Drawing huge audiences to stadiums and to television broadcasts, professional soccer plays a major economic role in Brazil.

Soccer scheduling goaaaaal!

With substantial revenue and community pride on the line, devising optimal "fixtures" for Brazil's national soccer tournament is crucial to players, teams, fans, cities, security and TV sponsors.

By **Celso C. Ribeiro and Sebastián Urrutia**

Photos courtesy of Celso Ribeiro (stadium shots) and Brazilian Football Confederation.

S occer, already far and away the most popular sport in Brazil, is sure to see its status raised to unprecedented levels both in the country and throughout the rest of the world, thanks to the upcoming 2010 World Cup in South Africa, the 2014 World Cup to be hosted by Brazil and the recent awarding of the 2016 Olympics to Rio de Janeiro.

Professional leagues of soccer and other sports are big businesses and a major economic activity in Brazil and around the world. Transfers of major soccer players amount to tens of millions of dollars each. The sponsorship of national teams by sporting goods makers involves huge contracts. Broadcast rights in some professional sports competitions amount to hundreds of millions of dollars. Television networks buy the rights to broadcast the games for huge amounts of money but, in return, want the most attractive games to be scheduled at certain times. Revenues from attendance and tournament attractiveness also strongly depend on the schedule of the games, which must satisfy a number of hard and soft constraints. Technical, fairness and security constraints impose intricate patterns of scheduling that are difficult to determine.

Teams and professional leagues do not want to waste their investments in the players and structure of the sport because of poor schedules involving, for example, unattractive teams playing on prime dates or several important games played at the same time (resulting in loss of television rights since they cannot be broadcast simultaneously). National and international competitions played in parallel require strong coordination of travel and game schedules. Efficient schedules are therefore of major interest for teams, leagues, sponsors, fans and the media. Recent surveys addressed the literature on sports scheduling [1,2].

The yearly national soccer tournament organized by the Brazilian Football Confederation (CBF) is the most important sport event in the country. Its major sponsor is TV Globo, the largest media group and television network in Brazil. The most attractive games are those involving stronger teams with more fans and better players – games that typically draw the largest stadium attendance and biggest broadcast shares. Games involving teams from São Paulo and Rio de Janeiro are of special interest for broadcasting through open TV channels due to their larger revenues from advertising, since these two cities are the largest and most important in the country in terms of economic and cultural activity.

Tournament Structure

In spite of the importance of having a strong schedule of games, relatively few professional leagues have adopted optimization models and software to handle scheduling [3]. This seems to be due not only to the difficulty of the problem and to some fuzzy preference restrictions and criteria that can be hard to describe and even harder to formulate mathematically, but also to the resistance of teams and leagues that are often afraid of using new tools that break with the past and introduce modern techniques in sports management.

Games involving teams from São Paulo and Rio de Janeiro are of special interest to broadcasting sponsors.

A remarkable history of success in the field is the pioneering work of George Nemhauser and Michael Trick [4] regarding the scheduling of a college basketball conference, followed by recent work for Major League Baseball in the United States. Another recent and successful application is the system developed by the Asociación Nacional de Fútbol Profesional (ANFP) in Chile to schedule the tournaments of its soccer professional leagues [5], aiming to provide lower costs and higher incomes to the teams, as well as to increase attendance and attractiveness of the tournaments.

However, the Brazilian national soccer tournament is bigger, has much larger attendance and draws more attention from TV audiences. Due to the importance of soccer in Brazil, fair and balanced fixtures (schedules) for all teams are a major issue for attractiveness and confidence in the outcome. Furthermore, TV sponsors invest a lot of resources on broadcast rights and condition their support to suitable fixtures that make it possible to broadcast the most important games by open TV channels. Finally, the fact that some large cities often host at least two and up to four traditional teams with a large number of fans impose additional security constraints to avoid clashes of fans before or after the games, even when they take place at different stadiums. As a result, a number of players have their say before a fixture is approved, along

Fair and balanced schedules

for all teams are a major issue

for attractiveness and confidence

in the outcome.

Teams from Rio de Janeiro and São Paulo are among the best and have the largest number of fans.

with team managers, league officials, media sponsors and city administrators.

The tournament lasts for almost eight months (from April to December) and is structured as a compact, mirrored, double-round-robin tournament [6] played by 20 teams. Every team is based at its home city, where it has its assigned stadium for home games. Some cities host more than one team. Each team faces every other twice: once at home and the other away. Every pair of teams plays once in the first half of the tournament and once in the second, with exchanged venues. Games in the second half occur exactly in the same order as in the first. There are at most two rounds of games per week; mid-week rounds are played on Wednesdays and Thursdays, while weekend rounds are played on Saturdays and Sundays.

Elite teams are those with larger numbers of fans, better records of previous participations in the tournament and more valuable players. The most important games involve elite teams and should as much as possible be played during the weekends, when they can attract larger stadium attendances and TV audiences. The participating teams and the dates available for matches change from every year to the next, which makes the fixture used in one year unusable in the next.

Since most rounds take place on weekends, often the teams play only once a week and have to return to their home cities after each game, which makes it irrelevant to minimize travel costs and distances. In general, league officials and media sponsors face two objectives when it comes to scheduling:

1. Fair and balanced fixtures. CBF imposes that the tournament should be equilibrated and that all teams should face the same difficulties. For example, a "home break" occurs whenever a team plays two consecutive home games. Similarly, a team has an "away break" whenever it plays two consecutive away games. Since an ideal schedule with no breaks – in which all teams alternate perfectly between home and away games – is impossible for more than two teams, the tournament organizers seek a

fixture in which all teams have the same number of home and away breaks and this amount should be minimized.

2. Broadcast by open TV channels. The media sponsor aims to maximize its revenues from advertising. To maximize stadium attendance, soccer games in Brazil cannot be broadcast live to the same city where they take place. Since the teams from Rio de Janeiro and São Paulo are among the best and with the largest number of fans, the most attractive games for the sponsors are those involving one elite team either from Rio de Janeiro or from São Paulo playing away against a strong team playing at home, to be broadcast to Rio de Janeiro or to São Paulo, respectively. Therefore, CBF requests that at least two attractive games (one involving a team from Rio de Janeiro and the other a team from São Paulo) be scheduled for each round whenever possible. On the other hand, if more than two of such games are scheduled for the same round, the games in excess will not be broadcast. Therefore, TV Globo wishes to have at least two attractive games every round while avoiding an excess of attractive games in the same round.

The fixture should satisfy more than 30 different types of hard and soft constraints, ranging from fairness to security issues, and from technical to broadcasting criteria. Soft constraints are handled through penalties and incentives. Some of the constraints are summarized below. Most of them reflect strategies for maximizing revenues and tournament attractiveness, while others attempt to avoid unfair situations that could benefit one team or another with a more convenient fixture. These requirements have been discussed and established over the years by teams, federations, city administrators, security forces and sponsors:

- Every team playing at home in the first round plays away in the last round, and vice versa.
- Every team perfectly alternates home games with away games in the first four rounds and in the last two rounds.
- Pairs of teams with the same home city have complementary patterns (i.e., whenever one of them plays at home, the other plays away).

> The fixture should satisfy more than 30 different types of hard and soft constraints.

- Games between teams based in the same city are not to be played in mid-week rounds, in the first two rounds or in the last four rounds.
- No team can play more than two consecutive home games or more than two consecutive away games (i.e., there are no breaks in consecutive rounds).
- No team should play more than five consecutive games against elite teams.
- There is at least one elite team from Rio de Janeiro playing outside Rio de Janeiro and one elite team from São Paulo playing outside São Paulo in every round.
- There is a limit on the number of consecutive games a team may play in its own state, considering both home and away games.
- There are upper and lower bounds on the number of games involving pairs of elite teams in every round.
- Certain games cannot be played at some specific rounds.
- Certain games have to be played at specific rounds.
- All games take place simultaneously in the last two rounds, which imposes constraints on the stadiums shared by two or more teams based on the same city.
- Other constraints handle specific or regional requirements, privileged dates, etc.

Solution Strategy and Implementation

A straightforward, integer-programming formulation of the problem cannot be solved by a commercial solver after an entire day of computations. Therefore, we developed a decomposition approach to tackle the problem. The initial phase is devoted to the generation of home-away patterns of matches that satisfy the hard constraints related exclusively to the patterns. Only home-away patterns with exactly the minimum number of breaks [7] are constructed. This is followed by an enumeration scheme that assigns a different home-away pattern to each team obeying the corresponding constraints. Once a full assignment of teams to home-away patterns is obtained, the algorithm proceeds to the solution of an integer programming problem considering the selected assignment of home-away patterns and optimizing a weighted sum objective function that considers violations of the soft constraints. This integer program defines the games to be played in each round according to the selected home-away patterns. This problem is much easier to solve than the original. If this integer programming model turns out to be infeasible (and it often is), then the algorithm returns to the second stage to enumerate another assignment of patterns.

The complete model and the software system have been developed and adjusted over the last three years. Staff of CBF and TV Globo participated actively in the formulation of the problem and in the validation of results. The optimization software is coded in C++ and runs on a standard processor with an efficient LP solver in a few minutes of processing time. A database with historical tournament data supports the user to avoid repetitions of fixtures and situations observed in previous years.

The resulting automatic system was tuned with data from the 2005 and 2006 editions of the tournament. Fixtures generated by the system have been compared with the real, manually built fixtures used in these previous editions of the tournament. The official schedules used in 2005 and 2006 violated some of the problem requirements, while the optimized schedules met all constraints. The fixtures obtained by integer programming (with all soft constraints satisfied) were much better than the unfeasible adopted schedules. Furthermore, the integer programming approach led to schedules in which all 56 of the most attractive games could be broadcast by open TV channels without conflicts, while the ad hoc rules used for scheduling the 2005 and 2006 tournament editions made it possible to broadcast only 43 and 47 games, respectively. At this point, the prototype system has been validated and was ready to be used in practice for the first time!

> **A straightforward, integer-programming formulation of the problem cannot be solved by a commercial solver after an entire day of computations.**

The integer programming approach led to schedules in which all 56 of the most attractive games could be broadcast by open TV channels without conflicts.

Practical Experience

The system was used for the first time in 2009 as the official scheduler to build the fix-

The 2009 tournament was the most attractive in a decade, with four teams still in contention for the title when the last round started.

tures of the first and second divisions of the Brazilian national soccer tournament. Several alternative fixtures were provided to the users, who selected their preferred choice. New criteria were proposed and introduced in the system along the decision process based on successive refinements of the solution, as the decision-makers evaluated and filtered the different fixtures proposed by the system. The final fixtures were announced in January 2009.

The 2009 tournament revealed itself as the most attractive in the last decade, with four teams (Flamengo, Internacional, São Paulo and Palmeiras) still in contention for the title when the last round started and when all the games were played simultaneously. The title changed hands several times during almost two hours due to changes in the scores of the 10 games underway. Flamengo scored the goal that decided the tournament only 20 minutes before the end of the tournament. The champion was known only when the last game ended, contrarily to what had happened in previous years when the winners were known up to four rounds before the end of the tournament, making the games of the last rounds very uninteresting. This attractive scenario observed in 2009 in terms of public attendance, game revenues and TV audiences was partly due to a fair and equilibrated schedule of games, in which no teams had specific advantages or disadvantages.

The new system was used for the second time in 2010, with the fixture being announced last February. Once again, the decision-makers were happy with the proposed alternatives and with the choices they had. This was a particularly difficult tournament to schedule. Since the tournament has to be interrupted in June and July during the 2010 World Cup, very few dates were available for matches, and the duration of the tournament will be much shorter than in previous years. As a result, there will be more midweek rounds and fewer weekend rounds, making

it harder to find feasible fixtures. One additional nice feature of the system is its capability to indicate to the user the constraints that should be dropped in case of infeasibilities.

Operations research and new technologies have certainly proved they have their place in sports management. Besides the quality of the solutions found, the main advantages of the optimization-based computational system are its ease of use and the construction of several alternative schedules, making it possible for the decision-maker planning the competition to compare and select the most attractive schedule from among different alternatives, which can contemplate other secondary goals and constraints, such as scheduling on weekends or major holidays the classical regional games characterized by the rivalry of teams and fans; scheduling only one game at each round in small cities or in cities with only one stadium; avoiding two rival visiting teams in the same city on the same day to avoid clashes between their fans; complementary schedules for teams sharing the same stadium; or ensuring that at least one game is played at every round in large cities. **IORMS**

Celso Ribeiro (celso@ic.uff.br) is a professor in the Department of Computer Science of Universidade Federal Fluminense, Brazil. *Sebastián Urrutia* (surrutia@dcc.ufmg.br) is a professor in the Department of Computer Science at the Universidade Federal de Minas Gerais, Brazil. The authors have developed the problem formulation, the solution strategy and the interactive software system that generates the solutions proposed to the decision-makers for the soccer-scheduling problem described in this article.

R E F E R E N C E S

1. G. Kendall, S. Knust, C.C. Ribeiro, and S. Urrutia, 2010, "Scheduling in sports: An annotated bibliography," *Computers and Operations Research,* Vol. 37, pp. 1-19.
2. R.V. Rasmussen and M.A. Trick, 2008, "Round robin scheduling: A survey," European Journal of Operational Research, Vol. 188, pp. 617-636.
3. K. Nurmi, D. Goossens, T. Bartsch, F. Bonomo, D. Briskorn, G. Duran, J. Kyngäs, J. Marenco, C.C. Ribeiro, F. Spieksma, S. Urrutia, and R. Wolf, 2010, "A framework for a highly constrained sports scheduling problem," to appear in the International Multi-Conference of Engineers and Computer Scientists, Hong-Kong.
4. G. Nemhauser and M. Trick, 1998, "Scheduling a major college basketball conference," *Operations Research,* Vol. 46, pp. 1-8.
5. G. Durán, M. Guajardo, J. Miranda, D. Sauré, S. Souyris, A. Weintraub, and R. Wolf, 2007, "Scheduling the Chilean soccer league by integer programming," Interfaces, Vol. 37, pp. 539-552.
6. K. Easton, G. L. Nemhauser and M. A. Trick, 2004, "Sports scheduling," in "Handbook of Scheduling: Algorithms, Models and Performance Analysis," (J.T. Leung, ed.), pages 52.1-52.19, CRC Press.
7. C.C. Ribeiro and S. Urrutia, 2007, "Scheduling the Brazilian soccer tournament with fairness and broadcast objectives," *Lecture Notes in Computer Science 3867,* pp. 147-157.