deduced from the task assignment. In the following, we refer to this problem as the shift-design personnel task scheduling problem with an equity criterion (SDPTSP-E), in reference to the shift minimization personnel task scheduling problem (SMPTSP). Even if the SDPTSP-E is related to several problems, none of them allow to grasp its full complexity. Consequently, we propose a dedicated method based on constraint programming. Several branching and exploration strategies are proposed and tested.

1. Introduction

Personnel scheduling and rostering problems tackle the difficult problem of building employee rosters respecting legal and organizational constraints to satisfy personnel requirements. These problems address two different questions arising in many companies: how to organize a given workforce in order to reduce the associated costs and how to build employee rosters in order to increase their satisfaction. It is often very difficult to make these two goals compatible, which explains the academic and industrial interest for personnel scheduling and rostering problems (see [16] for an overview).

In this paper, we present a real-world problem, which arises in a company specialized in drug evaluation and pharmacology research. Drug evaluations aim at checking the impact on the human body of new drugs. Healthy volunteers are therefore recruited by the company in order to consume these new drugs. After drug consumption, many tests have to be carried out on each volunteer to check several parameters such as blood pressure, heart rate or brain activity and samples have to be collected to be analyzed in laboratory. These tests are composed of a set of fixed tasks which have to be assigned to qualified and available employees. To that moment, the chief nurse designs employee rosters and assigns tasks to employees by hand, which is very complicated and could be helped with a dedicated tool. The aim of our study is to design the core of the optimizing part of this tool. The decision problem behind this case-study appears to be connected with different problems in the literature as shown in part 3, but with particular aspects that deserve a specific approach, as described in the following. In the sequel, this problem will be referred to as the shift-design personnel task scheduling problem with an equity criterion (SDPTSP-E).

The remainder of the paper is organized as follows: Section 2 is devoted to the description of the SDPTSP-E, Section 3 presents some related works, in Section 4 we propose a modeling of our problem, Section 5 describes some branching strategies. Our approach is validated by experimental results in Section 6, followed by our conclusions.

2. Problem description

This section presents the industrial problem studied in this paper: Section 2.1 gives information on the operational background, Section 2.2 summarizes the constraints of the problem, Section 2.3 presents the optimal criterion, Section 2.4 summarizes our hypothesis and choices related to the problem resolution.

2.1. Operational background

The company carries out clinical studies on behalf of pharmaceutical laboratories which need to control the impact of newly

* Corresponding author. Tel.: +33 251858538.
E-mail addresses: tanguy.lapegue@mines-nantes.fr (T. Lapègue), damien.prot@mines-nantes.fr (D. Prot), odile.morineau@mines-nantes.fr (O. Bellenguez-Morineau).

0305-0548/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cor.2013.04.005

developed drugs on the human body. Laboratories deliver to the company a very specific study procedure which contains a description of all the clinical tasks to be performed, along with their relative starting time and duration. These tasks will be performed on volunteers, i.e. people who are recruited by the company and hospitalized during the study. Each week, the various tasks related to the ongoing protocols have to be assigned to qualified and available employees. The individual rosters resulting from this task assignment have to respect a set of legal and organizational constraints, and also, up to a point, they are expected to be as fair as possible. This particular criterion will be detailed in the Section 2.3. The design of employee rosters is currently hand-performed on a weekly basis by the chief nurse, which is very time-consuming. While designing employee rosters, the chief nurse has to consider not only the clinical tasks, but also the compulsory administrative tasks and the free administrative tasks:

1. *Clinical tasks* are fixed by the protocol and must be performed at the given starting minute, which means that the granularity of the problem drops to the minute. These tasks are fixed whenever during the day of the week and the hour of the day.
2. *Compulsory administrative tasks* are also fixed but they are already assigned before the rostering-design procedure. This kind of tasks, such as meetings and trainings, is counted as working time, but not as clinical working time, and they could be assigned to more than one employee (in case of meetings within the company). These assignments lead to fixed periods of clinical unavailability that have to be included in designed shifts.
3. *Free administrative tasks*, such as medical reports writing, are not fixed, do not require any specific skills and could be preempted. Each employee has a specific set of free administrative tasks to do during the week, and they are free to work on it whenever they want, provided they are not already assigned in the mean time to clinical or compulsory administrative tasks. Consequently, these tasks do not appear in the final timetable. Nevertheless, the chief nurse takes them into account while evaluating the amount of clinical work that can be performed by each nurse.

A typical instance involves 20 nurses whose set of different skills is closed to 30 and 200 tasks, whose durations range from 5 min to 4 h. Consequently, the time granularity drops to the minute over a scheduling horizon of a week. This might look like an excess of precision, but it is very important for the company to follow scrupulously the given protocols. To highlight this fact, one can state the use of synchronized clocks in the whole building.

Another characteristic of the problem lies in the lack of fixed shifts: employees could start and end their working days whenever it is necessary, provided the resulting shift sequences respect the set of hard constraints due to work regulation, company organization, and nurses agreements. Consequently, working days refer to working periods and they may overlap two calendar days if needed.

2.2. Constraints

Two types of constraints are considered, the organizational ones and the legal ones. These constraints are summarized in the following:

Organizational constraints:

- *HC* 1: Employees cannot perform clinical tasks which require unmastered skills.
- *HC* 2: Employees cannot perform clinical tasks while unavailable.
- *HC* 3: Every clinical task must be assigned to one employee.
- *HC* 4: The assignment of compulsory administrative tasks must be respected.
- *HC* 5: Employees must finish a clinical task before starting another one.
- *HC* 6: Tasks starting after 6 am on a given day must not belong to the same shift as tasks starting before 6 am. More precisely, tasks starting before 6 am should be considered as night tasks, meaning that they should be performed during a night shift, whereas tasks starting after 6 am should be considered as morning tasks, meaning that they should be performed during a morning shift. The purpose of this constraint is to avoid shifts starting in the middle of the night and ending in the middle of the morning, because they are not appreciated by nurses.

Work regulation/nurses agreements constraints:

- *HC* 7: The daily working time must not exceed 10 h.
- *HC* 8: The weekly working time must not exceed 48 h.
- *HC* 9: The duration of a working day must not exceed 11 h.
- *HC* 10: The duration of a rest period must not be less than 11 h.
- *HC* 11: The duration of the weekly rest must not be less than 35 h.
- *HC* 12: Series of consecutive working days must not exceed 6 days.
- *HC* 13: Employees do not work more than one shift per working day.
- *HC* 14: Depending on the starting and ending times of their shifts, nurses may have different kind of breaks (eventually no breaks). More precisely: morning shifts (starting between 6 am and 8 am) should have a small break of 18 min; shifts overlapping the lunch time window (12 am to 2:30 pm) should have a lunch break of 1 h; shifts starting after the end of the lunch window and longer than 6 h should have a break of 30 min. Employees may have both a morning break and a lunch break.

The constraint (*HC* 13) limits the number of shifts of each employee to 7, one for each day. Out of these seven shifts, constraints (*HC* 12) reduce the number of worked shifts to 6. There is neither a minimal number of shifts, nor a minimal shift length, because shifts are deduced from the clinical assignment only. Consequently, if an employee has only one task to perform during one shift, which may last only a few minutes, then the employee may complete this shift with some administrative work. Likewise, if an employee has only a few working shifts assigned in the week, he/she will complete the week with pure administrative shifts.

During the task assignment process, the chief nurse takes into account this whole set of hard constraints which might lead to dead end, meaning that the problem admits no solution. Such cases are often due to a lack of people during an activity peak. If a solution violates (*HC* 14), the chief nurse may propose an arrangement to concerned nurses. When such arrangements cannot be reached, or when it is simply not possible to perform every task, then the chief-nurse strengthens the workforce with externals, who abide by the same rules as regular workers.

2.3. Objective function

Hard constraints must be satisfied, but they only ensure the feasibility of schedules. In order to build fine schedules, the chief nurse takes into account multiple criteria based on equity among employees. In this paper, we consider the most important of these criteria: we want to share the workload resulting from clinical and administrative tasks in a fair way. However, some nurses are less