Multi-Neighborhood Simulated Annealing for the Sport Timetabling Competition ITC2021

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1 Introduction

Sport timetabling is an active research field, mainly due to the commercial interest in the maximization of fan attendance (in person or remotely) to sport events. Among the various possible structures for sport competitions, the round-robin tournament is the most frequently used for most team sports.

We describe in this paper the solver that we developed for the Sport Timetabling Competition ITC2021, a three-stage Simulated Annealing approach, that makes use of a portfolio of six different neighborhoods. Five of them are classical ones, already proposed in the literature, whereas the sixth one, named PartialSwapTeamsPhased, is a variant of one of them that we specifically designed to deal with phased instances. Our solver has many parameters and it has been tuned using the FRACE procedure (Birattari et al., 2010), upon a set of experimental configurations designed using the Hammersley point set (Hammersley and Handscomb, 1964).

Overall, the final outcome is that the three-stage Simulated Annealing solver is able to find a feasible solution on 44 out of 45 instances and ranked second in both the first competition milestone and the final round.

2 Related Work

Interest in Sport Timetabling started growing from the 70s, with initial research by Gelling (1973), Russell (1980), Wallis (1983), de Werra (1981), and de Werra et al. (1990). Due to its complexity, (Rosa and Wallis, 1982; Dinitz et al., 1994), several metaheuristic and heuristic algorithms have been proposed for the Sport Timetabling Problem throughout the years. During the years 2000s, new neighborhoods for local-search-based metaheuristics were developed by Ribeiro and Urrutia (2004), Anagnostopoulos et al. (2006) and Di Gaspero and Schaerf (2007), as a consequence of rising interest in the Traveling Tournament Problem (Easton et al., 2001). More recent contributions to (meta)heuristic methods for Sport Timetabling are found in Lewis and Thompson (2011), Costa et al. (2012) and Januario and Urrutia (2016). Finally, Van Bulck et al. (2020b) proposed a unified data format for the round-robin sports timetabling, named RobinX, also employed in the Sport Timetabling Competition ITC2021 (Van Bulck et al., 2021). For a more complete bibliographic revision for sport timetabling we redirect the reader to Rasmussen and Trick (2008) and Kendall et al. (2010).
3 Problem Description

Many variants of the round-robin tournament problem have been discussed in the literature. We consider here the version proposed for the International Timetabling Competition ITC2021 (Van Bulck et al., 2021), which takes into account five types of constraints collected from real-world cases: capacity constraints, game constraints, break constraints, fairness constraints and separation constraints. This formulation has the peculiarity that every single specific constraint can be stated as either hard or soft, as they may express fundamental properties of the timetable and must be satisfied (hard version), or they may express preferences and can be violated (soft version). Another characteristic of the ITC2021 formulation is that it has abandoned the classical mirrored structure in which the second leg is identical to the first one, with home and away positions swapped. That is, the structure of ITC2021 instances is either completely free or phased, meaning that a team has to match all other teams in each leg (but not in the same order).

4 Solution Method

We designed a three-stage multi-neighborhood Simulated Annealing for the solution of the problem. As search space we consider the set of all two-leg round-robin timetables. The multi-neighborhood is a hexamodal neighborhood made up by a portfolio of six different local search neighborhoods, which are specifically tailored for the sport timetabling problem. Five of them, called SwapHomes, SwapTeams, SwapRounds, PartialSwapTeams, and PartialSwapRounds, are adaptations of classical ones from Ribeiro and Urrutia (2004), Anagnostopoulos et al. (2006), and Di Gaspero and Schaerf (2007).

The sixth one is a novel neighborhood called PartialSwapTeamsPhased, specifically designed to deal with phased instances. It is based on the concept of mixed phase, which is a partition of the timetable in two subsets, named mixed legs, where each couple of teams play together, respectively, for the first and for the second time. This definition is independent from the current satisfaction of the phase constraint. The move considers two teams and a set of rounds and swaps the positions of the two teams in the matches in the given set of rounds. A prerequisite is that the matches involved in the move must all belong to the same mixed leg. In this way, the move PartialSwapTeamsPhased swaps a subset of teams inside one of the two mixed legs and it is invariant with respect to the phase.

The metaheuristic employed is basically the classical Simulated Annealing defined by Kirkpatrick et al. (1983). The search is executed in three distinct sequential stages. Specifically, the first stage starts its search either from a random or from a greedy solution, the second and the third stages are warm-started with the output of the previous stage. The differences between the stages consist in the restrictions applied to the search space and in the exclusion or inclusion of certain constraints.

5 Experimental Results

Our code was developed in C++ and compiled with GNU g++ version 9.3.0 on Ubuntu 20.04.2 LTS. The tuning phase was partially performed on a cluster of virtual machines provided by the CINECA consortium. All the other experiments presented in this section were run on a machine equipped with AMD Ryzen Threadripper PRO 3975WX processor with 32 cores, hyper-threaded to 64 virtual cores, with base clock frequency of 3.5 GHz, and 64 GB of RAM. In both settings, one single virtual core is used for each experiment.

Table 1 reports the results obtained by the solver. The column Best solution found reports the best solution that our solver was able to find in all experiments. Some of these values are those that we submitted to the ITC2021 competition, others have been found in later experiments. When no feasible solution has been found, the number of hard violations followed by a letter H is reported. Next columns, labeled Average values, report the data obtained in a set of experiments that we run independently from the competition, in order to extract information on the average behavior of the algorithm in its final configuration. At least 48 runs per instance were performed to collect these data. Columns Cost and Time report, respectively, the average values of the objective function and the average time needed for a complete run of the three stages. Regarding the average cost, the value is computed only on feasible solutions. Column Feasible reports the ratio between feasible solutions and total runs. Finally, column Best known cost contains the best known results at the moment this
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| Instance   | Best solution found | Average values | Best known cost | Feasible |
|------------|---------------------|----------------|-----------------|----------|
| Early_1    | 424                 | 540.7          | 5667            | 1.00     |
| Early_2    | 318                 | 384.6          | 14843           | 1.00     |
| Early_3    | 1068                | 1176.5         | 12194           | 1.00     |
| Early_4    | 556                 | 1007.8         | 8759            | 0.56     |
| Early_5    | 4117                |  -             | 28517           | 0.00     |
| Early_6    | 3927                |  4543.0        | 35161           | 1.00     |
| Early_7    | 5205                |  6721.7        | 37486           | 1.00     |
| Early_8    | 1051                | 1151.9         | 21394           | 1.00     |
| Early_9    | 132                 | 228.7          | 10324           | 1.00     |
| Early_10   | 4986                |  -             | 35856           | 0.00     |
| Early_11   | 4526                |  5784.5        | 43992           | 1.00     |
| Early_12   | 1010                | 1200.2         | 14726           | 1.00     |
| Early_13   | 173                 | 233.8          | 19675           | 1.00     |
| Early_14   | 63                  | 82.3           | 5616            | 1.00     |
| Early_15   | 3556                | 3945.8         | 46714           | 1.00     |
| Middle_1   | 5657                |  6075.0        | 26290           | 0.06     |
| Middle_2   | 581                 |  -             | 26890           | 0.00     |
| Middle_3   | 9542                | 11403.1        | 44748           | 0.23     |
| Middle_4   | 16                  |  33.0          | 5660            | 1.00     |
| Middle_5   | 510                 |  624.4         | 6223            | 1.00     |
| Middle_6   | 1701                | 21183.3        | 21350           | 1.00     |
| Middle_7   | 2203                | 2452.7         | 16303           | 1.00     |
| Middle_8   | 136                 | 196.6          | 19717           | 1.00     |
| Middle_9   | 640                 | 772.1          | 17610           | 1.00     |
| Middle_10  | 1357                | 1687.5         | 14432           | 1.00     |
| Middle_11  | 2696                | 2996.5         | 43876           | 1.00     |
| Middle_12  | 950                 | 1054.2         | 14599           | 1.00     |
| Middle_13  | 362                 | 479.3          | 15687           | 1.00     |
| Middle_14  | 1172                | 1304.6         | 37483           | 1.00     |
| Middle_15  | 985                 | 1099.7         | 8704            | 1.00     |
| Late_1     | 2021                | 2573.7         | 20242           | 1.00     |
| Late_2     | 5715                | 6085.5         | 41432           | 0.49     |
| Late_3     | 2457                | 2718.0         | 18327           | 1.00     |
| Late_4     | 0                   | 0.0            | 2154            | 1.00     |
| Late_5     | 2341                | -              | 9190            | 0.00     |
| Late_6     | 930                 | 1121.3         | 7121            | 1.00     |
| Late_7     | 1765                | 2226.5         | 22959           | 1.00     |
| Late_8     | 997                 | 1155.3         | 11265           | 1.00     |
| Late_9     | 715                 | 881.2          | 25963           | 1.00     |
| Late_10    | 2571                | 3527.3         | 32511           | 0.05     |
| Late_11    | 207                 | 289.3          | 15891           | 1.00     |
| Late_12    | 3944                | 4830.6         | 35153           | 1.00     |
| Late_13    | 1868                | 2285.5         | 21006           | 1.00     |
| Late_14    | 1202                | 1320.3         | 39160           | 1.00     |
| Late_15    | 60                  | 82.8           | 6424            | 1.00     |

Table 1: Best and average results

We also assessed the impact of the new neighborhood `PartialSwapTeamsPhased`. To do so, we run an additional set of experiments on phased instances with and without making use of `PartialSwapTeamsPhased`. We highlight that employing the new neighborhood `PartialSwapTeamsPhased` brings benefit to the majority of the 22 phased instances: in 17 of these the average cost improvement is 4.24%. One of the remaining five was solved to feasibility only in the configuration that employs `PartialSwapTeamsPhased`. The other four are not solved by any of the two configurations in the given number of runs.
6 Conclusions

In this study, we considered the version of the Sport Timetabling Problem proposed for the ITC2021 competition. We tackled the problem employing a three-stage multi-neighborhood Simulated Annealing approach, which makes use of six different neighborhoods. In particular, the neighborhood that we named PartialSwapTeamsPhased is a novel contribution. Finally, we performed a parameter tuning for the solver using the F-RACE procedure that allowed us to find a set of parameters values for this problem.

This approach managed to find a feasible solution for 44 out of the 45 instances proposed by the competition. Feasible solutions were found rather easily for most of the instances, however the metaheuristic struggled to produce feasible solutions for certain instances, even in long execution times. The results obtained by the Simulated Annealing approach allowed us to rank second out of 13 participants in the final ranking of the competition.

Future work will be devoted to improve the results and performances on both the considered instances and on other benchmark instances for round-robin tournament. We think that relevant advancements can be achieved through a wider study and application of the PartialSwapTeamsPhased neighborhood on a larger set of instances. Possible research directions may also include the definition and integration of new neighborhoods in the Simulated Annealing algorithm, and the implementation and evaluation of new greedy techniques to generate different initial solutions, not restricted to the canonical pattern. Further research may also be committed to develop a matheuristic approach, such as Large Neighborhood Search (LNS), which embeds exact methods in our Simulated Annealing algorithm.

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