Days-Off Scheduling in Large-Scale Multi-Skill Staff Rostering: An Integer Programming Solution

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Keywords: Personnel Scheduling, Rostering, Days-Off Scheduling, Integer Programming

Staff scheduling and rostering typically involves a number of hierarchical subproblems including demand modeling, shift design, days-off scheduling, lines of work construction and staff assignment. When solving highly constrained large-scale rostering problems it is usually not computationally practical to deal simultaneously with all these tasks, and decomposing the problem into several separate modules is typical for most real-world solutions. The problem considered here focuses on the days-off scheduling phase of the rostering process, and has been tackled in the context of a large industrial project in the airport ground handling business.

Days-off scheduling has been extensively discussed in the literature in a variety of planning contexts and application areas, including many contributions from the area of nurse scheduling. Some recent papers presenting different models and solution approaches to days-off scheduling problems are listed below. Recent general surveys on personnel scheduling and rostering can be found in (Ernst et al 2004, Ernst et al 2004a, Alfares 2004 and Cheang et al 2003).

The main concern in days-off scheduling is to determine the off-work days for each staff member over the rostering planning horizon. In general, there are two categories of constraints to be considered. The first type is related to the individual line of work of each employee and originates from industrial regulations, labor contract, workplace agreements and individual preferences.

Typical examples of constraints are: the number of working days per month of each employee must meet some individually specified upper and lower bound; an employee must have at least one day off every week; he can work a maximum of seven days between two days off; if he works seven consecutive days he must have a minimum of three consecutive off-work days at least once within the same month; there should preferably be a minimum number of two consecutive work days between two days off; and so forth.

The other type of constraints refers to the individual days of the planning horizon and is concerned with satisfying the required daily staffing levels for each shift. According to the setting in our project, we assume that the required shifts and their staffing levels for each day have been determined prior to the days-off scheduling phase. Furthermore we assume a multi-skill staff environment, where shifts require certain skills and employees possess certain skills, and shifts can only be assigned to employees with appropriate skills. Hence staffing level constraints have to assure that on each day there are enough workers with appropriate skills for every shift.

In order to solve this type of multi-skill staff rostering problem an integer programming model has been developed with the following basic structure. For each person and each day a binary decision variable indicates whether that person is working on that day or not. In addition, a variety of other variables has been introduced to formulate the numerous and sometimes challenging constraints related to the individual lines of work. According to the specific requirements of the industrial project partner, a separation has been made between hard and soft constraints, and the latter have been dualized and managed through the objective function.

The constraints concerned with the daily staff requirements have been derived from the underlying daily shift assignment problems which must be guaranteed to have a feasible solution. Based on the well-known feasibility conditions for the assignment problem (corresponding to Hall's conditions in transversal theory), an exponential number of constraints can be generated to ensure feasibility of the daily shift assignment problems. These feasibility constraints basically say that for each day and each subset of active shifts, the total number of workers required for these shifts ("demand") must be less or equal to the total number of workers available for these shifts ("supply").

To avoid an intractable huge number of constraints, an additional integer programming model has been developed which iteratively constructs a subset of "most critical" feasibility constraints, i.e. constraints associated to subsets of shifts with minimum difference between supply and demand. These constraints are generated in an extensive preprocessing phase and added to the main model before solving.

The developed model successfully solves the complex large-scale problems posed by the industrial project partner. Typical problem dimensions are in the range of 500 - 800 staff members, 100 - 300 different shifts per day and up to 50 different skill combinations, yielding model sizes of more than 100'000 binary variables and constraints. The CPLEX 11.0 solver is able to find high quality solutions within a few hours which clearly outperform the sophisticated solutions constructed manually by the experts at the planning department of the industrial partner.

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