

Successful operations research and data sciences applications designed at universities in Argentina and Chile over the last 20 years

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Why Should Public Universities Work on Applications?

- As academics and students of public universities, we believe our institutions should be involved with the outside world, working on solutions to real problems.
- In this sense, operations research (OR) and data sciences (DS) are fields that have much to contribute.
- OR and DS develop models, methods and algorithms capable of simultaneously analysing thousands of variables and scenarios in order to determine efficient policies for different problems.

Why Should Public Universities Work on Applications?

- We have worked on operations research and data sciences applications in a range of areas such as logistics and transport problems, production planning, efficient distribution of human resources, network design, time planning, education, political sciences, health, sports scheduling and public tender management.
- Our intention is not to become a consulting firm or compete with existing ones, but simply to participate as members of public universities in the search for solutions to real problems that pose a genuine intellectual challenge.
- Our activities will lead to new research projects, new scientific papers, new thesis topics, etc. In other words, the world of real applications will stimulate the world of academic research and vice versa.

Why Should Public Universities Work on Applications?

- Our operations research and data sciences teams at the University of Buenos Aires and the University of Chile have gained much experience in real applications with the public, private and non-profit sectors.
- In what follows, we present some of the projects our teams have developed in collaboration with public and non-profit sectors in Argentina and Chile.
- We will examine the mathematical modelling, the computational implementation, the results and the impact obtained from these real-world implementations.

Public Sector Projects

- The Logistics of Population Census-Taking
- Urban Waste and Leaf Collection
- Covid-19 Analytics
- An Application to Education
- An Application to Political Sciences
- Combinatorial Auctions

The Logistics of Population Census-Taking

- The definition of population census divisions in Buenos Aires Province for the national population census in Argentina.
- A combinatorial optimization algorithm based on an integer programming model was developed to assign housing units to census-takers while complying with guidelines laid down by the census procedures manual for Buenos Aires Province.
- The assignments defined by the algorithm were successfully used for the census conducted in 2010 (and a similar tool was used in the population census taken last year).

The Logistics of Population Census-Taking

- This project was carried out in collaboration with a consulting firm. The use of our computer tool enabled us to obtain a homogeneous segmentation with uniform compactness criteria, unlike the manual segmentation method used before 2010 which depended in large measure on operator decisions.
- Publication: F. Bonomo, D. Delle Donne, G. Durán, J. Marengo, “Automatic Dwelling Segmentation of Buenos Aires Province for the 2010 Argentinian Census”, *Interfaces* 43 (4), 2013, 373-384.

Urban Waste and Leaf Collection

Optimization of Urban Waste Collection:

- Our first project in this area was Planning the Collection of Urban Waste Containers in South Buenos Aires.
- The objective was to study the collection of public waste containers in the south side of the city of Buenos Aires. The collection problem was reduced to the classic travelling salesman problem, where the nodes of the graph are the containers. Our tool defined efficient routes for each waste collection truck and was able to solve all problem instances.

Urban Waste and Leaf Collection

- The solutions resulted in significant reductions in the length of collection truck itineraries (with these reductions ranging from 10 to 40% of the existing routes) and the work done by the trucks, the latter metric defined as the product of the distance covered and the tonnage transported. Extrapolation of the results to the entire southern zone of Buenos Aires indicated potential savings for the city's waste collection service of more than US200 000 per year, in addition to the qualitative improvements due to reductions in traffic disruption, vehicle driver fatigue and pollution.
- Publication: F. Bonomo, G. Durán, F. Larumbe, J. Marengo, "A Method for Optimizing Waste Collection Using Mathematical Programming: A Buenos Aires Case Study", *Waste Management & Research* 30 (3) (2012), 311-324.

Urban Waste and Leaf Collection

- This experience has been extended to other municipalities in Argentina (Morón, San Miguel de Tucumán, San Carlos de Bariloche, Concordia, Berazategui).
- It should be noted that the mathematical approach can vary greatly depending on the specifics of each individual problem.
- For example, in the work indicated below the solution is associated with the Chinese postman rather than the TSP because the trucks have to visit every block in the city.
- G. Braier, G. Durán, J. Marengo, F. Wesner, “An integer programming approach to a real-world recyclable waste collection problem in Argentina”, *Waste Management & Research* 35 (5) (2017), 525-533.

Urban Waste and Leaf Collection

- In the next project, developed in Berazategui, we had to define *a priori* the zonification of the municipality before designing the routes of the waste collection trucks.
- F. Bertero, M. Cerdeiro, G. Durán, N. Faillace, “Developing Optimization Tools for Municipal Solid Waste Collection in the Argentine city of Berazategui ”, *INFORMS Journal on Applied Analytics* (2023), in press.
- The optimization problem is partitioned into three stages. In the first stage, a heuristic constructs structurally simple collection zones that are balanced in terms of the waste collectors’ walking distances.
- In the second stage, for each zone a truck route is designed whose length is minimized by a method based on a mixed integer linear programming model.
- In the third and final stage, each truck is assigned to two zones in such a way as to equalize, to the extent possible, the lengths of the drivers’ working day.

Urban Waste and Leaf Collection

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Urban Waste and Leaf Collection

- We are engaged in yet another projects with similar characteristics for the municipalities of Quilmes and Miramar.
- Quilmes is located in the south of Greater Buenos Aires, and in consequence, the approach should be similar to that one developed in Berazategui.
- Instead Miramar is a beach town located 450 km. from Buenos Aires city and so we faced with the challenge of organizing waste collection for a locality with a permanent population of 30 thousand that is multiplied by 5 during the summer season.

Urban Waste and Leaf Collection

Optimization of Leaf Collection:

- We developed mathematical programming algorithms to solve the problems of street-sweeping personnel assignment and leaf collection truck routing in the Argentine municipality of Trenque Lauquen (450 km. west of Buenos Aires, 34,000 residents).
- A preliminary study of the same problem carried out in the city of Salta in northern Argentina proved to be useful in understanding the characteristics of the leaf-sweeping problem there and the main requirements of a practical solution.
- The aim was to achieve efficiency in the assignment of sweepers to city blocks, the identification of leaf bag deposit points and the routes to be followed by collection trucks for leaf bag pickup.
- The assignment of sweepers was based on the ideas we developed for assigning housing units to census-takers in the census project.

Urban Waste and Leaf Collection

- The approach developed in this project optimized the distribution of sweepers across each zone, ensuring all streets are swept while determining how many sweepers were required (the model showed that the number previously employed was not sufficient to cover all streets properly).
- The model results also reduced the number of container deposit points by roughly one-half.
- The total travel distance of the truck routes, modelled as an asymmetric travelling salesman problem, was cut by 10–15%, with the consequent savings in time, vehicle use and fuel consumption.
- Publication: Delle Donne D., Di Tomaso V. and Durán G., “Optimizing Leaf Sweeping and Collection in the Argentine city of Trenque Lauquen”, *Waste Management and Research* 39 (2) (2021), 209-220.

Covid-19 Analytics

- With the arrival of Covid-19 in Argentina, a working group of scientists from the University of Buenos Aires and CONICET put our experience and knowledge in data science and associated disciplines at the service of the national, provincial and municipal government authorities responsible for decision-making in the difficult context created by the pandemic.
- Various data analysis projects were implemented using simulation and artificial intelligence tools and statistical models. These projects included estimating the pandemic's reproductive number (R), calculating case doubling time, analyzing and predicting case evolution, creating a control panel to provide information on the temporal evolution of metrics regarding the pandemic in the country, estimating prevalence at the national and sub-national levels, and analyzing quantitative, biological and social causes of virus immunity.

Covid-19 Analytics

- A number of rapid-response projects were also developed such as prevention centers set up in different areas of the country, a computerized system to coordinate admissions across networks of hospitals and an agent-based simulation platform, the latter two implemented for Greater Buenos Aires municipalities.
- Publication: Arrar M., Belloli L., Bianco A., Boechi L., Castro R., Durán G., Etchenique R., Fernández N., Ferrer L., Garbervetsky D., Goldsmit R., Grillo Vidal C., Kamienkowski J., Laciana, P., Lanzarotti E., Lozano M., Maidana R., Mendiluce M., Minoldo S., Pepino L., Pecker-Marcosig E., Puerta E., Quiroga R., Solovey G., Valdora M., Zapatero, M., “Mathematical and computational initiatives from the University of Buenos Aires to contribute to decision-making in the context of Covid-19 in Argentina”, Science Reviews from the end of the world (2021) 2 (2) 6-40.

Covid-19 Analytics

- Impact of the vaccination campaign: A study was conducted to develop an observational quantification of the impact on the probability of death due to COVID-19 of the vaccination campaigns conducted in 2021 in Buenos Aires Province (40% of Argentina's inhabitants). Included in the study was an analysis of 1.5 million confirmed cases.
- Death probability was modeled with breakdowns by age, sex, municipality of residence and vaccine scheme administered. Vaccine effectiveness curves and death probability reduction rates were derived using two statistical models: a generalized linear model and Cox's proportional hazards model.
- Levels of effectiveness on the death probability ranged from 50% al 90% for two or more doses. That effectiveness was greater in women than men and declined with age. Of the three vaccines widely administered during 2021, the most effective one was Sputnik, followed by AZ/Covishield and then Sinopharm, both with one dose and two or more.

Covid-19 Analytics

- To obtain a global measure that quantified the observed impact of the vaccination program for the period under study, we also calculated the additional number of deaths that would be expected if all persons in our data were unvaccinated.
- The expected additional deaths of confirmed cases in Buenos Aires Province during 2021 was 7,610, an excess of 25% over the number of deaths actually observed during that period.
- Publication: Durán G., Durán M., Farall A., García J., Parada D., Salgado A., “Impact of the COVID-19 Vaccination Campaigns in Argentina during 2021: An Observational Quantification of the Death Probability for Confirmed Cases in Buenos Aires Province” (2023), submitted.
- We submitted a paper reviewing these quantitative analyses on the impacts of COVID-19 to the 2023 IFORS Prize for OR in Development. It was chosen as a finalist in the last round of the contest, which will be held in July in Santiago, Chile.

An Application to Education

- An application of mathematical programming to the selection of applicants for a post-graduate degree programme at the University of Chile using affirmative action criteria.
- Mathematical programming models were developed to apply gender equity, regional and socio-economic criteria to the selection of applicants for the Master's degree programme in globalization management at the University of Chile.
- The algorithm, based in integer programming models, generated robust solutions in minutes, an achievement practically impossible using manual methods. The application's success demonstrates how mathematical programming and operations research can contribute to social policy.
- Publication: G. Durán and R. Wolf Yadlin, "A mathematical programming approach to applicant selection for a degree program based on affirmative action", *Interfaces* 41 (3) (2011), 278-288.

An Application to Political Science

- Improving access to voting in Argentina.
- We used mathematical models to quantify the differential cost of participation faced by voters, which was measured in terms of distance to polling stations and wait times for casting one's vote. To estimate the model parameters, we used real-world data on the 2013 midterm elections in Argentina.
- The assignment produced by our model cut average voting time by more than 27%, underscoring the inefficiencies of the current method of alphabetical assignment.
- Publication: G. Durán, M. Giorment, M. Guajardo, P. Pinto, P. Rey and N. Stier-Moses, "Improving access to voting with optimized matchings", *Electoral Studies* 51 (2018), 38-48.

Combinatorial Auctions

- Combinatorial Auctions. This involved auctions where the bids consisted of groups of items, thus turning the decision process into a combinatorial optimization problem.
- Many aspects have to be considered in these models, including the auction design, the development of mathematical models for determining the auction outcome, and the implementation of suitable algorithms for solving them. The organizer seeks to minimize its costs if it is a “buyer”, or to maximize its benefit if it is a “provider”.
- A successful case in Chile: Epstein, R., Henríquez L., Catalán J., Weintraub G. and Martínez C.. “*A Combinatorial Auction Improves School Meals in Chile*”, *Interfaces* 32(6), 1–14, 2002.

Combinatorial Auctions

- A project was designed for a Chilean government agency known as JUNAEB that provided meals at around ten thousand schools in Chile. Different kinds of meals were supplied to more than two million schoolchildren. At the time, the government was spending 500 million dollars a year on this program. The actual provision of the meals was handled by catering companies that participated in annual auctions for the award of meal supply contracts organized by the agency.
- For practical purposes, each of Chile's regions was subdivided into Territorial Units (TU). There were over 100 such TUs across the whole country. Each company participating in an auction submitted bids to supply meals in groups of TUs, and the bids would be either accepted or rejected as is. This ensured the potential for economies of scale would be realized. Annual auctions were held for TUs covering one-third of the country, and the contracts awarded are of three years' duration.

Combinatorial Auctions

- For 15 years beginning in 1997 a mathematical model developed by Rafael Epstein and his group was used to support decision-making process for the school meals auction. The model objective consisted in identifying the bids that covered all the auctioned TUs while minimizing total expenditure. Implementation of the model resulted in savings of over 40 million dollars a year.
- This project received the 2002 OR For Development prize, awarded every three years by IFORS to the best operations research/management science application in developing countries.

Combinatorial auctions

- As a subpart of this project we implemented quantitative methods for redesigning the TUs. Mathematical models using Analytic Hierarchy Process (AHP, by Saaty) as well as heuristics and integer programming models were developed to arrive at an efficient TU design. The divisions identified were used by JUNAEB since 2008.
- Before 2007, the TUs were defined manually and their attractiveness to potential suppliers was highly variable. This led to a series of problems for the government, both in the contract tender process and the service provided.

Combinatorial auctions

- Our proposal ensured that the level of attractiveness across all of the TUs was similar and that schools in each region of the country received meal service of good (and similar) quality. This homogenization of TU attractiveness helped reduce the uncertainty and bankruptcy risk faced by suppliers, a benefit to the entire system.
- This work was a finalist in the EURO 2010 competition for the best OR application, held in Lisbon.
- Publication: G. Durán, R. Epstein, C. Martinez and G. Zamorano, “Quantitative Methods for a New Configuration of Territorial Units in a Chilean Government Agency Tender Process”, *Interfaces* 41 (3) (2011), 263-277.

Combinatorial auctions

- With the school meals experience in mind, we worked on the design of a tender process and a mathematical programming model for the provision of Internet service to public schools in the City of Buenos Aires.
- This project consisted in designing the type of tender process and implementing a mathematical model to determine the best combination of offers. Our proposal was used for the tender process held in 2008.
- Publication: F. Bonomo, J. Catalán, G. Durán, R. Epstein, M. Guajardo, A. Jawtuschenko, J. Marengo, “An Asymmetric Multi-Item Auction with Quantity Discounts Applied to Internet Service Procurement in Buenos Aires Public Schools”, *Annals of Operations Research* 258 (2) (2017), 569-585.

Combinatorial auctions

The city government's original proposal was the following:

- Auction each school separately.
- Each Internet provider makes a bid for each school.
- Each school is assigned the Internet provider offering the best price for that school.

Problems with the proposal were the following: no economies of scale captured; possibility of collusion; possible price distortion (higher prices for schools in areas with little competence).

Combinatorial auctions

Our counter proposal, which was adopted by the city authorities, was the following:

- Each provider bids a price for a single school (the same for all schools).
- Each provider defines the list of schools it can serve.
- Each provider gives volume discounts (with pre-specified price intervals).
- An upper bound on the number of schools each provider can be assigned (this part of our proposal was not accepted).

Combinatorial auctions

- Benefits of our proposal:
 1. Almost impossible to collude.
 2. Impossible for a provider to bid a high price in areas with little competition and lower prices in areas with stronger competition.
 3. Economies of scale are captured.
 4. Each company defines its own coverage area in terms of the list of schools it can serve.

Combinatorial auctions

Foundations of the mathematical model:

- The optimal solution for the city is obtained, assigning a provider to each school.
- Territorial units are designed after the bids are presented, based on the school lists defined by the providers (note that this formulation is more efficient than the natural formulation with one binary variable per school and provider, which would have many more variables).
- The model solution determines how many (but not which) schools each provider receives within each territorial unit (whole units are not necessarily assigned to a single provider).
- If a solution determines that the school assignments in a territorial unit are to be shared among two or more providers, the unit's individual schools can be assigned to them by a manual or automatic process based, for example, on geographic criteria.

Combinatorial auctions

Model parameters:

- C : set of Internet providers
- R : set of territorial units, defined by the intersection of the providers' coverage areas
- $E_r, r \in R$: set of schools in the region r
- $p_{ji}, j \in R, i \in C$: 1 if the provider i bids in unit j , otherwise 0
- T : set of price intervals (0–19, 20–39, ..., 80–99, 100–149, 150–199, 200–299, ..., 500–600, 600–709)
- $\min(t)$ and $\max(t), t \in T$, lower and upper bounds of each price interval
- $c_{ti}, t \in T, i \in C$: cost per school in the price interval t offered by provider i

Combinatorial auctions

Model variables:

- $x_{ji} \in \mathbb{Z}_{\geq 0}$, $j \in R$, $i \in C$: number of schools in unit j assigned to provider i
- $y_{it} \in \{0, 1\}$, $i \in C$, $t \in T$: specifies whether provider i 's bid is within price interval t
- $z_{it} \in \mathbb{Z}_{\geq 0}$, $i \in C$, $t \in T$: number of schools assigned to provider i in price interval t . This variable can be defined in $\mathbb{R}_{\geq 0}$, since in the optimal solution it will be set at an integer value.

Combinatorial auctions

$$\min \sum_{i \in C} \sum_{t \in T} c_{ti} z_{it}$$

$$\sum_{i \in C} x_{ji} = |E_j| \quad \forall j \in R$$

$$\sum_{j \in R} x_{ji} \geq \min(t) - M(1 - y_{it}) \quad \forall i \in C, \forall t \in T$$

$$\sum_{j \in R} x_{ji} \leq \max(t) + M(1 - y_{it}) \quad \forall i \in C, \forall t \in T$$

$$\sum_{t \in T} y_{it} = 1 \quad \forall i \in C$$

$$z_{it} \geq \left(\sum_{j \in R} x_{ji} \right) - M(1 - y_{it}) \quad \forall i \in C, \forall t \in T$$

$$x_{ji} = 0 \quad \forall i \in C, \forall j \in R / p_{ji} = 0$$

$$\sum_{t \in T} z_{it} = \sum_{j \in R} x_{ji} \quad \forall i \in C$$

Combinatorial auctions

Searching for multiple optima:

- Let $x_{ij} = a_{ij}$ be the optimal solution for every provider i and unit j .
- To each such equation we add two binary variables w_{ij} and w'_{ij} . We also add the following constraints:

$$x_{ij} \geq (a_{ij} + 1)w_{ij} \quad \forall ij : a_{ij} \neq 0$$

$$709 - x_{ij} \geq (709 - (a_{ij} - 1))w'_{ij} \quad \forall ij : a_{ij} \neq 0$$

$$\sum_{a_{ij} \neq 0} (w_{ij} + w'_{ij}) = 1$$

Combinatorial auctions

Distribution within a territorial unit:

- Once the model has been solved and the definitive solution obtained, the schools in each unit are assigned to providers. In cases where schools in a single unit are assigned to two or more providers, the model specifies how many schools each provider is assigned but not which ones. A post-processing phase is therefore required to make the school-to-provider assignments.
- We suggested for the post-processing phase a straightforward greedy procedure that pans the unit from north to south, ensuring the specified number of schools is assigned to each provider over the whole process.
- The result is that the “sub-units” assigned to each bidder tend to be compact areas, thus simplifying each provider’s logistics. In cases where the unit is longer along the east-west than the north-south axis, the unit can be panned east to west.

Combinatorial auctions

Results and Conclusions:

- Four providers participated of the tender.
- Model execution time was a matter of seconds.
- The definitive solution awarded all of the schools to the same provider at a unit price of U\$\$ 234.84 per month. This is consistent with the existing literature, which predicts that the strongest bidder is always the winner.
- The winning price bid was 6% lower than the U\$\$ 250 regarded as a good price by the city authorities. Based on this, the savings to the city under the model solutions may be estimated at U\$\$ 250,000 for the two years (although given what was made public regarding the bids, the actual savings would have been much greater still).

Combinatorial auctions

Results and Conclusions:

- Our main contribution was the design of the auction process given that the number of bids received and their properties were such that the optimal assignment was not difficult to find.
- Further perspective on the effectiveness of the proposed tender format may be had by calculating what would have been the highest unit price the winner firm could have bid for the most discounted volume interval and still be awarded the contract for every school.
- This highest price turned out to be 71% above the actual winning bid, suggesting that the tender was indeed competitive and there was no collusion between bidders.

Sports Projects

- Sports applications in non-profit sectors
- Data sciences in sports applications
- A survey about our sports applications

Sports applications in non-profit sectors

- The design of Chilean football league schedules.
- Summary: Mathematical models were developed that have been used to schedule the First Division of Chile's professional football league since 2005, the Second Division since 2007 and the Third Division since 2013. The application was a finalist for the 2016 Franz Edelman Award, the most important operations research competition at the world level. Held that year in Orlando, Florida, the contest is organized by INFORMS, the U.S.-based Institute for Operations Research and the Management Sciences.

Sports applications in non-profit sectors

Works published on the design of Chilean football league schedules:

- F. Alarcon, G. Durán, M. Guajardo, et al, “Operations Research Transforms Scheduling of Chilean Soccer Leagues and South American World Cup Qualifiers”, *Interfaces* 47 (1) (2017), 52-69.
- G. Durán, M. Guajardo and R. Wolf-Yadlin, “Operations Research Techniques for Scheduling Chile’s Second Division Soccer League”, *Interfaces* 42 (3) (2012), 273-285.
- G. Durán, J. Miranda, M. Guajardo, D. Sauré, S. Souyris, A. Weintraub and R. Wolf, “Scheduling the Chilean Soccer League by Integer Programming”, *Interfaces* 37 (2007), 539-552.
- T. Noronha, C. Ribeiro, G. Durán, S. Souyris and A. Weintraub, “A branch-and-cut algorithm for scheduling the highly-constrained Chilean soccer tournament”, *Lecture Notes in Computer Science* 3867 (2007), 174-186.

Sports applications in non-profit sectors

- A mathematical model for referee assignment in Chilean football.
- Summary: This application addressed the problem of assigning referees to matches in the First Division of the Chilean professional football league using an integer linear optimization model. The model is able to capture criteria that lent transparency and objectivity to the process, ensuring a balance in both the number of matches assigned to each referee and their total travel distances. It also takes account of refereeing experience when assigning special matches.
- Publication: F. Alarcón, G. Durán, and M. Guajardo, “Referee Assignment in the Chilean Football League using Integer Programming and Patterns”, *International Transactions in Operational Research* 21(3), 2014, 415-438.

Sports applications in non-profit sectors

- The design of the season schedule for the First Division of the Argentine men's volleyball league.
- Summary: The Argentine men's volleyball league has 12 teams that play a regular season followed by playoffs. During the season each team plays every other one, once at home and once away. A notable characteristic of the season schedule is that the teams are grouped into pairs which play other pairs on two dates within each weekend. The project, commissioned by the *Asociación de Clubes Liga Argentina de Vóleybol*, consisted in optimizing the season schedule so as to minimize the total distance travelled by the teams. The resulting schedule has been used successfully since 2007.
- Publication: F. Bonomo, A. Cardemil, G. Durán, J. Marengo, D. Sabán, "An application of the traveling tournament problem: The Argentine volleyball league", *Interfaces* 42 (3) (2012), 245-259.

Sports applications in non-profit sectors

- The design of the season schedules for the First and Second Divisions of the Argentine basketball league.
- Summary: The First Division of Argentine basketball (the National League) has 20 teams that play a regular season divided into a regional phase (two conferences of 10 teams each) and a national phase, followed by playoffs to determine the overall champion. In both phases each team plays every other one, once at home and once away. Unlike the volleyball league schedule, however, the teams are not grouped in pairs and matches are not confined to weekends. This format is similar to the one used by the NBA in North America and was proposed by the authors for use by the Argentine league.

Sports applications in non-profit sectors

- This scheduling project, undertaken for the *Asociación de Clubes de Básquet de la Argentina*, creates road trips of 2, 3 or 4 games as requested by the individual teams in such a manner as to minimize the teams' total distance travelled. The season schedule created by our application has been used successfully for the last four seasons, with reported travel savings of more than 30%. A similar schedule has been created for the Second Division and the Women's League.
- Publication: G. Durán, S. Durán, J. Marengo, F. Mascialino, P. Rey, "Scheduling Argentina's Professional Basketball Leagues: A Variation on the Relaxed Traveling Tournament Problem", *European Journal of Operational Research* 275(3) (2019), 1126-1138.

Sports applications in non-profit sectors

- This project on basketball has been extended to the efficient assignment of referees for the First and Second Divisions.
- Publication: G. Durán, M. Guajardo, F. Gutiérrez, “Efficient Referee Assignment in Argentina’s Professional Basketball Leagues using Operations Research Methods”, *Annals of Operations Research* 316 (2) (2022), 1121-1139.

Sports applications in non-profit sectors

- The design of the South American qualifying stage for the 2018 and 2022 World Cups.
- Summary: Integer programming models were implemented to design the schedule for the completely South American qualifying stages of the 2018 and 2022 football World Cups. After many years using a different arrangement, the decision was made to change the schedule and our proposal for a new one was approved unanimously by the South American Football Confederation (CONMEBOL).
- Publication: G. Durán, M. Guajardo and D. Sauré, “Scheduling the South American Qualifiers to the 2018 FIFA World Cup by Integer Programming”, European Journal of Operational Research 262 (3) (2017), 1109-1115.

Sports applications in non-profit sectors

- Recent projects in football (Argentina and Ecuador).
- Youth divisions: G. Durán, M. Guajardo, A. López, J. Marengo and G. Zamorano, “Scheduling Multiple Sports Leagues with Travel Distance Fairness: An Application to Argentinean Youth Football”, *INFORMS Journal on Applied Analytics* 51 (2) (2021), 136-149.
- Superliga Argentina de Fútbol 2018-2019 and 2019-2020: G. Durán, M. Guajardo, F. Gutiérrez F., J. Marengo, D. Sauré. and G. Zamorano, “Scheduling the Main Professional Football League of Argentina”, *INFORMS Journal on Applied Analytics* 51 (5) (2021), 361-372.
- First and Second Division of Ecuadorian football in Covid context: G. Durán, M. Guajardo and G. Zamorano, “Mathematical models for rescheduling Ecuador’s 2020 professional football league season disrupted by COVID-19”, *Society and Economy* 44 (1) (2022), 360-377.

Data sciences in sports applications

- A quantitative analysis of the FIFA ranking procedure and World Cup draw.
- Summary: This project analysed the procedure used by FIFA to rank national soccer teams and define by random draw the team groups for the World Cup. A predictive model was calibrated as a baseline ranking to evaluate the performance of a series of simple changes to the existing procedure. The use of this ranking was then analysed to determine the groups for the World Cup finals. After pointing out a series of deficiencies in the group assignments made for the 2014 World Cup, a mixed integer linear programming model was implemented that balanced the difficulty levels of the groups.
- Publication: S. Cea, G. Durán, M. Guajardo, D. Sauré, J. Siebert and G. Zamorano, “An Analytics Approach to the FIFA Ranking Procedure and the World Cup Final Draw”, *Annals of Operations Research* 286 (2020), 119-146.

Data sciences in sports applications

- 301060: A web-site to predict football results.
- The web-site 301060.exactas.uba.ar was created for the 2018 Football World Cup, which was held in Russia. Using statistical models we try to predict the results of each game and the whole tournament.
- We have applied this model to the Superliga Argentina de Fútbol and the America Cups (2019 and 2021), and it was used again in Qatar 2022.
- Extensions to basketball, rugby and tennis were also implemented.
- Joint works with A. Álvarez, M. Durán, G. Lancioni and I. Monardo.

A survey about our sports applications

- G. Durán, “Sports Scheduling and other Topics in Sports Analytics: A Survey with Special Reference to Latin America”, TOP 29 (2021), 125-155.

Some conclusions

- This talk summarized a series of projects carried out for various public entities and sports organizations over the last 20 years by operations research and data sciences groups based at the University of Buenos Aires and the University of Chile,
- The transfer of technology from public universities through its academics and students is one of the key roles played by our academic centers, contributing to the generation of knowledge and the education of quality human resources in applied topics.
- Fundamental to the success of these projects has been the diverse backgrounds of both the academic and student members of the project teams. Though all have a solid foundation in mathematics and computation, they have not restricted themselves to any particular set of techniques but rather have been open to applying whatever methods might be most appropriate for the problem at hand.

Some conclusions

- Our projects have resulted in two clearly distinguishable types of output: the submission of reports and recommendations to the requesting entity on the best manner to proceed (in such cases the models developed are executed by the project team), or alternatively, the provision of a user-friendly computational tool to be operated by the requesting entity itself.
- The latter case typically requires considerable training for the user and a follow-up and maintenance period of up to a year during which the tool is fine-tuned and any kinks ironed out. Also in this case, the user will often need to acquire a commercial solver that works in parallel with the tool, which may significantly increase the cost of the project.
- As regards the projects' successes and failures, a central issue is the task of convincing the requesting organization of the need to modernize its logistics and operations and to work with our OR group as one single team united in a common purpose.

Some conclusions

- A major issue is the financing of the projects. In some cases, particularly those involving the public sector, the entity providing the funding for a project will derive no direct benefit from it. Such situations typically lead to problems, for if the entity is not the principal user and does not see the project as key to its daily operations, it is unlikely to be committed to its success.
- Another challenge is the fundamental need for access to good data. The chances of a favorable outcome are always much greater when the project starts out with a full dataset on the problem to be addressed.
- Regarding the areas of application of the projects, operations research and data sciences have the potential to make contributions to just about any private sector industry or public sector activity. Our group at the University of Chile has undertaken projects in numerous key sectors.

Some conclusions

- In Argentina, we have recently begun work on problems in hydrocarbon extraction and are open to possible projects in agriculture and livestock, the country's main industries (as forestry and mining are for Chile). These areas of the economy could no doubt benefit greatly from the application of mathematical and computational techniques.
- In closing, we note that the opportunities for having a positive impact through the application of the sort of projects discussed here are much greater in developing countries than in the developed world, which makes the challenges involved that much more motivating.

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