Referee Assignment for a Basketball League with Multiple Divisions using Local Search

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1 Introduction

The *referee assignment* is one of the classical problems in sport scheduling (see [4]). We consider a version of the referee assignment problem arising from an amateur basketball league with many divisions. The problem consists in assigning a variable number of referees to each game of the full season according to a set of constraints and objectives. In fact, games of different divisions have a different number of mandatory and optional referees.

For each referee we consider: address (with geographic coordinates), qualification, experience, incompatible teams/referees, and unavailabilities (day and time interval). In our scenario, a referee receives a lump sum for the performance plus a mileage allowance for the distance travelled. For this reason, the minimisation of the total amount of kilometres travelled is a critical aspect of our problem.

A match is represented by the following data: home team, away team, division, date, starting time, venue, and total required experience. We assume a maximum duration of two hours for every match and the number of mandatory and optional referees is inferred from the division.

As a matter of fact a venue may be shared by different teams, and a team can have more than one venue. At present, distances among venues and between referees and venues are calculated as Euclidean ones using the geographic coordinates.

Constraints refer to the suitable number and qualification of referees according to the level of the division to which each game belongs. Other constraints regard the maximum number of matches per day that a referee can attend (typically two) and the compatibility of games in terms of travelling time.

The objective function takes into account the total travelling of the referees (from/to home and between games), the number of assignments in the overall season, the fairness between referees on the number of assignments, missing optional referee, and lack of experience of the refereeing team.

Finally, the model also takes into account the unavailabilities and the possible incompatibilities among referees and between referees and teams.

2 Related work

A basic formulation of the referee assignment problem is provided by Duarte *et al* [2]. The main differences between our problem and the one of Duarte *et al* stem from the variable number of referees, the compatibility issues, and the fact that we allow travelling between game venues in the day.

The case of variable number of referees is taken into account, among others, by Lamghari and Ferland [5], which tackle to problem of assigning judges to projects in a fair way. Their formulation, however, is rather different from ours as they do not consider travelling minimisation, which is an important aspect of our problem.

On the other hand, this problem is also different from the well-known *travelling umpire* problem ([6]), given that our referees go home every night, as the distances they cover are limited.

3 Local search for referee assignment

For this problem, we implemented a local search method based on the following features:

Search space: The search space is represented by an array collecting all *referee slots* requested. Some of the slots might be taken by the *dummy referee*, which represents the absence of a referee for that slot. The search space is reduced by excluding *forbidden* assignments. An assignment is forbidden in the following cases:

A) a referee doesn't have the necessary qualification for the division of a match;
B) a referee is unavailable for the time of the match;
C) a referee is assigned to two matches either overlapping in time or incompatible it terms of travelling distance;
D) a referee is assigned more than once to the same match.

Initial solution: The initial solution is generated assigning a referee (including the dummy one) to each slot at random, but avoiding forbidden assignments (see conditions A-D above).

Neighbourhood relation: We use a composite neighbourhood relation, obtained by the union of the following two basic ones:

Replace: A referee is replaced by a new one in a given slot.
Swap: The referees of two slots (of different matches) are swapped.

The dummy referee is handled like a normal one and, according to the search space conditions, the moves leading to forbidden assignments are excluded from the neighbourhood.

Cost function: The cost function is composed by the objective function and the violations of some hard constraints, including the presence of the dummy referee in places where it is not allowed.

As metaheuristic technique, we resort to Simulated Annealing (SA), with geometric cooling and exponential acceptance rule (i.e., $e^{-\Delta/T}$); including also a cut-off mechanism that speeds-up the search in the early stage of the process.

The random move is generated by selecting first the atomic neighbourhood (Replace or Swap) and then the single move inside it. The first selection is performed according to a distribution controlled by a parameter $sr \in [0, 1]$ (*swap rate*), such that Swap is selected with probability sr and Replace with probability $1 - sr$. The latter selection is done uniformly.

4 Experimental analysis

We put together a set of 5 instances, obtained starting from a real scenario and completing it with the missing information (mainly referees' data, unavailable due to privacy issues). The main features of the instances are shown in Table 1.

Instance	Divisions	Teams	Matches	Referee slots	Venues	Referees
1	1	14	182	364	14	30
2	2	26	314	496	26	30
3	2	26	314	628	26	50
4	3	36	404	718	35	50
5	3	36	404	718	35	80

Table 1: Features of the instances

We set the total number of iterations for the SA solver equal to 10^8 iterations, corresponding to a running time of approximately 2 minutes on a single core of an i7 processor (3.40 GHz). We tuned the parameters using the tool JSON2RUN [7], which samples the configurations by means of the *Hammersley points* [3] and implements the F-Race procedure [1] for the comparison. The winning configuration is shown in Table 2.

Parameter	Value
Start temperature	488.0
Cooling rate	0.99
Moves sampled at each temperature	172117
Moves accepted at each temperature	11359
Swap rate	0.907

Table 2: Parameter configuration

For all instances we have found a feasible solution, with no incompatibilities and unavailabilities violated. The average distance travelled by each referee for a match is about 53Km. The number of matches with under-experienced refereeing team is 4.7%.

5 Discussion

At present, the problem is solved manually every week one round at the time. The comparison with the manual solutions is still ongoing, but at least our solver has the advantage of providing the complete solution at the beginning of the season, allowing the referees to better plan their activities. It also leads to a fairer partition of the games among the referees as this is part of the objective function. Obviously, the solution needs to be revised due to possible last-minute changes and unavailabilities.

For the future, we plan to collect and publish more instances, either real-world or artificial (by means of a generator), in order to test the solver on a larger set of situations. In addition, we want to complete the real-world ones with the missing data so that we can test and set up the solver for the next seasons of the league. Finally, we plan to design new solution methods in order to make a fair comparison of techniques.

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