

Successful Operations Research applications from the academy in Chile and Argentina in the last 15 years

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Why Should Public Universities Work on Applications?

- We believe public universities should be involved with the outside world, working on solutions to real problems.
- In our case, operations research (OR) is a field that has much to contribute.
- OR develops methods and algorithms capable of simultaneously analysing thousands of variables and scenarios in order to decide what is the optimal policy for a given problem.

Why Should Public Universities Work on Applications?

- We have worked on operations research applications in a range of areas amenable to OR approaches such as logistics and transport problems, production planning, the efficient distribution of human resources, network design, time planning, 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 academic 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 teams at the University of Buenos Aires and the University of Chile have gained much experience in real applications linked with the public, private and non-profit sectors.
- In what follows, we present some of the projects our teams at the two institutions have developed.

Definition of population census divisions

- The use of combinatorial optimization to automatically segment residential areas of Buenos Aires Province for purposes of census-taking in the 2010 national population census.
- Summary: A combinatorial optimization algorithm was developed to assign housing units to census-takers while complying with guidelines set down by the census procedures manual for Buenos Aires Province. The assignments defined by the algorithm were successfully used for the census conducted on October 27th 2010. This project was carried out in collaboration with the consulting firm Impronta IT S.A.
- 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.

Optimization of Urban Waste Collection

- Planning the Collection of Urban Waste Containers in South Buenos Aires.
- Summary: The objective was to study the collection of public waste containers in the south side of the city of Buenos Aires. The work consisted in proposing algorithms that would define efficient routes for each waste collection truck. A program was developed that was able to solve all instances of the problem. The results demonstrated significant reductions in the length of the truck itineraries and the work done by the trucks, the latter measure calculated as the product of the distance covered and the tonnage transported.
- 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.

Optimization of Urban Waste Collection

- This experience has been extended to 5 other municipalities in Argentina (Morón, Salta, Tucumán, Bariloche, Concordia, Berazategui). However, the mathematical approach can vary greatly depending on the specifics of the problem in each case.
- Second publication: 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.
- Last year, we worked with the municipality of Trenque Lauquen (Buenos Aires Province) on the problems of street-sweeping personnel assignment and leaf collection truck routing (joint project with Valeria Di Tomaso and Diego Delle Donne, paper in preparation).

Logistics of a Salmon Farming Operation

- Optimisation of the use of salmon farm cage nets in seawater.
- The project created a tool based on a linear programming model to optimise resource use, improve planning and conduct economic analyses that would facilitate decision-making in the maintenance of salmon farm cage nets in seawater. The tool prototype was tested at one of the largest firms in the industry. The results were a reduction in cage net maintenance costs of about 18% as well as a number of qualitative benefits.
- Publication: F. Cisternas, D. Delle Donne, G. Durán, C. Polgatz and A. Weintraub, “Optimizing Salmon Farm Cage Net Use”, *Journal of Operations Research Society* 64 (2013), 735-747.

Ship routing for a salmon feed supplier

- Efficient scheduling of maritime routing for a salmon feed supplier.
- Summary: The objective of this project was to develop a system for scheduling the maritime deliveries of a salmon feed supply firm operating in southern Chile. The company faced a ship routing problem with a heterogeneous fleet, soft time windows, and accessibility and precedence restrictions, in which it had to decide how much product to deliver to each client subject to a minimum percentage of the original order. Solutions were generated using a GRASP heuristic approach.
- Publication: G. Romero, G. Durán, J. Marengo and A. Weintraub, “Efficient Ship Routing and Scheduling for a Salmon Feed Supplier”, *International Transactions in Operational Research* 20(6), 2013, 767-794.

Planning the production chain of a salmon farmer

- Mathematical models for optimizing the production planning of a salmon farming firm.
- Summary: Planning for a salmon farming production chain is structured in two major fish growth phases, freshwater and seawater. Two mixed integer linear programming models were developed that satisfied a series of biological, economic and health-related constraints in each phase. The models created an integrated planning process for the salmon production chain that incorporated the various requirements of the operation's two phases and improved coordination in operations planning.
- Publication: F. Bravo, G. Durán, A. Lucena, J. Marengo, D. Morán and A. Weintraub, "Mathematical Models for Optimizing Production Chain Planning in Salmon Farming", *International Transactions in Operational Research* 20 (5) (2013), 731-766.

Ship and truck routing at a salmon farming firm

- Mathematical programming of the maritime and land transport logistics of a Chilean salmon farmer.
- Summary: In the salt water stage of a salmon farming business, the fish are fattened in large floating cages grouped into seafarms. When the fish are ready to be harvested, they are transported in boats to holding facilities located at primary processing plants. There, they are slaughtered and cleaned before being loaded on trucks for transport to secondary processing plants, the last stage in the chain of processes where the final product is obtained. A heuristic was implemented to plan the logistics of the maritime and land transport operations in conjunction with the management of stock maintained in the cages at the holding facility. This tool is currently being applied with notable success at one of Chile's main salmon farmers.

Ship and truck routing at a salmon farming firm

- Publication: D. Delle Donne, G. Durán, G. Fuentes, J. Marengo, J. Villasante, A. Weintraub, “A Mathematical Programming Approach to the Maritime and Land Transport Logistics of a Chilean Salmon Farmer”, submitted.

Production planning at a salmon farming firm

- Production planning at a salmon farm processing plant using integer linear programming
- Summary: This project focussed on the final stage of the production process at a Chilean salmon farming business, which is the preparation of the final product. This stage is of key importance, for it is here that value is added to the raw material (harvested salmon at holding facilities) through the choice of which products to make and which markets they will be exported to. To address this decision problem, a computational tool was developed that runs an integer linear programming model which maximizes the economic benefits while satisfying a series of restrictions specific to the industry.

Combinatorial auctions

- 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.
- Summary: Consisted of designing the type of tender process and implementing a mathematical model to determine the best combination of offers. The call for tenders was organized by the City to provide Internet service in all of its public schools. Our proposal was used for the tender process of 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

- Quantitative methods for redesigning the territorial divisions used in the tender process for school meals in Chile.
- Summary: Mathematical models were developed to create an efficient design of the territorial divisions used by the *Junta Nacional de Auxilio Escolar y Becas* (JUNAEB) in its annual tender process for school meals in Chile. The divisions proposed have been used by JUNAEB since 2008. The project was a finalist in the 2010 competition for the best OR application held in Lisbon by the Association of European Operational Research Societies.
- 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.

Simulations for urban improvement

- Two projects for the development of simulation tools to support urban improvement in Buenos Aires Province municipalities.
- The first project generated recommendations for regulating heavy vehicle traffic in La Matanza, the largest municipality in the province (a joint project with the municipality).
- The second project was a study of an urban improvement project for several blocks of Mitre and Belgrano avenues in the centre of Avellaneda, involving the relocation of bus stops, newspaper kiosks, etc. (a joint project with the municipality and UNDAV).

Application to Education

- Mathematical programming applied to the selection of candidates for a post-graduate degree programme at the University of Chile using positive discrimination criteria.
- Summary: Development of mathematical programming models for the application of gender equity, regional and socio-economic criteria to the selection of candidates for the Master's degree programme in globalization management at the University of Chile. Begun in 2007, work on the project continued without interruption until 2011.
- 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.

Airport security

- A Stackelberg model of mobile patrols for Ezeiza Airport
- Summary: A Stackelberg game was created to optimize the patrolling of public areas at Ezeiza Airport. The game was modelled using integer linear programming. The model divides the airport into 3 independent areas, which in turn are partitioned into 5 or 6 zones. The number of police personnel available to patrol each area at each moment of the day is inputted to the model from information provided by the head of airport security. The model determines the locations to which police should be deployed, based on parameters stipulating the “value” of locating a police official in a given zone. These parameters were established using statistical data on pedestrian traffic and crimes committed in each zone. A prototype of this tool was implemented at Ezeiza in 2015 (joint work with C. Ferrari, E. Ferreyra, I. Koch and F. Ordoñez).

Application to Political Sciences

- Improving access to voting in Argentina.
- Summary: Using analytical models, we quantify the differential costs of participation faced by voters, which we measure in terms of distance to polling stations and wait times to cast a vote. To estimate the model parameters, we use 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.

Sports applications

- 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

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

- 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

- 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

- 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

- 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.
- The project has been extended to the efficient assignment of referees for the First and Second Divisions.
- 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

- The design of the South American qualifying stage for the 2018 World Cup.
- Summary: Integer programming models were implemented to design the schedule for the recently completely South American qualifying stage of the 2018 football World Cup to be held in Russia. 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

- 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* (2019), in press (DOI: 10.1007/s10479-019-03261-8).

Sports applications

- Three recent projects in Argentine football and another one in Ecuador.
- The first project was the implementation of an integer linear programming model that assigned days and kickoff times for the 2018 First Division schedule (joint work with M. Guajardo, F. Gutiérrez and G. Zamorano).
- The second project was the scheduling of the youth divisions for the 2018 season, also using an ILP model (joint work with M. Guajardo, A. López, J. Marengo and G. Zamorano).
- The third project was the scheduling of the Superliga Argentina de Fútbol (SAF) for the 2018-2019 season, also using a tool based on an ILP model (joint work with M. Guajardo, J. Marengo, D. Saure and G. Zamorano).
- Last season a similar model was implemented to schedule First and Second Division of Ecuadorian football (joint work with M. Guajardo and G. Zamorano).

Sports applications

- 301060: A web-site to predict football results.
- The web-site 301060.exactas.uba.ar was created for the last Football World Cup, which was held last year in Russia. Using statistical models we try to predict the results of each game and the whole tournament.
- We have extended this model to the Superliga Argentina de Fútbol and the America Cup, which is playing now in Brazil.
- Joint work with F. Bertero, F. Bonomo, M. Lin, I. Monardo and S. Vassiliev.