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Crew rostering with fair satisfaction of personal preferences

Extended Abstract

A. Wemans · J. Roussado · R. L. Saldanha

Abstract We address the personalised crew rostering problem in a context where each employee has his own skills, seniority and preferences, where all work has to be assigned and optimisation goals include maximising preference satisfaction and fairness. We propose an approach that combines operational research with auction theory for addressing scenarios where employees may prefer different things and seniority may not be strict, which have not yet been addressed. We evaluate the approach with real world data.

Keywords Personalised crew rostering · Fairness · Crew preferences

1 Introduction

The personalised crew rostering problem (PCRP) is well known in the transportation domain and can be stated in the following way: given a set of rosters each one defining a sequence of duties (a.k.a. pairings) and days off assigned in the past to a specific crew member with given skills, seniority and preferences, we want, as shown in Figures 1 and 2, to extend those rosters for a given planning period in the future, by assigning a given set of duties to the crew members in a way that all business rules are satisfied, all duties are assigned, and collective and individual preferences are satisfied as much and as fairly as possible. The individual preferences of an employee specify what he would like to do on certain days of the week/month/year (e.g. preference for early duties on Tuesdays and Thursdays). In this work, when we say that an assignment of duties to employees is fair, we mean that it is envy-free as defined in the literature (see Varian (1974)). As shown in Wedelin (1995), the crew rostering problem is NP-hard.

We address the PCRP in a context where some preferences may not be shared among all employees and where preference satisfaction is not distributed

A. Wemans · J. Roussado · R. L. Saldanha
SISCOG - Sistemas Cognitivos, SA
E-mail: rsaldanha@siscog.pt

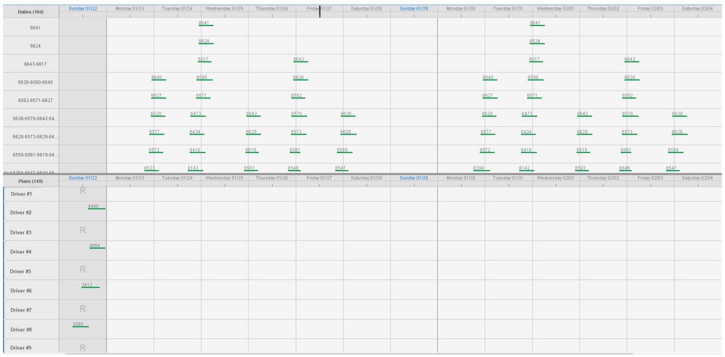

Fig. 1 A crew rostering problem where duties (above) have to be assigned to employees (below) in the form of rosters.

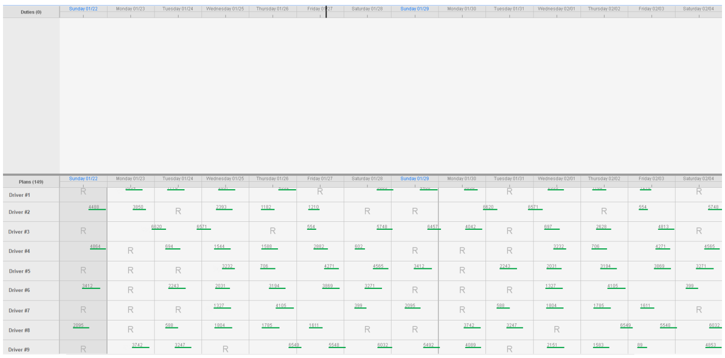

Fig. 2 A solution where all duties were assigned to employees in the form of rosters given as sequences of duties and days off (denoted by "R").

solely based on seniority, a combination of requirements that has not been addressed in previous work (Quesnel et al (2022), Quesnel et al (2019), Achour et al (2007), and Gamache et al (2007)). In this context fairness may be achieved with an uneven distribution of preference satisfaction even in scenarios where seniority is neglected.

2 Solution method

The PCRP is solved with an approximate solution method that can be described as an iterative process.

1. Compute fair preference satisfaction targets.
2. Build unimproved solution with a greedy heuristic.
3. Improve the solution with large neighbourhood search.
4. If not enough improvement achieved after several iterations or timeout reached, quit; otherwise go back to 2.

Step 1 aims at defining the component of the cost function related with preference satisfaction, which is given by the mean square error of the preference satisfaction with respect to a satisfaction target defined for each employee. These targets are calculated with a procedure, based on a multi-item auction (Demange et al (1986)) model, that simulates a bidding process where employees associate a monetary value with their bids according to their preferences. According to the corresponding seniority level each employee has a budget that is equal to the one of his colleagues with the same seniority level, in order to ensure fairness. The satisfaction target is an upper bound for the achieved preference satisfaction as it takes in consideration only a limited number of business rules, namely the ones related with skills.

Step 2 aims at building a solution to be used as a warm start for the improvement step. It uses a greedy heuristic combined with a dynamic programming procedure to generate roster extensions for each employee. In order to avoid building the same solution all over again, some algorithmic randomness was incorporated in the heuristic.

Step 3 aims at improving the solution produced in the previous step with respect to preference satisfaction and fairness while making sure all duties are assigned. It repeats a destroy and repair cycle until no further improvement is obtained. For each pair of calendar days it destroys the roster extensions for those days and repairs them with a known integer programming heuristic (Wedelin (1995)).

3 Computational evaluation

In order to evaluate our solution method we created seven problem instances based on a real world crew rostering problem from a northern European intercity railway operation where 3266 duties have to be assigned to 136 train drivers for a planning period of one month.

Table 1 shows the differences among the instances. Columns 2-4 show the percentage of drivers preferring different types of duties, and therefore how they compete more or less for the same duties. Column 5 shows if seniority is taken into consideration or not. Column 6 shows if the goal of satisfying the preferences fairly is active or not. Finally, column 7 shows if the goal of distributing evenly the workload among drivers, which is a collective preference, is active or not.

Results are shown in Table 2. Column 2 (3) shows the average preference satisfaction target of (achieved by) each employee. As mentioned in section 2 the former is an upper bound of the latter. Column 4 shows, as a measure of unfairness, the average standard deviation of the satisfaction of shared preferences. Finally, column 5 shows, as a measure of unevenness, the standard deviation of the workload assigned to each employee.

Results show that, by activating the preference goal, overall preference satisfaction increases from 22.51% to 50.20% (2.1 vs 2.2) and unfairness decreases from 17.18 to 1.00 (1.1 vs 1.2) or from 14.31 to 2.58 (2.1 vs 2.2). By

Table 1 Problem instances defining different seniority and preference scenarios and optimisation goals

Prob. inst.	Staff pref. early duties	Staff pref. late duties	Staff pref. night duties	Seniority?	Sat. prefs. fairly goal	Distrib. work evenly goal
1.1	100%	0%	0%	No	Off	Off
1.2	100%	0%	0%	No	On	Off
1.3	100%	0%	0%	Yes	On	Off
2.1	33%	33%	33%	No	Off	Off
2.2	33%	33%	33%	No	On	Off
2.3	33%	33%	33%	No	Off	On
2.4	33%	33%	33%	No	On	On

Table 2 Results for the problem instances shown in Table 1

Prob. inst.	Pref. sat. avg (ub)	Pref. sat. avg	Pref. sat. std	Workload std
1.1	36.61%	36.51%	17.18	-
1.2	36.61%	36.58%	1.00	-
1.3	36.56%	36.56%	18.37	-
2.1	66.55%	22.51%	14.31	4.48
2.2	66.55%	50.20%	2.58	5.38
2.3	66.55%	24.66%	11.08	0.28
2.4	66.55%	46.91%	7.97	0.49

activating the workload goal after activating the preference goal, the overall preference satisfaction and fairness decreases from 50.20% to 46.91% (2.2 vs 2.4). Results also show that, as competition for the same duties decreases, the preference satisfaction increases from 36.58% to 50.20% (1.2 vs 2.2). Finally, results demonstrate that, when seniority is considered, the unevenness of preference satisfaction increases from 1.00 to 18.37 (1.2 vs 1.3).

4 Conclusions

We addressed the personalised crew rostering problem in a context where each employee has his own skills, seniority and preferences, where all work has to be planned and optimisation goals include maximising preference satisfaction and fairness. We proposed an approach that combines operational research with auction theory for addressing a more generic case where employees may prefer different things and where seniority may not be strict.

We evaluated our approach with several instances of a real world crew rostering problem. In each of these instances one component of the input is changed, either the seniority policy, the preference distribution or the optimisation goals. By making pairwise comparison of the results we conclude that the solution method responds consistently to the changes in the input and maximises preference satisfaction and fairness in several contexts.

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