Combined activity selection and skilled staff scheduling for the Red Cross blood donation services

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Abstract The Red Cross blood donation services face a complex optimization problem consisting of three stages: 1) Choose the most promising blood donation activities out of a list of potential activities, 2) decide on which of the set of feasible days the chosen activities should take place and 3) assign skilled staff members to these activity-day-combinations so that legal and individual working time agreements are adhered. We solve this problem in an interleaved two-stage way: The staff rostering problem is formulated as a column generation (CG) problem with a set-covering master problem of required staff for the activities and a shortest path problem with resource constraints as a subproblem. The CG is then embedded in a logic-based benders decomposition to decide on the activity-day-combinations.

1 Problem Description

The Viennese Red Cross blood donation center yearly collects and processes around 130,000 blood donations. The majority of these donations are raised at blood donation activities conducted at different locations in Vienna, Lower Austria and Burgenland. Here, a team of doctors, nurses and medical assistants drives to some previously agreed location (i.e., a local red cross building, a school or a company building) where potential participants gather to donate blood.

Various locations are willing to host such a blood donation activity. These activities normally can take place on a number of predefined days. E.g., if

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the University of Vienna is willing to host a blood donation activity, they would probably provide resources on a set of possible days. It is then up to the Red Cross to decide, whether they accept the invitation of a host location and on which of the offered days the accepted activity should take place. The duration of activities as well as their start and end time are fixed for each of the potential days, as they mainly correlate with the opening hours of the facility the activity takes place.

The Red Cross, however, faces limited resources (staff members, blood donation buses, etc.) but still needs to satisfy demand for blood products. Therefore, a minimum number of donations needs to be collected during the planning horizon given limited number of skilled staff members and their associated contractual agreements. The latter contain employee specific arrangements such as weekday availabilities, minimum and maximum weekly and monthly working time agreements as well as general EU's Working Time Directive including minimum rest time between two activities and maximum consecutive working days. Additionally, the Red Cross implemented further regulations in agreement with all employees: Each employee has to have one weekend completely off per month and within each week there must be at least two consecutive days off.

Finally, each staff member has individual skills whereas each activity needs to be served by employees with a set of specific skills, resulting in a classical set-covering problem. To summarize, the problem at hand consists of three main decision levels:

1. Select activities to take place from the set of potential activities.
2. Choose a day out of the set of possible days on which the selected activity should take place.
3. Assign skilled staff members to the chosen activity-day combinations considering legal regulations as well as personal agreements of the employees.

We aim to minimize costs of overtime and costs of weekend hours, which for some employees are additionally compensated while others do not get extra payment on weekends, depending on the contract type. Simultaneously we strive to maximize the number of collected blood donations, given that each potential activity has an associated number of predicted participants. However, the above listed decision levels are highly interconnected, as decisions from part 1 and 2 highly affect costs arising from staff scheduling in part 3, rendering a purely hierarchical solution approach (without any feedback loop) ineffective.

Previous, comparable work on staff scheduling problems contain similar constraints as the ones mentioned above, see e.g. an extensive literature review by Van den Bergh et al. [1]. The problem of developing a staff roster for a fixed set of activities or projects has already been extensively studied. Column generation approaches dominate the literature (e.g., [2]). Heimerl and Kolisch [3] combine various planning stages (project selection and project scheduling with project staffing), but they do not incorporate legal constraints or availabilities of staff members. The novelty of our work is to combine different planning stages into one solution approach while simultaneously considering all real-world constraints concerning staff assignment decisions.

2 Methodology

Solving the full, monolithic model including all three decision stages simultaneously is intractable, when using a straightforward mixed-integer programming approach. Therefore, we split the problem into two hierarchically interleaved sub-problems:

We solve the staff rostering problem (decision level 3) using column generation where we assume that the decision which activities to organize on which days has already been made. The column generation master problem is composed of a classic set-covering formulation where for each chosen activity the required number of employees per skill needs to be assigned. The column generation pricing step involves a resource constrained shortest path problem in our case.

The decision, which activities to organize on which days (levels 1 and 2) forms the upper part of the optimization process. The two levels are then connected using a logic based benders decomposition (LBBD) approach, since the staff rostering sub-problem is an integer problem and not a pure LP. Within the LBBD master problem, we embed an estimate of the objective function, i.e., costs of overtime and costs of weekend hours, of the chosen activity-day assignment, while simultaneously maximizing the number of collected blood donations. Then, for a particular activity-day assignment, the LP relaxation already gives us a tight lower bound on the objective function. When solving the staff rostering problem to integer optimality, on the other hand, we are able to add (no-good) cuts to the LBBD master problem that will potentially bound the overall objective function value from below in an effective manner. Applied in an iterative fashion, it is thus possible to solve the overall problem including all three decision levels to optimality, by repeatedly adding those cuts.

We compare the presented solution approach with heuristic techniques, where we replace either both or a single sub-problem solver by a heuristic solution approach. We present computational results on randomized as well as real-world instances and thereby mimic the every-day decision process of the Viennese Red Cross blood donation services.

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