Automatic Constraint Weight Extraction for Nurse Rostering: A Case Study

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Abstract

Nurse rostering is the complex problem of scheduling the shifts of nurses in hospitals. Scheduling by hand, which is still performed in many hospitals, is a relatively intensive and time consuming task, motivating the need for automated scheduling methods. Automatic scheduling, however, typically relies on accurate constraint weights. Manually defining constraint weights is often unintuitive even for the most experienced practitioners. In a case study we compare the amount of constraint violations of real-world manual rosters to the importance of constraints, as defined by nurses, and observe a mismatch between the two. Based on this real-world data we attempt to automatically extract constraint weights to allow for a more efficient and straightforward transition from manual to automatic scheduling.

Automatic scheduling is a constraint optimization problem that typically employs weighted sum objective functions due to their simplicity and ease of implementation. However, one disadvantage of these methods is that constraint weights are problem dependent and therefore expert knowledge is needed to set the correct weights. Many nurse rostering approaches in the literature that utilize weighted sum objective functions define their constraint weights with the help of health care practitioners [1]. Others simply set the weights by trial-and-error, without elaborating on the choice of values or on their effect on the overall quality of generated schedules.

Setting numerical values for the constraint weights required by automatic planners is simply not intuitive even for experienced practitioners. As part of a software training for the use of an automatic planner, head nurses in a given Belgian hospital ward were asked to manually define, based on their experience and intuition, the importance of all 50 constraints for their rosters. Despite their extensive experience in manually designing schedules, the head nurses found it difficult to set these “abstract” values. In addition, weights were chosen in only 6 discrete categories (namely 1, 200, 500, 750, 1000, 1500), where a lot of constraints have the same weight, giving a low resolution to this highly complex problem.

Although the automatic planner generated schedules with low overall penalty with respect to these weights, head nurses were often more satisfied after modification of the automatically generated schedules. As a consequence, the penalty of the resulting rosters increased, suggesting that the manually defined constraint weights do not correspond to the true importance of constraints.

For this reason, three years of manual schedules in the same hospital ward were evaluated in an attempt to automatically extract constraint weights, which were then compared to the manually defined weights. We employed statistical methods to determine the number (and magnitude) of violated constraints in these manual schedules, and to find out whether these violations correspond to the constraints' importance, defined by the head nurses. Initial analysis of these 36 hand-crafted monthly rosters confirms that manually determined weights do not accurately resemble the importance of constraints, based on the recorded violations. For example, some constraints with high weights were violated more often (and with a higher magnitude) than constraints with low weights for the same time period. It remains unclear, though, whether high-weighted constraints are violated more often because they are *difficult* to satisfy, or because they are *impossible* to satisfy, e.g. due to conflicting constraints.

We redefined the weight for each constraint to be proportional to the ratio of the number of times that constraint is respected in the manual schedules versus the total number of occurrences of that constraint. We applied a heuristic search approach [2] to automatically generate 36 schedules both with the old (manual) and with the new (automatically extracted) weights and calculated their total penalties.

For a fairer comparison, the weighted sum of constraint violations (or penalty) for each of the 72 rosters is computed using the old weights. We observed that schedules generated with the automatic weights have on average 20% lower total penalty than the manual schedules, while still closely resembling the latter in terms of respected and violated constraints. In contrast, schedules generated using the manual weights, despite their low total penalty, diverge from the constraint violation patterns of the manual rosters. Nevertheless, further validation by an expert is necessary to confirm whether the automatically extracted weights produce better schedules than the weights set by head nurses.

Further statistical analysis of the real-world data revealed also that constraints are not violated equally on both sides of the required limits. For example, for a given constraint, most violations lie slightly below the required minimum, while in a few instances the constraint is violated highly above its maximum. Such information, for instance, could be automatically determined from past data, combined with the automatically extracted constraint weights, and easily incorporated in the objective function of the automatic roster generator. Such improvements will not only result in better solution quality, but will also alleviate head nurses from the unintuitive and error-prone task of manually defining constraint weights.

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References

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