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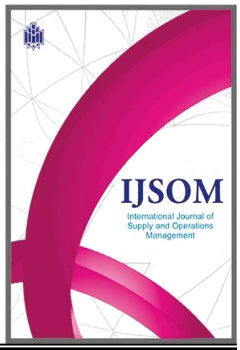

Integrated Scheduling of Sports Events: A Macroscopic Perspective

Mehdi Iranpoor[a*], Ali Aghadavoudi Jolfaei[a], Mohammadreza Batavani[b]

[a] *Department of Industrial and Systems Engineering, Isfahan University of Technology, Isfahan, Iran*
[b] *Department of Physiology, Faculty of Center of Physical Education, Isfahan University of Technology, Isfahan, Iran*

Abstract

The scheduling of sports events has a high degree of complexity due to the large number, diversity, and the interdependence of events as well as the existence of conflicting objectives. The present study investigates the integrated scheduling of multiple types of sports events simultaneously. A variety of sports events, including competitions, management meetings, training camps, and training workshops, are scheduled simultaneously regarding the appropriateness of the timeslot for each event and the suitability of the length of the time interval between each pair of events. Previous studies were limited to detailed scheduling of single types of events. For instance, they determine when and where each team plays with other teams. However, the current paper takes a macroscopic view and sets the timeslots in which the competitions and other types of events will be held. The part of output which sets the competition timeslots can be further given as input to one of the existing algorithms which determine the detailed schedule of competitions. An integer programming formulation is developed. Numerical examples demonstrate that the general-purpose solvers cannot obtain the optimal solution of real-sized problems within an acceptable time. To solve larger problems, the fix-and-optimize matheuristic approach is employed. Numerical results show the satisfactory performance of this approach. To validate the proposed method, the sport events of the Karate Federation of Iran for a whole year are scheduled as a real case study. Finally, using the data of this case study, a sensitivity analysis is performed for some of the parameters.

Keywords: Sports scheduling; Multiple sport events; Integer programming; Fix-and-optimize matheuristic; Case study; Sensitivity analysis.

1. Introduction

Scheduling has an essential role in sports management. It is a critical task since sport events involve massive investments and millions of fans (Kendall et al, 2010; Pinedo, 2005). Sports scheduling represents an important application field of operations research methodologies. The fields of operations research and theory of scheduling originated in the 1940s and 1950s, respectively. However, operations research was employed primarily in the 1990s to schedule sports events (Wright, 2016).

The tournaments scheduling problem is one of the most studied areas in sports scheduling (Kendall et al, 2010). De Werra (1981) was one of the first researchers who examined the problem of sports planning and used graph theory to schedule sports events. Some studies address the scheduling of single or double round-robin competitions.

Wright (2018) presented a timetable for England amateur cricket double round-robin league for a nine-year period. He implemented the simulated annealing algorithm to solve the problem. Urban and Russell (2003) have investigated the planning of the competitions and allocation of the venues. They developed a goal programming approach for this problem. Russell and Urban (2006) also solved the above problem with a two-stage constraint programming procedure. Rasmussen and Trick (2007) studied the constrained minimum break problem in planning the double round-robin tournaments aiming to minimize the number of consecutive matches of a team at home or away. They have considered the venue as a resource

*Corresponding author email address: iranpoor@iut.ac.ir
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and used the Benders decomposition algorithm to solve the problem. Briskorn (2011) developed an IP formulation to find a minimal cost single round-robin tournament considering a minimum number of breaks, stadium unavailability, fixed matches, and regions' capacities. Recalde et al. (2013) tackled the problem of scheduling the Ecuadorian football league. In addition to the minimization of consecutive matches of the teams as host or away, some notion of the fair plan was also considered. They presented an integer programming formulation and a heuristic algorithm to solve the problem. In most sports leagues, first the sequence and venues of the matches are determined. Afterwards, the matchdays are scheduled. Çavdaroğlu and Atan (2020) determine the dates of the tournament matches by considering the fair rest conditions of the teams. They proposed a polynomial-time exact algorithm for scheduling the matches.

Another class of studies considers the traveling distances of the teams as the objective function. Durán et al. (2019) have proposed an integer programming model to minimize the traveled distance of the teams to perform matches for the professional basketball league of Argentina. Their problem is a variation of the traveling tournament problem in which the day of the week for each game is also determined. In addition to minimizing the traveled distance for performing matches, Kim (2019) has considered match and attendance fairness in his study. He has developed a mixed-integer linear programming formulation for the South Korean baseball league and developed a decomposition heuristic based on the fix-and-optimize (F&O) approach. Chandrasekharan et al. (2018) studied the traveling umpire problem. They tackled assigning umpires to games in such a way that minimizes the travel distances. Bender and Westphal (2016) considered umpires along with teams. In this problem, the goal is to find a schedule with minimum total travelled distances of both teams and umpires. Kyngäs et al. (2017) considered travel distances and balancing breaks, simultaneously. They proposed a three-phase heuristic algorithm to solve the problem of the Australian Football League. In another study, Günneç and Demir (2019) proposed a different objective function. They presented an objective function to minimize the carry-over effects in round-robin tournaments. They implemented a heuristic algorithm to schedule the Turkish professional football league.

Van Bulck and Goossens (2020) considered time-relaxed timetables to confront player and venue availability constraints. They presented some measures to consider fairness issues. They formulated this problem in several integer programming formats and implemented adaptive large neighborhood search and memetic algorithms to solve the problem. In another study, Van Bulck and Goossens (2021) implemented the relax-and-fix (R&F) and F&O heuristic algorithms for scheduling time-relaxed timetables. They proposed two approaches for variable partitioning: one based on time and another based on team variables. They showed that F&O performed better than R&F heuristic and also a team-based variable partitioning worked better than time-based variable partitioning.

Another part of studies on sports scheduling, investigates on referees scheduling and assigning them to matches. Durán et al. (2021) studied the problem of assigning referees to the games. They utilized a method based on integer linear programming model and used Argentinean professional basketball league. Mancini and Isabello (2014) studied referee assignment in the Italian soccer league (SERIE A). They proposed objective function as minimizing the violation of optional constraints, while satisfying all the hard ones. Atan and Hüseyinoğlu (2017) considered the referee assignment simultaneously with the games scheduling. They designed a genetic algorithm and studied the Turkish football league.

To the best of the authors' knowledge, all of the publications of sports scheduling have dealt with detailed scheduling of a single type of event. However, this paper takes a macroscopic view and determines the time of occurrences of multiple event types. In other words, for instance, this paper does not deal with when and where team A plays with team B. Instead, it sets the timeslots in which the competitions (as one of the event types) and other types of events should be held. It is worth mentioning that the part of the output schedule that sets the competition timeslots can be further given as input to one of the existing algorithms which determines the detailed schedule of competitions (e.g., when and where team A plays with team B).

The contributions of the present paper are threefold. First, the previous studies in the sports scheduling area were limited to one type of event (e.g., competitions). This study schedules multiple types of sports events simultaneously, including but not limited to the management meetings, workshops, sports camps, and competitions. Second, this study considers the suitability and permissibility of timeslots for performing each type of event. Third, this study regards the appropriateness of the length of time interval between occurrences of each pair of events.

The rest of the paper is organized as follows. Section 2 states the problem, introduces the notations, and develops the integer programming formulation. Section 3 proves the NP-hardness of the problem and develops the fix-and-optimize matheuristic algorithms. Section 4 analyzes the efficiency and effectiveness of the heuristic algorithms. Section 5 examines the weekly planning of sports events for the Iran Karate Federation as a real case study. Further using the data of this case study, the sensitivity analysis of the parameters is conducted in this section. Finally, the last section concludes and recommends some areas for future research.

2. Problem Statement

This paper studies the integrated scheduling of multiple types of sports events simultaneously. There are some constraints and preferences which can be classified into four categories. The first category is the inconsistencies of events. For instance, when two events require the same resource, these two events may not be carried out simultaneously. These resources include players, common stadiums, coaches, referees, and senior executives. The second category could be considered as precedence relationships between the events. The third category would ensure a suitable length of time between events. Finally, the last category is related to the impossibility of carrying out an event in some timeslots.
The assumptions of the problem are as follows:

- Location and traveling of teams and exact time of matches are not considered. The paper has a macroscopic view while part of its output, which determines the timeslots of competitions, can be further fed into a detailed scheduling algorithm like round-robin scheduler.
- The planning horizon would be finite and consists of timeslots with equal duration.
- Events can be individual (i.e., of single occurrence) or repeating (i.e., with multiple occurrences).
- The frequency of events, preferences, and constraints of timeslots for performing each event, and precedence relations between the events are given.
- Every occurrence of each event is assigned to one timeslot.
- Each timeslot can accommodate no event, one event, or multiple consistent events.
- The entire data of the problem are deterministic and known in advance.

Table 1 introduces the parameters that appear in the paper.

Table 1. Parameters

W	Number of timeslots
N	Number of sports events
n_i	Frequency of event i
c_{ij}	Cost of performing event i in timeslot j
$q_{ii'jj'}$	Cost of performing event i in timeslot j, event i' in timeslot j', and no occurrence of these events between timeslots j and j'
$m_{ii'jj'}$	A binary parameter, being one means that it is possible to perform event i in timeslot j and event i' in timeslot j'simultaneously
a_{ij}	A binary parameter, being one means the possibility of performing event i in timeslot j
$\Delta_{ii'}$	The shortest permissible interval (in terms of the number of timeslots) between an occurrence of event i' and the first occurrence of its prerequisite event i. The parameter takes zero when i is not a predecessor of i'.
ω	Relative importance factor of components of the objective function

It is important to consider permissible intervals between consecutive occurrences of an event. For instance, the time between two consecutive workshops for referees must be within an acceptable interval. Further, a minimum gap may be required between the last occurrence of an event and the first occurrence of another one. This finish-to-start relationship is very common in sports planning. For example, training camps should be completed some weeks before the start of the international championship. Parameters $q_{ii'jj'}$ and $m_{ii'jj'}$ and variable $y_{ii'jj'}$ are used to accommodate both of these concerns.

The decision variables are introduced in Table 2.

Table 2. Decision Variables

x_{ij}	The binary variable, being one means an occurrence of event i is performed in timeslot j
$y_{ii'jj'}$	The binary variable, being one means an occurrence of event i is performed in timeslot j, an occurrence of event i' is performed in timeslot j', and no occurrence of these events is performed between timeslots j and j'

The mathematical programming formulation of the problem is as follows.

P:

$$Min\ Z = \omega \sum_{i=1}^{N} \sum_{j=1|a_{ij}=1}^{W} c_{ij} x_{ij} + \sum_{i=1}^{N} \sum_{j=1|a_{ij}=1}^{W} \sum_{i'=1}^{N} \sum_{j'=j|a_{i'j'}\ ,m_{ii'jj'}=1}^{W} q_{ii'jj'}\, y_{ii'jj'} \qquad (1)$$

$$y_{ii'jj'} \geq x_{ij} + x_{i'j'} - \sum_{j''=j+1|n_i>1\ and\ a_{ij''}=1}^{j'-1} x_{ij''} - \sum_{j''=j+1|n_{i'}>1\ and\ a_{i'j''}=1}^{j'-1} x_{i'j''} - 1; \qquad (2)$$

$$\left(j < j'\ or (j = j'\ and\ i < i')\right), a_{ij} = 1, a_{i'j'} = 1, m_{ii'jj'} = 1$$

$$x_{i'j'} \leq \sum_{j=1|a_{ij}=1, m_{ii'jj'}=1}^{j'-\Delta_{ii'}} x_{ij}\ ; \qquad i, i', j' | \Delta_{ii'} > 0, a_{i'j'} = 1 \qquad (3)$$

$$\sum_{j=1|a_{ij}=1}^{W} x_{ij} = n_i\ ; \qquad i = 1, .., N \qquad (4)$$

$$x_{ij} + x_{i'j'} \leq 1\ ; \qquad i \leq i', j, j' |\ m_{ii'jj'} = 0\ , a_{ij} = 1\ , a_{i'j'} = 1 \qquad (5)$$

$$x_{ij} = \{0,1\}; \qquad i, j | a_{ij} = 1 \qquad (6)$$

$$y_{ii'jj'} = \{0,1\}; \qquad i, i', j \leq j' | a_{ij} = 1, a_{i'j'} = 1 \qquad (7)$$

The objective function of the problem (i.e., Equation (1)) includes the minimization of two penalties. The first term penalizes events that are planned at inappropriate times in the planning horizon. On the other hand, the second term is the total undesirability of all pairs of events planned in an ill-timed manner relative to one another.

Constraint (2) calculates binary variable $y_{ii'jj'}$. This variable is one if x_{ij} and $x_{i'j'}$ are one and no events of type i or i' is performed between timeslots j and j'. In the cases that this constraint is not binding, $y_{ii'jj'}$ will be zero since it appears in the objective function of the minimization problem with non-negative coefficient $q_{ii'jj'}$.

In some cases, the first occurrence of an event (e.g., i') can only happen if some interval time has passed since the first occurrence of its prerequisite event (e.g., i). The lag in this start-to-start relationship is defined by $\Delta_{ii'}$. This type of precedence may also occur in sports planning. For instance, the evaluation and selection of the players for the national team may be triggered only if some weeks have passed since the start of the national league. Constraint (3) ensures the establishment of these prerequisite relations. Constraint (4) guarantees that the number of timeslots assigned to each event must be in accordance with its frequency. Constraint (5) shows the impossibility of carrying out two inconsistent events simultaneously. Finally, constraints (6) and (7) determine the domain of the decision variables.

3. Solving Algorithms

In this section, the computational complexity class of the problem is demonstrated at first. Then multiple variations of the fix-and-optimize algorithm are developed to solve the problem.

3.1. Investigating the Computational Complexity of the Problem

Theorem 1. Problem P is NP-hard.
Proof. To prove the theorem, it suffices to demonstrate that this problem contains a previously known NP-hard problem as a special case (Garey & Johnson, 1979). In other words, it should be shown that any instance of a previously known NP-hard problem can be transformed in polynomial time into an equivalent instance of problem P (Garey & Johnson,

1979). Quadratic assignment problem (QAP) is an NP-hard problem with the following definition (Garey & Johnson, 1979):
Given, non-negative integer costs c_{ij}, $1 \leq i, j \leq n$ and distances d_{kl}, $1 \leq k, l \leq m$, find a one-to-one mapping $f: \{1, \cdots, n\} \rightarrow \{1, \cdots, m\}$ which minimizes $\sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} c_{ij} d_{f(i)f(j)}$.
Consider a special case of the problem P with $N = n$ events and $W = m$ timeslots with the following characteristics:
- The frequency of each event is one (i.e., $n_i = 1$).
- There is no absolute cost of assigning an event to a timeslot (that is, $c_{ij} = 0$).
- No pair of events are allowed to be performed simultaneously (that is, $a_{ij} = 0$).
- There is no prerequisite relations between events (that is, $\Delta_{ii'} = 0$).
- Each pair of events can be performed in all distinct pairs of timeslots (that is, $m_{ii'jj'} = 1$).
Clearly, every instance of QAP can be transformed to the above special case of problem P in polynomial time by setting $q_{ii'jj'} = c_{ii'} \times d_{jj'}$. Since QAP is an NP-hard problem, problem P is also NP-hard. □

3.2. Fix-and-Optimize Matheuristic Algorithms

According to the NP-hardness of problem P, it seems unlikely to obtain an optimal or even approximate solution for the real world instances in a reasonable time. Therefore, this section develops multiple variations of the fix-and-optimize matheuristic to solve the problem. According to the literature, the fix-and-optimize algorithm has a wide range of applications in scheduling.

This algorithm consists of two steps. In the first step, a feasible initial solution is generated. For this problem, randomly generated solutions and the solutions which are generated by constructive heuristics like relax-and-fix algorithm are in danger of infeasibility. Hence, these approaches cannot be used. Instead, we run the Cplex solver for a short time to find an initial solution.

The second step tries to improve the existing solution. At each iteration of this step, a subset of variables is fixed to their current values, and the resulting subproblem of the remaining variables is solved (Turhan and Bilgen, 2020). We have developed five different approaches to select the variables to be fixed. These approaches are as follows.

- Random timeslots: A subset of timeslots are randomly selected, and all of the variables of these timeslots are fixed.
- Random events: A subset of events is randomly selected. Then all of the variables of these events are fixed.
- Rolling events: A number of events with sequential indices are selected in a rolling and forward manner. Then all of the variables of these events are fixed.
- Rolling timeslots: A number of consecutive timeslots are chosen in a rolling and forward manner. Then all of the variables of these timeslots are fixed.
- Adjacent timeslots: A series of consecutive timeslots are randomly selected, and their variables are fixed.

The general flowchart of the developed fix-and-optimize algorithms in this paper is shown in figure 1. In these algorithms after determining the fixing approach, relevant parameters should be set. After initializing algorithm, a feasible initial solution is constructed. To this purpose, we run Cplex solver in a predetermined short time. The obtained solution, is an initial solution that is improve iteratively. In the improvement phase, a fix-and-optimize strategy is applied. First, according to variable fixing approach, a subset of binary variables in the best-found solution, is selected and the values are fixed. Then obtained subproblem is solved using Cplex. If the new solution is better than best-found solution, best-found solution is updated, else another subset of variables is selected and the mentioned process is repeated as long as the stop condition (execution time) is established.

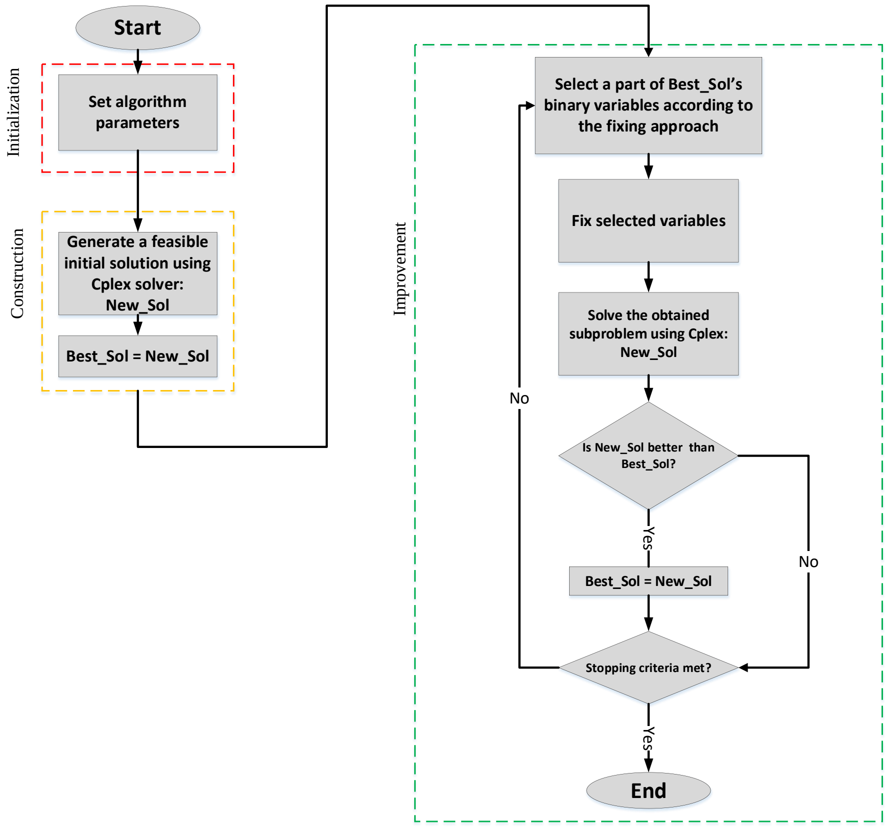

Figure 1. General flowchart of the proposed fix-and-optimize matheuristics

4. Numerical Results

In the previous section, five variations of fix-and-optimize matheuristic algorithm were developed to solve the problem. In this section, the efficiency of these algorithms is investigated. To this end, some instances are generated randomly. Three parameters are considered as the input to create these instances. The first parameter is the number of timeslots, which is considered from 20 to 50. The second parameter is the number of events. This parameter is considered proportional to the number of time slots. And the last parameter would determine the average frequency of event types. All examples were solved using Cplex 12.9.0 in GAMS 27.1.0 on a computer with a Core i7 processor and 16 GB RAM.

Table 3 demonstrates the results of solving problem instances. We examine the performance of the designed algorithms in comparison to Cplex by solving 20 instances made. The time constraint for Cplex was set to 3600s. In contrast, the stopping condition of the developed matheuristic algorithms was considered to be 600 seconds. The best-found solutions are highlighted in Table 3.

It is evident that for the first group of instances, except instance number 4, Cplex performs the same as the developed algorithms. Moreover, in instance number 4, Cplex has performed very close to the developed algorithms. For the other instances with larger sizes than 20 timeslots, all proposed algorithms outperform Cplex. Further, as shown in Table 3, the *Random events heuristic* has the best performance. Figure 2 compares the objective function values of the Cplex and this heuristic for these examples.

Table 3. Numerical results

#Instance	Timeslots	Events	Average frequency	Cplex		Objective function values of the proposed heuristics				
				Objective	Time (sec)	Adjacent timeslots	Random events	Random timeslots	Rolling events	Rolling timeslots
1	20	9	5	149.6	417	149.6	149.6	149.6	149.6	149.6
2				201.7	3600.0	201.7	201.7	201.7	201.7	201.7
3				401.6	3600.1	401.6	401.6	401.6	401.6	401.6
4				228.0	3600.3	228.0	227.2	227.2	228.0	227.2
5				201.7	3600.2	201.7	201.7	201.7	201.7	201.7
6	30	15	7	623.9	3600.9	583.3	576.7	577.6	577.6	576.7
7				1209.3	3601.3	997.3	932.7	981.5	932.7	969.8
8				862.3	3601.1	776.5	775.6	775.6	775.6	775.6
9				543.8	3600.8	541.4	486.1	541.4	486.1	541.4
10				1183.1	3601.1	1046.5	994.8	1121.8	1025.6	1152.7
11	40	18	9	767.5	3602.3	519.5	436.3	556.5	476.8	477.1
12				799.7	3602.6	540.2	445.7	570.6	489.1	624.6
13				292.9	3601.9	278.2	264.9	264.9	264.9	292.9
14				347.8	3601.1	346.4	327.5	346.4	343.3	343.3
15				1081.5	3602.9	709.4	513.5	648.6	522.2	723.5
16	50	20	10	215.5	3603.4	178.9	170.6	172.3	172.3	172.3
17				813.2	3605.7	296.1	262.4	274.4	262.4	274.4
18				478.4	3605.2	287.1	262.5	266.9	262.5	266.9
19				1536.5	3606.1	697.1	681.9	683.4	683.4	696.2
20				478.4	3604.9	276.3	255.7	276.3	255.7	267.7

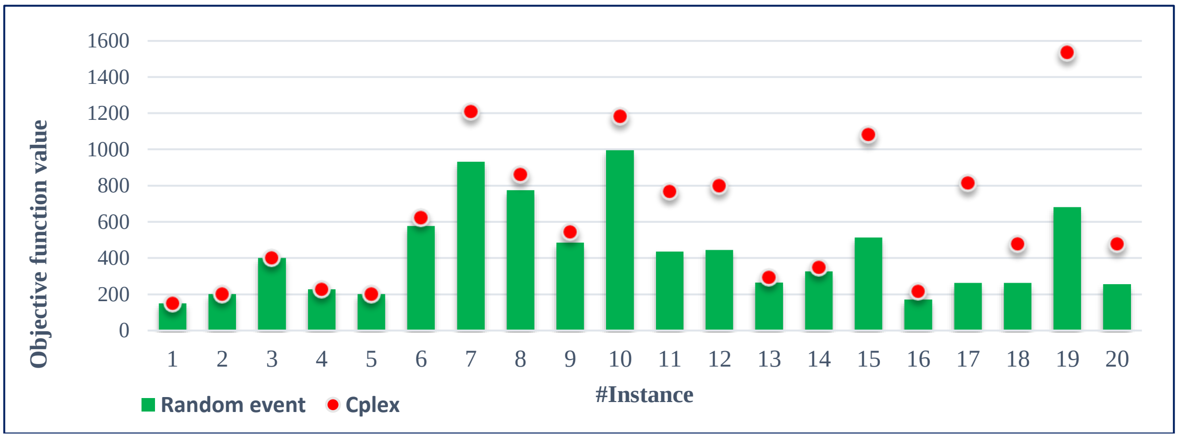

Figure 2. Performance of the Random events heuristic vs. Cplex

5. Case study of Iran Karate Federation

In this section, the scheduling of sports events of the Karate Federation of Iran is studied. Section 5.1 introduces the problem. Section 5.2 presents the generated schedule. Finally, Section 5.3 analyses the effects of changes in some parameters.

5.1. Case Study Statement

In this case, planning is carried out on a weekly basis for a one-year horizon. The list of events of the Karate Federation is shown in Table 4. The frequency column demonstrates the number of occurrences of each event in the time horizon. The last column indicates whether the event is planned by the federation or is fixed by other organizations.

Table 4. List of sports events in the one-year planning horizon

Events	Abbreviation	Frequency	To be scheduled/Fixed dates
Iran League Championships	League	10	To be scheduled
Karate Series A & Premier League	Series A	11	Fixed dates
Asian Championships	Asia	1	Fixed dates
World Championships	World	1	Fixed dates
Dispatch to Multisport Event & International tournaments	Dispatch	1	To be scheduled
Host of Multisport Event & International tournaments	Host	2	To be scheduled
Iran National Championships	National	1	To be scheduled
National team training camp	Training	13	To be scheduled
Selective National team training camp	Selective	3	To be scheduled
Strata sports competitions	Strata	3	To be scheduled
Provincial chief elections	Elections	8	To be scheduled
Annual executive committee meeting	Meeting	1	To be scheduled
Referees seminar	Referees	6	To be scheduled
Coaches seminar	Coaches	6	To be scheduled
Dan (belt) Exam	Dan	2	To be scheduled

Figure 3 exhibits the precedence diagram of the events. The arcs represent the precedence relation between the corresponding events, while the numbers written beside the arcs indicate the minimum required lag between the predecessor and successor. In addition, in the case of recurring events, the numbers written inside a loop represent the minimum lag between two consecutive occurrences of the corresponding event. As an example, the Selective National team training camps (Selective) are predecessors of the Asian championship (Asia). In this case, the final occurrence of the former should be carried out at least two weeks before the (first) occurrence of the latter. Moreover, according to the number in the attached loop to the Selective National team training camps (Selective), the time interval between two consecutive occurrences of this event has to be at least three weeks.

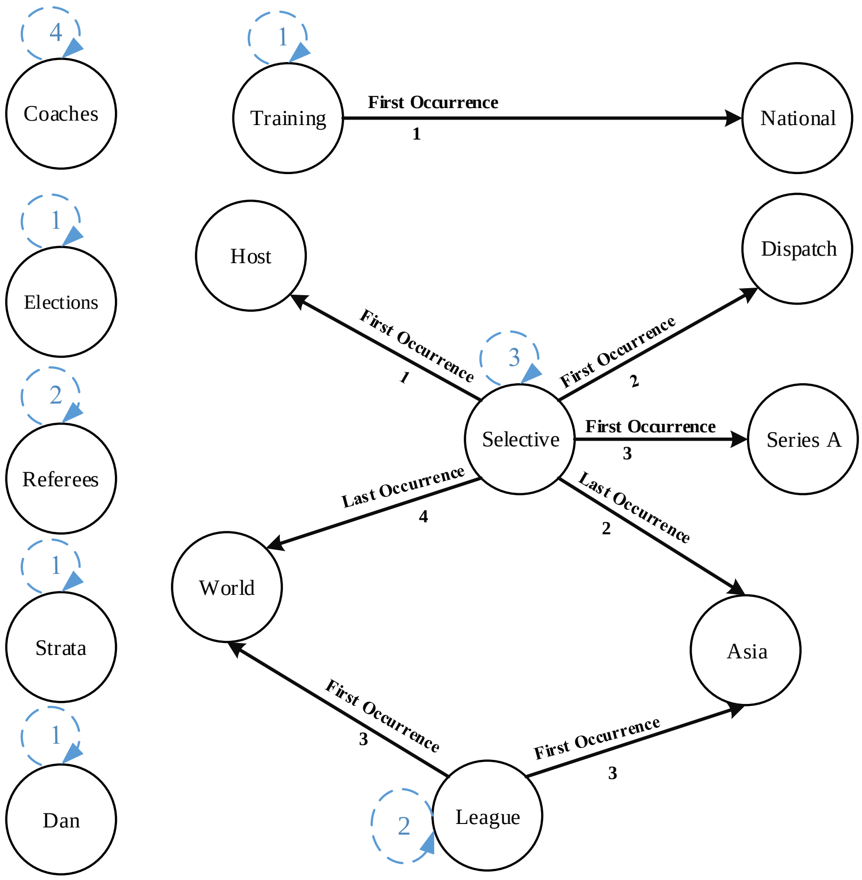

Figure 3. Precedence diagram of the events

Table 5 represents the quantities of the parameters of permissibility and penalty of performing events. The values of parameters of the possibility of performing each event in each timeslot, as well as the cost of performing these events (inappropriateness), are depicted in Figure 4. These values were determined through interviews with experts in this field. In order to calculate the appropriateness of any event per week, factors such as the practice cycles of athletes, holidays, and the presence of a valid international event are considered in that week (extracted from the International Federation of Karate and sportdata.org).

Table 5. The quantification of permissibility and cost parameters

	Not allowed	Undesirable	Neutral	Desirable	Strongly desirable
a_{ij} and $m_{ii'jj'}$	0	1	1	1	1
c_{ij} and $q_{ii'jj'}$	-	3	2	1	0

Parameter q in the objective function is calculated as a function of the time interval between two events using the presented trapezoidal function in Figure 5. The appropriateness of intervals is based on the level of readiness required for the event, preventing injuries, the tapering requirement for players, and managerial considerations. Because of the large size of the table, we avoided mentioning the values of this parameter here. The data of these parameters could be presented in an Excel file to the interested readers. It is worth mentioning that the values of alpha and lambda of each pair of events were determined through the interviews.

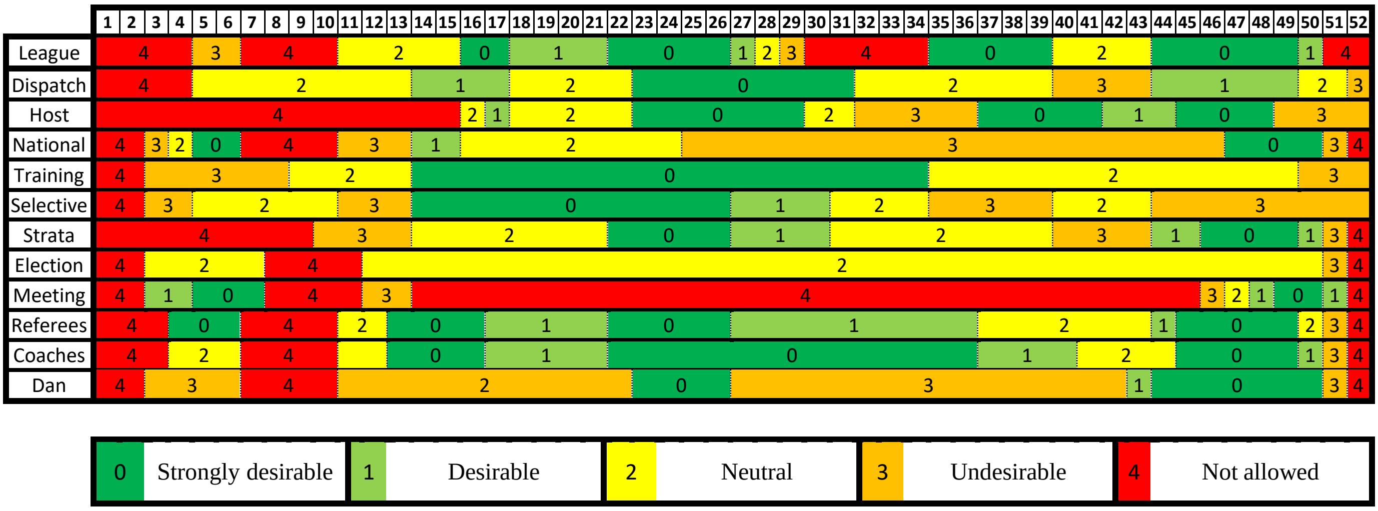

Figure 4. Desirability of timeslots for determining c_{ij} and a_{ij}

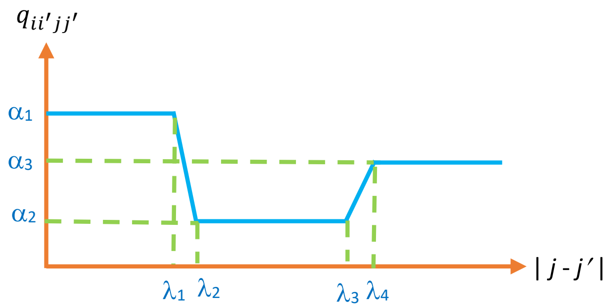

Figure 5. Trapezoidal function to calculate q in terms of length of the interval between events

Due to the need for common resources, some events cannot be performed in the same timeslot. These couple of events are marked by asterisks in Figure 6.

Figure 6. The impossibility of happening in the same timeslot

5.2. Solving the Case Study Problem

According to the numerical results, Random events matheuristic showed the best performance among the proposed algorithms. Therefore, we use this algorithm to solve the case study problem. The Gantt chart of events, resulting from solving the case study is shown in figure 7. As can be seen, all of the constraints are met. Besides, firstly none of the events are scheduled at undesirable times, secondly most of the events are scheduled at desirable and strongly desirable weeks.

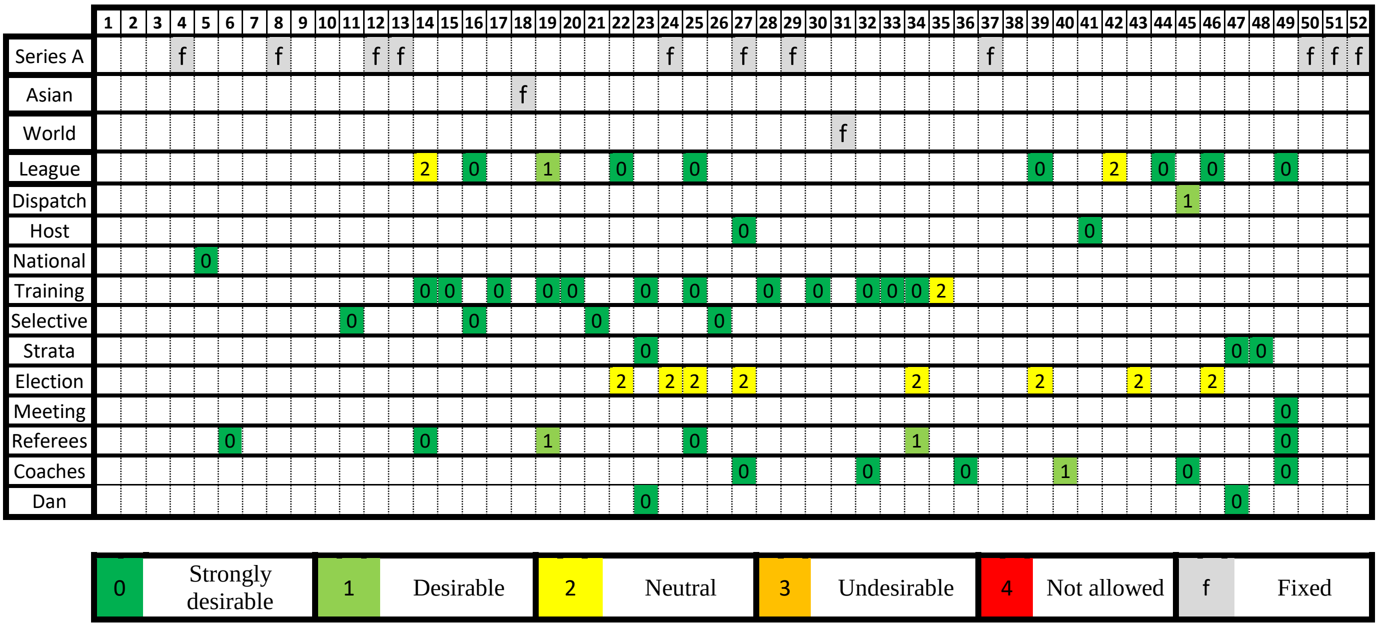

Figure 7. Gantt chart of the case study

5.3. Convergence Analysis

This section focuses on comparing the convergence of the designed FO matheuristic algorithm against Cplex solver. To this purpose we compare the objective value of the solutions along the run time. As shown in figure 8, although the time limit was set to 600 seconds for the Random events fix-and-optimize matheuristic, this algorithm converged within two minutes. Further, even if the Cplex is given 1000 seconds, its objective function is not improved. In addition, the obtained objective value by Random events fix-and-optimize matheuristic is 27% more favourable than the answer obtained by Cplex. This means achieving a schedule that better adheres to the timing of events and the intervals between them.

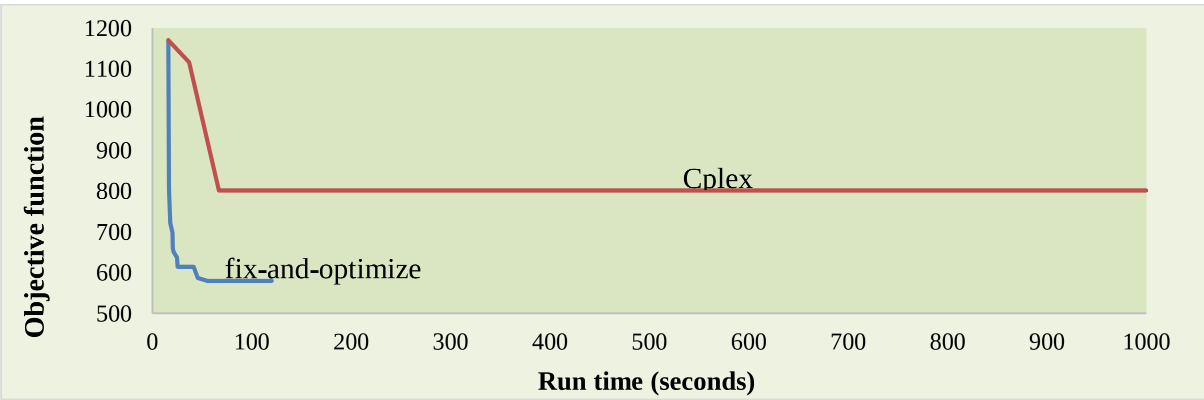

Figure 8. Convergence of Cplex and fix-and-optimize matheuristic in solving the case study problem

5.4. Sensitivity Analysis

In this section, the effects of changing the minimum required time intervals between two consecutive occurrences of recurring events (i.e., written numbers in loops in Figure 3) are examined. We used Random events algorithm to solve these problems. The results are shown in Figure 9. Increasing the minimum required time intervals restricts the feasible solution space and raises the total costs. This effect is exhibited by the upward trends in the figure. By comparing these trends, it is found that the change of minimum permissible length of intervals between the occurrences of the league event has the most significant effect on the objective function. The high number of matches in the league could be the cause of this high effect. It can also be noted that by changing this time interval to 5 weeks, the problem becomes infeasible.

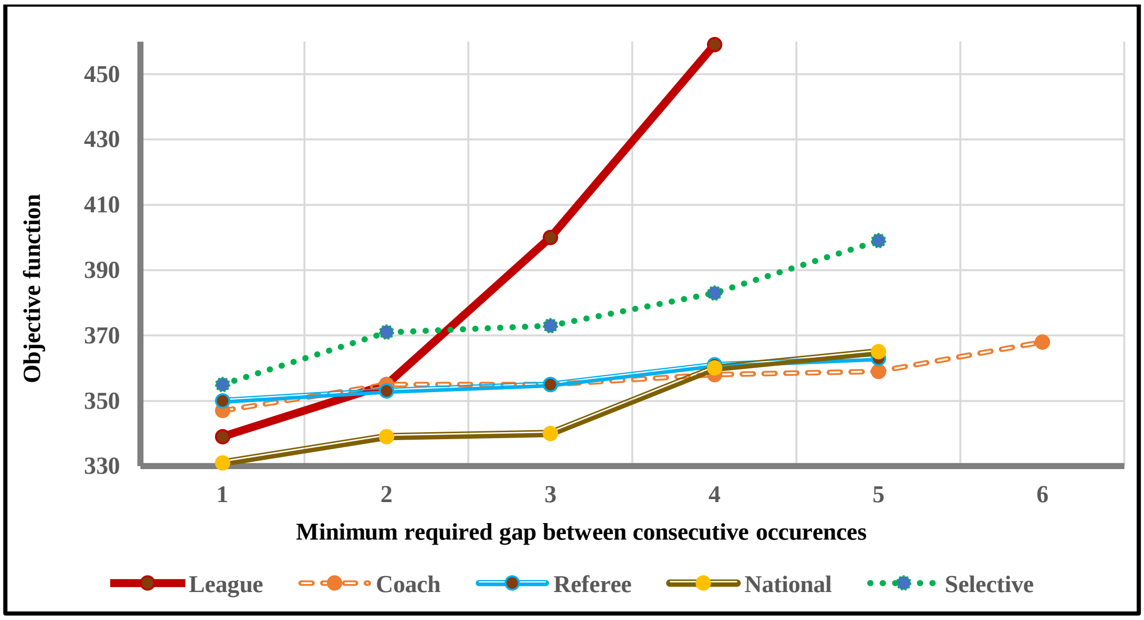

Figure 9. Sensitivity analysis for time lags of recurring events

6. Conclusion

In this study, a novel macroscopic sports scheduling problem was studied. The examined events in the present study were the most comprehensive in the literature. In other words, in contrast to the previous studies, which considered one event type (e.g., competitions), this paper schedules multiple types of sports events simultaneously, including but not limited to tournaments, management sessions, courses, and camps. For the first time in this paper, constraints and appropriateness of timeslots for performing events, prerequisite relations between events, and length of suitable intervals between events were considered simultaneously. To plan these events, an integer programming formulation was presented. In order to solve the problem and obtain a quality solution, five variations of fix-and-optimize matheuristic algorithm were developed. In the next step, the planning of Karate events of Iran was studied as a real case study, and a weekly plan was presented for a one-year horizon. Finally, the sensitivity of the problem to different parameters was analysed.

Future research could aim to consider uncertainty into the problem. For instance, contingencies like bad weather, short-term lockdowns during pandemics, or equipment failure may lead to cancellation of events. In addition, the frequency of events could be considered as decision variable. To this end, the number of occurrences of each event should be determined considering budgetary constraints and preferences of events.

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