Multi-Contract Integrated Shift Design and Rostering

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According to the review by Ernst et al. [3], personnel scheduling is typically done in several stages, including demand modelling, shift scheduling, and line-of-work construction (rostering). In shift scheduling or shift design, the goal is to select shifts to use for covering the demand based on a wide range of possible shift start and end times. However, there are typically additional constraints to fulfil. For example, in Minimum Shift Design [2], the number of different shift start and end times in use across the scheduling horizon should be minimized to reduce complexity of the resulting employee schedules.

On the other hand, decisions in this phase can have significant impact in the next phase, which is called rostering. In this phase, specific rosters are designed for individual employees based on constraints about their total working hours, their allowed shifts (e.g., not all employees might be available for night shifts), their specified working days and many other rules. Further, legal and health-related rules need to be respected [4], e.g., regarding consecutive working days, required rest between shifts, and forbidden sequences of shifts.

In most work in literature, these stages are solved consecutively due to the complexity of the overall problem. Typical applications for problems showing both of these stages are call centres, but also nurse scheduling and production [6]. However, integrations of the two stages are rare [7]. On the other hand, in several problem classes the demand is based on certain tasks that need to be covered, e.g., legs in scheduling for public transport or airlines [1]. In these problems, integrations are more common, e.g., for integrated crew and vehicle scheduling, or for integrated scheduling and rostering.

Limitations of the Sequential Approach. Despite having good or even optimal solutions for shift design, it might be very difficult to find good solutions for the rostering stage or even lead to scenarios where no feasible solution can be found. In particular, reacting to spikes in demand promotes the use of short shifts as these are more flexible, but rostering a large number of short shifts for full-time employees can easily lead to scenarios where these do not have enough weekly hours considering the maximum number of shifts per week (e.g., they should work 5 shifts of 8 hours, but most shifts are around 5 hours).

A partial solution is to integrate extra constraints into the shift design phase. Bounds for average shift lengths [5] work well for a homogenous workforce, e.g., setting these constraints to a narrow window around 8 hours would allow good rosters for full time employees in the previous example. However, this technique can fail in more complex examples. One issue might be very uneven demand across days. In this case, constraints on the sequences of consecutive days might be hard to satisfy, e.g. if most of the workforce is required on Monday, but then there is a sharp drop to Tuesday, while at the same time individual working days are not allowed.

Another critical case is the existence of a heterogenous workforce, e.g., a combination of full-time and part-time employees. Restricting the average does not work in this case, as, e.g., a workforce consisting of 50 % full-time and 50 % part-time employees requires an average shift length of around 6 hours but preferably achieved by 8-hour shifts for full-time and 4-hour shifts for part-time employees. On the other hand, a different company might have part-time employees with different contracts, requiring fewer shifts with 6 hours, or even mix multiple types of part-time contracts.

Integrated Problem Formulation. Therefore, we propose an integrated formulation for combined shift design and rostering in the presence of multiple contracts, named the Multi-Contract Integrated Shift Design and Rostering Problem, which covers a real-life use case from a collaboration with the company XIMES GmbH. The problem demand is specified by a time series, giving the required number of employees at each point in time. This could be extended to multiple time series, e.g., also including required skills of employees. Constraints on shifts are specified by a set of shift types, each defining aspects including windows for shift start time, end time, and length, and allowed days. Contracts can specify rules for employees including, but not limited to constraints about:

- Required working time
- Maximum deviation from working time
- Allowed shift types per day
- Minimum and maximum number of shifts per week
- Minimum and maximum consecutive assignments
- Minimum and maximum consecutive rest days
- Forbidden shift sequences
- Minimum rest time between shifts

For each contract, the number of employees available under the contract is specified. For optimization, the goal is to balance the objectives taken from shift design (minimize overcover, minimize undercover, minimize number of different shift start and end times) with optional soft constraints on the contracts (e.g., there might be a hard minimum number of consecutive assignments of 2, a soft minimum of 3, or both of them at once).

Solution Approach. Based on the combination of rules from two different problems, the search space can be very large and include a large number of competing objectives to optimize, on the other hand, there is the potential for substantial gains in solution quality over the sequential approach. The current solution approach uses Simulated Annealing with multiple neighbourhoods:

– Add / remove / replace shift
– Move shift within / across contract
– Move multiple shifts within contract
– Replace all shifts with certain start and end time

Preliminary results show that the approach is able to provide high-quality solutions to real-life and real-life-based instances scheduling up to several hundred employees for a week that closely cover the demand while satisfying the contract-based constraints. Results also show a clear benefit over the sequential approach using the same solution method in two stages in scenarios with different contracts, validating the decision to solve the problem in an integrated style. Future work will include a more detailed evaluation of different moves, developing other solution approaches, and evaluating the approaches in more varied scenarios with different contract and demand structures.

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