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Scheduling the Italian National Volleyball Tournament

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Abstract. In this paper, we present our approach to sports scheduling, a process that led the Italian Volleyball League to adopt our calendar for the 2016–2017 and subsequent seasons. Sports scheduling is a hard combinatorial optimization problem whose solution requires modeling many different aspects of sports, some of which are unique to each sport or nation. The capability of producing a high-quality schedule is important for both balancing undesirable matches among teams and ensuring adequate coverage by television and other media. Through strong interaction with the Italian Volleyball League, we modeled and solved the problem to optimality using standard mathematical programming solvers. We also tested our solution using previous seasons' tournaments to prove the capability of our model.

History: This paper was refereed.

Keywords: sports scheduling • round-robin tournament • mixed-integer programming • volleyball

Introduction

Sports scheduling in professional sports is a crucial task that involves massive investments in players, millions of fans, and television contracts. It usually requires the definition of dates and venues of matches between teams attending a tournament, and represents an important application field of operations research methodologies, as the increasing number of papers on the topic prove; examples include those collected in special issues of *Interfaces* (2012a and 2012b). The underlying combinatorial optimization problems are usually difficult and challenging, and they have been solved by both exact and approximate approaches. The amount of literature on applications of operations research techniques to sports scheduling is extensive. Knust (2017) maintains a website classifying this literature. Each sports league has its own specific peculiarities and the objectives of scheduling must take into account the characteristics of the country in which the tournament will be held, because these characteristics often influence the structure and the rules of the tournament. For example, in large countries, such as Russia or the United States, minimizing the total distance traveled may be one of the main objectives of the schedule. Sports scheduling is intrinsically a multiobjective optimization problem whose formulation is based on the objectives and requirements defined by the stakeholders.

In this paper, we present the development and application of a mixed-integer linear programming (MILP) model to create a regular season schedule for the Italian Volleyball League, which usually comprises 12 or more teams. The teams that can take part in the Italian volleyball championship are determined by the Italian Volleyball League (the league), based on sports achievements and suitable criteria, such as stadium suitability and registration fees. Italy mandates standard requirements that the tournament schedule must satisfy and others that the league must introduce or modify year by year; however, they always require schedules that are fair and balanced for all teams to maximize both the attractiveness of the tournament and the number of fans who watch on television or attend at an indoor stadium. Travel issues must be considered for slots played on dates close to those of the European competitions, which may involve lengthy travel times and in particular slots (e.g., games scheduled on December 26). As a result, the schedule must satisfy several hard and soft constraints, which may differ from year to year.

For two decades prior to the 2016–2017 season, the Italian Volleyball League created its schedules using a decision support system to define the matches among teams, after it had built each team's *home-away patterns*, according to a two-phase approach. The schedule was determined by trial-and-error techniques based on experience. Thus, the Italian Volleyball League employed a combination of a computer-based system and manual operations. In this paper, we adopt an approach based on operations research methodologies, and we present a mixed-integer linear formulation for scheduling tournaments for the Italian Volleyball League. The schedules were obtained as exact solutions of the MILP problem and were used in partnership with the Italian Volleyball League. More specifically, we tested the solutions we generated using the mathematical programming approach on the 2013–2014, 2014–2015, and 2015–2016 seasons, for which other schedules had been used, and then successfully applied our solution to produce the official schedule of the 2016–2017 tournament.

We organized this paper as follows. The next section, *Volleyball League Scheduling in Other Countries*, provides a brief review of the literature on the scheduling of volleyball tournaments. We summarize the main characteristics of the Italian volleyball tournament in *Italian Volleyball Tournament Structure*. In the *Schedule Requirements* section, we present the hard and soft constraints that the schedule must satisfy. The resulting MILP model is defined in the appendix. The results of the practical experience we gained in obtaining the schedule of the new 2016–2017 tournament (used officially by the Italian Volleyball League) are analyzed and discussed in the *Computational Results on Current and Past Tournaments* section.

Volleyball League Scheduling in Other Countries

Sports scheduling has been widely considered in the literature for different sports and types of tournaments; Rasmussen and Trick (2008) and Ribeiro (2012) provide surveys, while Kendall et al. (2010) include a bibliography of scheduling problems in sports. Bonomo et al. (2012) and Meng et al. (2014) consider the scheduling of volleyball leagues. Meng et al. (2014) consider the problem of organizing a volleyball tournament, given the number of teams, game days, and courts. They use integer programming to select the number of teams that should be in each division and the number of time slots that are needed. They also consider the referee assignment problem, which they solve using a genetic algorithm, and test their approach on simulated data.

Bonomo et al. (2012) consider the Argentine Volleyball League and formulate its scheduling as a variant of the traveling tournament problem (TTP). The TTP problem consists of scheduling a double round-robin tournament, given a set of n teams and the travel distances matrix, with $2(n-1)$ time slots, such that no team plays less than L (typically $L=1$) or more than U (typically $U=3$) home (resp. away) matches in a row, no two teams play against each other in two consecutive time slots, and the total travel distance is minimized. In addition, no team returns home between consecutive away matches. It is NP-hard when $L=1$ and $U=3$, or when $L=1$ and $U=\infty$; however, its complexity is unknown in the other cases (Thielen and Westphal 2011, Bhattacharyya 2009). Because the teams in the Argentine Volleyball League are scattered throughout the country and road trips are usually made by bus, the main objective of the league's scheduling process is to adequately manage travel distances, which they do using different objective functions. To optimize distances, the league play is organized based on the *coupled format*: teams are divided into geographically close couples and the matches are grouped into pairs of temporally close meetings (usually held on Thursdays and Saturdays), which are also grouped into pairs, thus forming a weekend. Each weekend, half of the couples visit a couple from the other half, and each visiting-couple team plays each of the two home-couple teams that are hosting it. On two special weekends, called *intra-couple weekends*, the two teams in each couple play against each other.

Here, we list the problem constraints.

1. To ensure fairness, the two top teams cannot form a couple.

2. A team cannot play more than two consecutive home or two consecutive away weekends (not counting intra-couple weekends), and two couples cannot play each other twice on consecutive weekends; although this constraint is trivially satisfied in a mirrored schedule, the schedule may also not be mirrored.

Disregarding the intra-couple weekend, this problem is a special case of the TTP, with couples replacing teams and pairs of matches (i.e., weekends) replacing single matches. Under this arrangement, $L = 1$ and $U = 2$ (i.e., at most, two consecutive home and away weekends). Therefore, defining the schedule consists of both defining the couples and defining the schedule. Bonomo et al. (2012) propose a two-stage process: the first stage is coupling (i.e., matching in a complete graph with distances on the edges); the second stage is generating the schedule (i.e., a TTP with six teams). The coupling, which reduces the number of weekends, and the constraints on the home-away games imply that the distribution on the home and away weekends can be deduced in advance: there exists an optimal solution such that the set of tours for each couple consists of a specific number of two-weekend trips and, at most, one single-weekend trip (or exactly one if the number of couples to be visited is odd). Some constraints are added depending, for example, on the unavailability of a team's stadium on prespecified weekends; for example, another local sports team has booked the stadium on those dates. In some cases, because of special events, the matches on a prespecified weekend must be played near a specific city.

Italian Volleyball Tournament Structure

In this paper, we consider a tournament played by n teams: each year, the Italian Volleyball League establishes the number of teams (usually an even number) that can take part in the first (Serie A) and second (Serie A2) division; teams can be promoted to the first division because of their sports achievements, or they can be relegated to the second division if a specific requirement, such as financial stability or stadium suitability, is not satisfied. Hence, the number of teams can vary; therefore, the model we describe in this paper addresses the case in which the number of teams is even, but it can be easily extended to address an odd number of teams. The Italian Volleyball Championship is structured as a regular phase, which is a *double round-robin* (DRR) tournament, and a playoff phase. In a DRR tournament, each team plays exactly twice with each other team, once in each half. The second half of the DRR is a mirror of the first half, with home games and away games exchanged. In this paper, we address the regular phase, which is the most difficult to schedule.

The games must be associated with the $n-1$ *slots* for each half. Every team has its venue in its hometown in which the team must play exactly one of the two matches played against each other team. When a team plays at its venue, it plays a *home game*; at any other venue, it plays an *away game*.

A *home-away pattern* is the sequence of home games and away games played by a team during the tournament. Two consecutive home games or away games are defined as a *break*.

The tournament schedule must establish for each half the pair of teams that must face each other in each slot and the location at which the game will be played. Because the schedule is mirrored, scheduling the first half of the schedule and exchanging home and away games for the second half is sufficient.

The annual Italian Volleyball Championship involves n teams (usually 12, but 14 for the 2016–2017 season); therefore, the tournament is made up of $2 \cdot (n-1)$ slots, $n-1$ in the first half and $n-1$ in the second half. These slots usually cover the period from the beginning of October to the end of March. The days on which the matches are played are set, year by year, after a phase in which the league coordinates with other sports' competitions and with national and international tournaments (e.g., the basketball first division, the Italian Tournament (Coppa Italia), the European Championship). The preferred day of the week on which to play matches is Sunday; however, because a team might have to share its venue (usually an indoor sport arena) with a team that plays a different sport and for which Sunday is also the preferred day, a game might be shifted to Saturday or sometimes to Wednesday. If Wednesday is selected, it is called a *midweek day*; Sundays and Saturdays are called *weekend days* and are considered equivalent from this perspective. Among the n teams that enter the tournament, some are also involved in other national championships; therefore, they may have some privileges or may have additional requirements to meet.

Each year, a rank based on the placement during the previous season is generated, and the most qualified teams (usually from the first ranked to the sixth ranked) are called *top teams*; these teams usually receive major TV rights, marketing revenue, gate attendance and sponsorship revenue, and significant media coverage. Table 1, which shows $n = 14$ teams, is an example

Table 1. All Teams Participating in the 2016–2017 Championship Including Team Name, Team Rank, and a Short Code, Which We Use Throughout the Paper

Index	Team	Code	Team rank	
1	AZIMUT MODENA	MO	Super top team	Top team
2	CUCINE LUBE CIVITANOVA	CM	Super top team	Top team
3	DIATEC TRENTINO	TN	Super top team	Top team
4	SIR SAFETY CONAD PERUGIA	PG	Super top team	Top team
5	CALZEDONIA VERONA	VR		Top team
6	EXPRIVIA MOLFETTA	ML		Top team
7	TOP VOLLEY LATINA	LT		
8	KIOENE PADOVA	PD		
9	GI GROUP MONZA	MB		
10	BUNGE RAVENNA	RA		
11	POWER VOLLEY MILANO	MI		
12	LPR PIACENZA	PC		
13	BIOSÌ INDEXA SORA	SO		
14	TONNO CALLIPO CAL. VIBO VALENTIA	VV		

from the 2016–2017 season. In some years, the set of *top teams* includes a more specific subset of teams, which we call *super top teams*; for example, the first six teams are ranked as top teams, but only the first four teams are considered super top teams. Each match between two top teams is called a *big match*; avoiding a big match in specific slots of the season is preferable in some situations. For example, a fundamental rule in scheduling the Italian volleyball tournament is that a big match cannot be scheduled in the first two slots of each half. Each team that shares its venue with another team (e.g., teams from the same city or from the same regional area) should play away each time the other team plays at home. The match in which they play against each other is called a *derby*. Although breaks must be minimized, they are allowed in the home-away patterns; however, consecutive breaks are forbidden. A home-away pattern without breaks (i.e., an alternating pattern of home and away games) is considered favorable for a team. However, because a maximum of two teams can benefit from alternating patterns, avoiding a schedule with alternating patterns is preferable.

Teams that also play in European championships should not be scheduled to play away from their venues in more than two slots. The Italian Volleyball League does not want to prevent fans, particularly fans who have purchased season tickets, from watching home games of their favorite teams.

Each year, the league chooses December 26 as a tournament day; this is a special date because the majority of team supporters can attend the match or see it on television; therefore, ensuring a turnover (i.e., a team plays at home on one December 26 and away on that day the next year) is important, especially for fans. Thus, fans who want to attend their favorite team's game on December 26 must wait at most two years.

Schedule Requirements

The schedule should satisfy requirements that can be imposed based on tournament structure, television rights, and marketing revenues, and should be organized in such a way that the most influential and attractive teams can take advantage of the benefits (especially near European matches played away) that the schedule provides them, but no team is disadvantaged by the schedule. The Italian Volleyball League imposes many nonflexible requirements on the schedule; the double round-robin structure of the tournament also dictates mandatory constraints (modeled as hard constraints). Other requirements are not mandatory; therefore, we model them as soft constraints. Below, we list all the constraints of our model, categorized based on their origins.

Round-Robin Structure Constraints

(R_1) Each team must play exactly one game in a single slot.

(R_2) Each team must meet all other teams once in each half.

League Requirements

(L_1) No breaks are allowed in the first two and the last two slots of each half.

(L_2) Two consecutive breaks are not allowed.

(L_3) Let H and A be a home game and an away game, respectively: patterns containing sequences of the form *HHAHH* or *AAHAA* are forbidden; that is, two breaks must be separated at least by two slots.

(L_4) Specific games must be scheduled or avoided in particular slots.

(L_5) For each team, there must be an equilibrium between home and away games.

(L_6) Away breaks with a tournament stop in the middle are not allowed.

(L_7) The number of big matches among top teams B_T or super top teams B_{ST} played in a slot are bounded. Usually, $B_{ST} = 0$ in the first two slots and $0 \leq B_{ST} \leq 1$ in the other slots, while $B_T = 0$ only in the first slot and $0 \leq B_T \leq 2$ in the other slots.

(L_8) For each top team, there must be an equilibrium between home and away games played against other top teams. We also define a similar constraint for the super top teams set.

(L_9) There should be balance between the number of midweek games played at home and those played away.

(L_{10}) The number of breaks in the schedule should be as low as possible.

(L_{11}) Teams with no breaks in their schedule are considered to have an advantage; therefore, we avoid generating a schedule without breaks.

(L_{12}) Big matches during midweek days should be avoided.

Club Requirements

(C_1) On specific days, selected teams (e.g., a team that shares its venue with a team from another sports competition) are forced to play an away game or a home game.

(C_2) Pairs of teams from the same city should play one game at home and the other game away; derbies are an exception.

(C_3) Each team can express preferences for scheduling home or away games on specific slots; an example is a team involved in European championships, which aim to play at home before a cup match or do not want to spend too many days playing away from their venues.

(C_4) If two consecutive away games are scheduled and the two relative slots are temporally close (e.g., on Wednesday and on Sunday), the overall distance traveled should be as small as possible.

(C_5) Games on December 26 should be played by teams whose venues are geographically close, thus avoiding having to travel long distances on December 25.

We partition the above requirements, which come from teams, the league, television networks, and fans, into hard and soft constraints (Table 2). Following the outline of the typical constraints (i.e., place, top team, break, game, complementarity, geographical, pattern constraints), as Rasmussen and Trick (2008) discuss, we also include the type of constraint for each requirement in Table 2.

The problem we must address is a *breaks minimization problem* where other factors are present; therefore, we model the volleyball scheduling problem as an MILP to minimize an objective function, which is given by the sum of the violated soft constraints. Here, we list the components.

(F_1) Number of breaks: related to (L_{10});

(F_2) Number of unbalanced matches for midweek slots: related to (L_9);

(F_3) Number of big matches played during midweek slots: related to (L_{12});

(F_4) Number of alternating patterns: related to (L_{11});

(F_5) Number of unsatisfied home or away preferences: related to (C_3);

(F_6) Total distance traveled: related to (C_3), (C_4), and (C_5).

We adopted a mixed-integer programming formulation based on three-index standard binary decision variables; we then directly applied the MILP solver to the formulation and obtained the exact solution of the problem within a few seconds for up to $n = 14$ teams, which is the case for the 2016–2017 season—the subject of this paper. This allowed us to avoid having to develop specialized solution strategies. In most papers, these strategies are based on decomposing the problem into different phases, which involve the generation of feasible home-away patterns and the assignment of teams to patterns, considering all other constraints. In the next section, we discuss and analyze the results we obtained and the computational details.

Table 2. Problem Constraints with Their Associated Categories; Specifying Whether the Model Treats Each Constraint Type as a Hard or Soft Constraint

Hard championship requirements		Soft championship requirements	
Constraint ID	Type	Constraint ID	Type
(R_1)	Round-robin constraint	(L_{10})	Break constraint
(R_2)	Round-robin constraint	(L_{11})	Pattern constraint
(L_1)	Break constraint	(L_9)	Balance constraint
(L_6)	Break constraint	(C_3)	Place constraint
(L_2)	Pattern constraint	(C_4)	Geographical constraint
(L_3)	Pattern constraint	(C_5)	Geographical constraint
(L_7)	Top team constraint	(L_{12})	Top team constraint
(L_8)	Top team constraint		
(L_4)	Game constraint		
(L_5)	Balance constraint		
(C_1)	Place constraint		
(C_2)	Complementary constraint		

Computational Results on Current and Past Tournaments

The model we describe previously and in the appendix was implemented in Pyomo (Hart et al. 2017) and optimized on an Intel 2.5 GHz six-core multithread computer when the solver allowed it; some solvers cannot exploit multithread computation. In this paper, we tried several solvers, including Gurobi v. 6.5.0, CPLEX 12.1.0, cbc 2.8.12, and glpk v. 4.55, and generated the final schedule using Gurobi 6.5 (2016).

First, we tested our model on previous tournaments and verified the quality of the solutions by allowing the Italian Volleyball League to evaluate them; we then applied the model to the 2016–2017 season.

We found exact solutions for the MILP instances, both for the past tournaments (with $n = 12$ and $n = 13$ teams) and for the 2016–2017 season (with $n = 14$ teams), within a few seconds.

We set the six weights of the terms (F_1)–(F_6) of the objective function, as we show next, taking into account the priority levels of the league:

$$\omega_1 = \omega_2 = \omega_3 = 1 \quad \omega_4 = 3 \quad \omega_5 = 0.5 \quad \omega_6 = 0.1.$$

The 2016–2017 Season

In the 2016–2017 season, 14 teams played in the tournament (Table 1), and the schedule included a slot planned on December 26.

Here, we list the most important features that characterize the requirements of the 2016–2017 season:

- For the games played on December 26, the teams that played away on that day in the previous year must play at home and against teams coming from near cities;
- Five teams play European championships;
- Trento stadium is shared with a noteworthy basketball team; therefore, we need to plan the home-away pattern of Team 3 (i.e., Diatec Trentino) so that the schedule includes a minimum number of concomitances with the basketball championship schedule;
- A set of top and super top teams is present, as we show in Table 1;
- In the first and last game, each team must play against a team other than the team it faced during the previous season;
- The season has four midweek days (i.e., the fourth and ninth slots during both the first half and second half);
- There is one tournament stop between the seventh and eighth slots of the second half;
- Only one derby, between MI and MB, is present.

In Table 3, we summarize the schedule that the league accepted. A nonzero entry represents the match in which the team specified in the row plays at home against the team specified in the column. In Table 4, we show the home-away pattern set.

All the hard constraints are satisfied by the schedule we generated for the 2016–2017 season. The following relate to the six terms of the objective function related to the soft constraints:

- The total number of breaks (F_1) is 28, two for each team; therefore, the breaks are perfectly balanced among the teams and the overall number obtained ($2n$)

Table 3. Matrix of Matches for the First Half of the 2016–2017 Season; We Obtained This Matrix by Solving the MIP Model

	MO	CM	TN	PG	VR	ML	LT	PD	MB	RA	MI	PC	SO	VV
MO		13	11		8			4	9				1	6
CM				8	11	12		6				2	4	
TN		10		6			4		12		8			1
PG	7					9	11	2		4	13			
VR			9	12		2			4				6	10
ML	10		13							6	1	4	8	
LT	5	3			1	7		10					9	13
PD			3		13	5			7	1		11		8
MB		1		10		11	6			8	3	13		
RA	3	9	7		5		2				11		13	
MI	2	5			7		12	9						4
PC	12		5	1	3		8			10	6			
SO			2	3				12	5		10	7		
VV		7		5		3			2	12		9	11	

Notes. In the table, each nonzero entry corresponds to the day on which the match is scheduled. For example, on the first day, team MO will meet team SO at home and will play away against MI on the second day.

is the minimum number of breaks allowed if we consider that alternating patterns (F_4) are not present (de Werra 1981). Note that de Werra (1981) counts the number of breaks in both halves. The league requirements specify that breaks counting is limited to the first half, and *border breaks* (i.e., the breaks between the first and the second half) are counted once as the other breaks;

- We have perfect balance in midweek slots (F_2) between home and away games;
- We have two big matches in a midweek slot (F_3); that is, PG-ML and VR-TN are scheduled in the 9th slot;
- The number of violated preferences (F_5) for home and away games is 12, although 28 were requested;
- The overall distance in the schedule generated is such that on December 26, games between geographically close teams are scheduled and short travel times are planned in case of unsatisfied preferences or away breaks in slots that are temporally close.

Table 4. In the Home-Away Pattern Set of the 2016–2017 Season for the First Half, Rows Correspond to Teams and Columns to Days in the First Half; the Second Half Is Mirrored

	1	2	3	4	5	6	7	8	9	10	11	12	13
MO	H	A	A	H	A	H	A	H	H	A	H	A	H
CM	A	H	A	H	A	H	A	H	A	A	H	H	A
TN	H	A	A	H	A	H	A	H	A	H	A	H	A
PG	A	H	A	H	A	A	H	A	H	A	H	A	H
VR	A	H	A	H	A	H	A	A	H	H	A	H	A
ML	H	A	A	H	A	H	A	H	A	H	A	A	H
LT	H	A	H	A	H	A	H	A	H	H	A	A	H
PD	H	A	H	A	H	A	H	H	A	A	H	A	H
MB	H	A	H	A	A	H	A	H	A	H	H	A	H
RA	A	H	H	A	H	A	H	A	H	A	H	A	H
MI	A	H	A	H	H	A	H	A	H	A	A	H	A
PC	H	A	H	A	H	H	A	H	A	H	A	H	A
SO	A	H	H	A	H	A	H	A	A	H	A	H	A
VV	A	H	H	A	H	A	H	A	H	A	H	H	A

Notes. Breaks are highlighted in gray. *Border breaks* appear between the end of the first half and the beginning of the second half. For example, MO has two breaks; TN also has two breaks; however, one is a border break.

Table 5. We Summarize the Attendance in the First Half of the 2013–2016 Seasons

Season	All slots	Midweek slots
2016–2017	2,514.59	2,440.4
2015–2016	2,325.41	2,292.28
2014–2015	2,343.59	2,273.5
2013–2014	2,114.68	n.a.

Note. The second column (All slots) shows the attendance in all slots of the first half; the third column (Midweek slots) shows the attendance in midweek slots only.

Table 6. Normalized Mean μ and Standard Deviation σ of the Score Differences Between the First- and Last-Ranked Teams After the First Half

Season	μ	σ
2016–2017	0.39	0.25
2015–2016	0.43	0.30
2014–2015	0.40	0.30
2013–2014	0.45	0.21

Note. The μ and σ can be interpreted as indicators of a competitive and balanced schedule, because lower values of the mean and standard deviation result in a less predictable final ranking of the championship.

For the 2016–2017 season, the league did not design a schedule, as it had in previous tournaments; therefore, we could not compare the schedule our MILP model generated to a league-designed schedule.

To appreciate the quality of the schedule we generated, we compare it with schedules from previous tournaments in terms of stadium attendance, on both weekend and midweek days, and note that the related revenue is an important issue for both the league and the clubs. We limit the comparison to only the first half of the seasons, because these were the only data available for the 2016–2017 season at the time this paper was written. Table 5 shows the results; note that the 2013–2014 season included only weekend slots.

From Table 5, we can observe a significant improvement for the current season. The schedule strongly influences the tournament competitiveness and, consequently, the revenue from stadium attendance. We are aware that the strong performance of the Italian volleyball team at the 2016 Olympic Games, for which the team received a silver medal, might have contributed to the increased stadium attendance.

We also investigated the tournament competitiveness, analyzing the ranking of the teams after the first half of the current and the previous seasons. For each season, we considered the differences in scores between the first-rank and last-rank positions. Then, we computed the averages and standard deviations (Table 6) of the score differences normalized by the score of the first position, over the n teams, and used it to determine a measure of the tournament's competitiveness.

From the results in Table 6, we notice that the competitiveness in the 2016–2017 season seems to be better than (or at least comparable to) that in the previous seasons.

In summary, the current season shows good competitiveness and attractiveness. We view this as a confirmation that the generated schedule is suitable.

Comparison with Past Tournaments

We tested our model on some past tournaments (i.e., the 2013–2014, 2014–2015, and 2015–2016 seasons, with $n = 12, 13$, and 12 teams, respectively) using the

Table 7. We Compare the League's Approach and That of the MILP Model

Season	Approach	Viol. hard constr.	Breaks	Unbal. midweek	Big match midweek	Unsat. prefer.	Dist.
2015–2016	League	0	24	12	3	0	0.24094
	MILP	0	24	12	2	0	0.00564
2014–2015	League	6	18	12	0	7	0.13828
	MILP	0	11	12	0	8	0.04825
2013–2014	League	3	27	2	3	0	0.13307
	MILP	0	24	0	0	0	0.00174

Notes. The comparison concerns the number of violations of both hard and soft constraints. For each season the league and our approaches are compared on: the number of violations of hard constraints, the total number of breaks, the number of unbalanced midweek games, the number of midweek big matches, the number of unsatisfied preferences, the (normalized) total traveled distance.

preferences of the clubs and the constraints provided by the league. We compare the schedules obtained by our MILP model with those designed and adopted by the league. For the previous tournaments, the league used a two-phase approach, based on a combination of manual operations (to determine the home-away patterns of each team) and a computer-based system (to schedule the games among the teams).

The results in Table 7 show that the quality of the schedule we created using the MILP approach is clearly better than that adopted by the league for its 2013–2014 and 2014–2015 seasons. The two schedules for the 2015–2016 season are comparable, with the exception of the penalty-term values related to the total distances of the away breaks, which involve consecutive midweek and weekend days (i.e., distance breaks). The value of this latter penalty term, which we obtained using the MILP approach, is significantly lower, as in the other seasons, than that obtained by the league's approach. The above results on the previous tournaments convinced the league to adopt the schedule we generated using the MILP approach for the 2016–2017 and the subsequent seasons.

Supporting the Italian Volleyball League Tournament Scheduling Process

In this paper, we have described a mathematical programming model that we used to schedule the 2016–2017 tournament of the Italian volleyball championship. Although the application of our model has been successful, it is not yet a decision support system, because it required significant interaction between our research team and the Italian Volleyball League, which we did through telephone calls. However, the experience we gained helped our team to understand the decision process of the league managers and the typical

Table 8. In This Excerpt from the Data File Used for the 2016–2017 Volley Tournament Schedule, the Syntax and the Names Used Are Self Explanatory

```
param n := 14;  # number of teams

set teamNames :=   "AZIMUT MODENA"
                   "CUCINE LUBE CIVITANOVA"
                   "DIATEC TRENTINO" ....;

set datesSlots := "02/10/2016 18.00"
                   "09/10/2016 18.00"
                   "16/10/2016 18.00" ....;

param distanceMatrix :
               1       2       3       4   :=
1            0.0  0.0661  0.0259  0.0568
2         0.0661     0.0  0.1711  0.0111
3         0.0259  0.1711     0.0  0.1553  ....;
# distance between team locations

set TopTeams := 1 2 3 4 5 6;
set SuperTopTeams := 1 2 3 4;
set derby := (9,11);

set mustPlayHome :=  (3,1) (8,8) (9,1) (9,11) (5,10) (1,4) (1,8) (10,13) (14,3) ...;
# set of pairs (i,k): team i must play at home on slot k

set mustPlayAway :=  (3,3) (3,11) (8,4) (8,6) (8,10) (8,12) (9,12) .... ;
# set of pairs (i,k): team i must play away on slot k

set ForcedMatches := (14,9,2) (10,1,3) (9,11,3) (10,2,9) ...;
# set of triplets (i,j,k): team i (home) must play with team j on slot k

set ForbiddenMatches :=  (3,14,5) (3,14,8) (1,14,2) (1,14,3) (1,14,8) (1,14,12) ....;
# set of triplets (i,j,k): team i (home) must not play with team j on slot k
```

cycle of optimization—analysis of the outcome and proposal of new constraints. As a result of our scheduling efforts, we came to understand the overall process and concluded that upgrading our mathematical programming model to an automated decision support system would require only a few steps, as follows:

- We determined all the changes we had to apply after generating our first tentative schedule by modifying the data file. That is, the model is stable; making changes to consider new or varied constraints requires only a data modification. Our data file is a standard Pyomo (or AMPL) data file in which some data are stable (e.g., number, names, team locations). Some data can be changed (e.g., dates in which a team playing at home is either forbidden or required). Some data concern triplets (i, j, k) associated with the requirement that home team i cannot meet team j on day k; these data are changed frequently after a schedule has been generated, for example, to meet the requirements of some soft objectives or to induce some constraints that had not been formalized in advance. Table 8 shows part of the input data file we used for the 2016–2017 tournament schedule.
- Other changes might concern the weights given to the various components; these might be required to give more importance to a specific component (e.g., to the total number of breaks) when generating a schedule.
- Finally, a backup procedure should be developed to ensure that if the MILP optimizer takes too long to generate a schedule, heuristic procedure that can generate an acceptable schedule is called—even if that schedule is not provably optimal. This procedure might return the incumbent solution found by the optimizer.

The actual system produces a results file, which is then parsed through a Python script, which generates readable output for the league and allows it to suggest changes. In Table 9, we show an example of the output of this procedure. After a summary of violated soft constraints, the matrix of matches (Table 3), the home-away pattern set (Table 4), and the complete calendar

Table 9. Part of the Output Generated Includes a List of Soft Constraint Violations

```
#
# Soft constraints violations
#

Breaks:
        AZIMUT MODENA (1)               : 2
        CUCINE LUBE CIVITANOVA (2)      : 2
        DIATEC TRENTINO (3)             : 2
        SIR SAFETY CONAD PERUGIA (4)    : 2
        ...

MidWeek Big Matches:
        Slot 9: 2

Unsatisfied home preferences:
        CUCINE LUBE CIVITANOVA (2)      : 13th slot, away at AZIMUT MODENA  (1)
        SIR SAFETY CONAD PERUGIA (4)    : 10th slot, away at GI GROUP MONZA (9)

Unsatisfied away preferences:
        CUCINE LUBE CIVITANOVA (2)      : 6th slot, at home with KIOENE PADOVA (8)
        CUCINE LUBE CIVITANOVA (2)      : 11th slot, at home with  CALZEDONIA VERONA (5)
        ...

Distance cost for unsatisfied home/away preferences: 0.0687

Distance cost for teams with breaks in midweek slots: 0.01231

Distance cost December 26th: 0.02982

Total cost: 36.11083
```

are generated. Although these steps require careful planning and a nontrivial software engineering phase, we believe that the experience we gained will allow us to transform the manual data-change procedure to an interactive process with limited effort.

Conclusions

In this paper, we considered the problem of defining the double round-robin tournament for the Italian Volleyball League. We developed an MILP model that is flexible enough to accommodate the requirements of several practical constraints. We directly applied the MILP solver to the formulation and obtained the exact solutions of all the tested problems, for the current (2016–2017) and the previous seasons, using an extremely low CPU time. The Italian Volleyball League adopted the schedule obtained by solving the MILP model for the current season. We have also shown that the first half of the current tournament shows good competitiveness and attractiveness, compared with previous seasons. In addition, we also tested our MILP approach on some previous tournaments, and the results we obtained show that the schedules generated are better than those that the league designed and adopted. The application of our MILP model has been successful both in terms of schedule quality and CPU time requirements. These results were not ensured a priori, because we did not find experiments using similar MILP models in the literature; however, they convinced the league to adopt our schedules for subsequent tournaments. We are currently planning to develop a fully automated decision support system.

Acknowledgments

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Appendix

Detailed Model

Let $n \in \mathbb{N}$ be the number of teams. The following model considers the case in which n is even. However, when n is odd, a similar model can be derived with only minor modifications by introducing a *dummy* team that represents rest slots. The entire model is based on binary decision variables, which we define as follows:

$$\delta_{ij}^k = \begin{cases} 1 & \text{if team } i \text{ plays at home against team } j \text{ in slot } k, \\ 0 & \text{otherwise.} \end{cases}$$

All the variables and the constraints, unless otherwise explicitly indicated, relate to the first half of a round-robin tournament; we obtain the second half by mirroring the first half.

Sets

- $N = \{1, 2, \ldots, n\}$, the set of teams;
- $M = \{1, 2, \ldots, n-1\}$, the set of slots to be scheduled;
- $T \subset N$, the set of top teams;
- $ST \subseteq T$, the set of super top teams;
- $MW^1, MW^2 \subset M$, a set of slots to be played during workdays (i.e., midweek slots), in the first or in the second half, respectively;
- $HPr, APr \subseteq N \times M$, a set of preferences for each team to play in a specific slot, home or away, respectively.

Variables

- $\delta_{ij}^k \in \{0,1\}, i \neq j \in N, k \in M$, a binary variable with value 1 if and only if team i plays at home against team j in slot k during the first half of the tournament;
- $I_i \in \mathbb{N}$, a slack variable representing the unbalance between home and away matches played during midweek slots for team i;
- $DA_i^k \in \mathbb{R}$, $i \in N$, $k \in M$, the total distance traveled by team i when an away break occurs in slots k and $k+1$, where $k+1$ is a midweek slot of the first half; for midweek slots of the second half, the variable DH_i^k for home breaks is also defined.

Auxiliary variables

To formulate the objective function and to better describe some constraints, some auxiliary variables can be defined as follows:

- $H_i^k = \sum_{j \neq i} \delta_{ij}^k \in \{0,1\}$, a binary variable that states if team i plays at home in slot k; the variable A_i^k for away matches is defined similarly;
- $HH_i^k \in \{0,1\}$, a binary variable that states if team i plays at home in both slot k and $k+1$, that is, it has a break; the variable AA_i^k for away breaks is also defined;
- $AP_i \in \{0,1\}$, a binary variable that states if team i has an alternating pattern.

Parameters

- D_{ij}, $i, j \in N$, the distance between the home towns of teams i and j normalized in $[0,1]$; it holds $D_{ij} = D_{ji}$ and $D_{ii} = 0$.

Objective function

The function to be minimized is a weighted sum of various penalties:

$$\min \sum_{r=1}^{6} \omega_r F_r,$$

where ω_r is the weight associated with objective r, and

(F_1) Total number of breaks (home or away):

$$F_1 = \sum_{\substack{i \in N \\ k \in M}} (HH_i^k + AA_i^k). \tag{A.1}$$

(F_2) Total number of unbalanced matches for midweek slots:

$$F_2 = \sum_{i \in N} I_i. \tag{A.2}$$

(F_3) Total number of big matches played during midweek slots:

$$F_3 = \sum_{\substack{i, j \in T \\ k \in MW^1 \cup MW^2}} \delta_{ij}^k. \tag{A.3}$$

(F_4) Total number of alternating patterns:

$$F_4 = \sum_{i \in N} AP_i. \tag{A.4}$$

(F_5) Total number of unsatisfied home or away preferences:

$$F_5 = \sum_{(i,k) \in HPr} A_i^k + \sum_{(i,k) \in APr} H_i^k. \tag{A.5}$$

(F_6) Overall distance term comprising the following components:

- Total distance covered by away teams on December 26, (denoted by slot $\bar{k}$) :

$$\sum_{i, j \in N} \delta_{ij}^{\bar{k}} D_{ji}. \tag{A.6}$$

- Total distance covered by away teams on unsatisfied home or away preferences:

$$\sum_{(i,k) \in HPr} \sum_{j \in N, j \neq i} \delta_{ji}^k \cdot D_{ij} + \sum_{(i,k) \in APr} \sum_{j \in N, j \neq i} \delta_{ij}^k \cdot D_{ij}. \tag{A.7}$$

- Total distance covered by teams that have breaks in midweek slots:

$$\sum_{k \in MW^1} \sum_{i, j \in N} DA_i^k + \sum_{k \in MW^2} \sum_{i, j \in N} DH_i^k. \tag{A.8}$$

Round-robin structure constraints

(R_1) Each team must play exactly one game in a slot:

$$\sum_{j \neq i} \delta_{ij}^k + \sum_{h \neq i} \delta_{hi}^k = 1 \quad \forall\, i, k. \tag{A.9}$$

(R_2) Each team meets all other teams once in each half:

$$\sum_k (\delta_{ij}^k + \delta_{ji}^k) = 1 \quad \forall\, i \neq j. \tag{A.10}$$

League requirements

(L_1) No breaks are allowed at the beginning and at the end of the half:

$$HH_i^1 = AA_i^1 = HH_i^{n-2} = AA_i^{n-2} = 0. \tag{A.11}$$

(L_2) No two consecutive breaks are allowed:

$$HH_i^k + HH_i^{k+1} \leq 1. \tag{A.12}$$

$$AA_i^k + AA_i^{k+1} \leq 1. \tag{A.13}$$

(L_3) Sequences *HHAHH* or *AAHAA* are forbidden:

$$HH_i^k + HH_i^{k+3} \leq 1. \tag{A.14}$$

$$HH_i^{n-1} + AA_i^3 \leq 1. \tag{A.15}$$

$$AA_i^k + AA_i^{k+3} \leq 1. \tag{A.16}$$

$$AA_i^{n-1} + HH_i^3 \leq 1. \tag{A.17}$$

Constraints (A.15) and (A.17) are imposed to handle border situations between the two halves.

(L_4) If the league requires it, a team $\bar{\imath}$ must play at home against team $\bar{\jmath}$ in slot $\bar{k}$:

$$\delta_{\bar{\imath}\bar{\jmath}}^{\bar{k}} = 1. \tag{A.18}$$

Similarly, a team $\hat{\imath}$ cannot to play at home against team $\hat{\jmath}$ in slot $\hat{k}$:

$$\delta_{\hat{\imath}\hat{\jmath}}^{\hat{k}} = 0. \tag{A.19}$$

(L_5) The number of matches in a half that each team plays at home and away must be balanced:

$$\left\lfloor \frac{n-1}{2} \right\rfloor \leq \sum_{k \in M} H_i^k \leq \left\lceil \frac{n-1}{2} \right\rceil. \tag{A.20}$$

(L_6) If the tournament stops after slot $\bar{k}$ for a specific period, no away breaks are allowed before, over, and after the stop:

$$AA_i^{\bar{k}-1} = 0. \tag{A.21}$$

$$AA_i^{\bar{k}} = 0. \tag{A.22}$$

$$AA_i^{\bar{k}+1} = 0. \tag{A.23}$$

(L_7) In each slot k, the number B_T^k and B_{ST}^k of matches between top teams and super top teams are limited, respectively:

$$\begin{cases} B_T^k = 0, & \text{if } k = 1; \\ B_T^k \leq 2, & \text{otherwise.} \end{cases} \tag{A.24}$$

$$\begin{cases} B_{ST}^k = 0, & \text{if } k \leq 2; \\ B_{ST}^k \leq 1, & \text{otherwise.} \end{cases} \tag{A.25}$$

(L_8) The number of matches in a half that each top team $i \in T$ plays with another top team at home and away must be balanced:

$$\left\lfloor \frac{|T|-1}{2} \right\rfloor \leq \sum_{k \in M} \sum_{j \neq i, j \in T} \delta_{ij}^k \leq \left\lceil \frac{|T|-1}{2} \right\rceil, \quad i \in T. \tag{A.26}$$

The rule is also applied for super top teams

$$\left\lfloor \frac{|ST|-1}{2} \right\rfloor \leq \sum_{k \in M} \sum_{j \neq i, j \in ST} \delta_{ij}^k \leq \left\lceil \frac{|ST|-1}{2} \right\rceil, \quad i \in ST. \tag{A.27}$$

(L_9) There should be balance between the number of midweek games played at home and those played away. Using

$$H_i^{MW} = \sum_{k\in MW^1} H_i^k + \sum_{k\in MW^2} A_i^k, \tag{A.28}$$

$$A_i^{MW} = \sum_{k\in MW^1} A_i^k + \sum_{k\in MW^2} H_i^k, \tag{A.29}$$

we denote the number of home and away matches in midweek slots during the whole tournament, respectively; we have the following:

$$|H_i^{MW} - A_i^{MW}| \le I_i, \tag{A.30}$$

where I_i should be minimum.

(L_{10}) The number of breaks should be as small as possible. This requirement translates into the term F_1 of the objective function.

(L_{11}) Teams with no breaks in their schedule are considered to have an advantage; therefore, this pattern should be avoided. These soft constraints end up in the term F_4 of the objective function. In particular, a team $i \in N$ has an alternating pattern (i.e., $AP_i = 1$) if and only if

$$\sum_{k\in M}(HH_i^k + AA_i^k) = 0; \tag{A.31}$$

that is, no breaks exist in the pattern.

(L_{12}) Avoiding playing a big match during midweek slots is preferable. Total number of big matches during midweek slots has already been reported in the objective function.

Club requirements

(C_1) There are specific slots in which a team $\bar{\imath} \in N$ is forced to play a home game, or a team $\hat{\imath} \in N$ must play an away game in those slots:

$$H_{\bar{\imath}}^k = 1; \tag{A.32}$$

$$A_{\hat{\imath}}^k = 1. \tag{A.33}$$

(C_2) If two teams $i, j \in N$ share the same venue (i.e., derby) at each slot, one must play at home and the second must play away:

$$H_i^k + H_j^k = 1, \quad k \in M. \tag{A.34}$$

(C_3) Each team can express preferences for scheduling home or away games on specific slots. The overall number of unsatisfied preferences was already reported in the objective function.

(C_4) If two consecutive away games are scheduled and the two relative slots are temporally close (e.g., in midweek slots), the overall distance traveled should be as low as possible.

$$\sum_{j\ne i}\delta_{ji}^k D_{ij} + \sum_{j\ne i}\delta_{ji}^{k+1} D_{ij} - DA_i^k \le (1 - AA_i^k), \quad k \in MW^1,\ i \in N, \tag{A.35}$$

$$\sum_{j\ne i}\delta_{ji}^k D_{ij} + \sum_{j\ne i}\delta_{ji}^{k+1} D_{ij} - DH_i^k \le (1 - HH_i^k), \quad k \in MW^2,\ i \in N, \tag{A.36}$$

where quantities DA_i^k and DH_i^k are summed in the term F_6 of the objective function.

Let us consider the first inequality. When $AA_i^k = 1$ (i.e., an away break occurs in slot $k \in MW^1$), the sum of the distances traveled is lower than or equal to DA_i^k. Because DA_i^k is in the objective function, the equality holds when the optimum is reached. Otherwise, if $AA_i^k = 0$, the inequality is always satisfied regardless of the value of DA_i^k; thus, DA_i^k is forced to be zero at the optimum. Analogous considerations can be made for the second inequality.

(C_5) The games on December 26 should be played by teams whose venues are geographically close to avoid lengthy travels on December 25. The overall distance traveled by the teams that play away in that slot has already been reported in the objective function.

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Verification Letter

Fabrizio Rossini, Assistant Director, Lega Pallavolo Serie A, Via Rivani, 6 40138 Bologna (I), writes:

"It is a pleasure for me to provide this verification letter for the paper 'Scheduling the Italian National Volleyball Tournament' by Guido Cocchi, Alessandro Galligari, Federica Picca Nicolino, Veronica Piccialli, Fabio Schoen, Marco Sciandrone.

"We had the opportunity of meeting this research group and have been impressed from the very beginning by their rigorous scientific approach towards this problem. Scheduling each year's tournaments has always been a challenging task, due to many clashes of dates, international games and to the Italian sport venues planning. A complex problem we had to face every year devoting many hours in manual trial-and-error runs.

"This is the first time we've obtained the support of the research group composed by the authors of the paper and we can confirm without any doubt that this has been a really positive experience.

"As in previous years, we had to face several trials to be run in order to accomplish many different requirements, some of which arriving in an unpredictable way. But in every occasion, the research team was very efficient in providing us with new solutions, sometimes different plans among which we might have chosen the preferred one.

"The quality of the schedules, from our point of view, is excellent, with a good balance among the teams and all their competition tasks. The final schedule was eventually approved on July 19, 2016, and officially presented to the clubs and media on July 21. The calendar is available on our official language, both in Italian and English (www.legavolley.it). The presentation was performed live on our webTV Lega Volley Channel; we can deliver the full program on file upon request.

"The collaboration with the research group has been very productive and spared us many days of manual planning and, at the same time, granted us an error-free schedule.

"We are grateful to the authors, who devoted a significant part of their time to invent, code and run a complex optimization model, driven only by their enthusiasm and by their desire to apply Operations Research to Sport.

"I would like also to add that they produced the schedule on a voluntary basis, without requesting any fee, except the participation to the official presentation of their schedule.

"Lega Pallavolo Serie A is at your disposal for any further request."

Guido Cocchi is a PhD candidate in operations research in the Department of Information Engineering at the University of Florence. After his graduation from classical lyceum, he received BS and MS degrees in information engineering in 2012 and 2015, respectively, from the same institution. His research interests lie in continuous and derivative-free multiobjective optimization, machine learning, and big data analytics.

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Veronica Piccialli earned her PhD in operations research at University of Rome La Sapienza in 2004. She was a postdoc in the Department of Combinatorics and Optimization in 2006 with Henry Wolkowicz. She has been an assistant professor at University of Rome Tor Vergata since 2008. In 2013 she received the national habilitation as associate professor. She has published widely. Her research interests include nonlinear optimization, game theory, and machine learning.

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Marco Sciandrone received an MSc degree in electrical engineering and PhD degree in systems engineering from the Sapienza Università di Roma, Rome, Italy, in 1991 and 1997, respectively. He has been an associate professor with the Università di Firenze, Florence, Italy, since 2006. He has published widely. His current research interests include nonlinear optimization, operations research, and machine learning. He serves on the editorial boards of two journals.