Lessons from Latin America for sustainable, healthier cities

ISE teams create solutions for recreation, traffic, pollution problems

By Andrés Medaglia

Bogotá, Colombia, is a capital city that serves as an example of the challenges and solutions toward creating sustainable urban environments in Latin America.

Photo courtesy of O.L. Sarmiento

Latin America is a region of many challenges but also of innovation and opportunities. It is a region of rapid urbanization, with 80% of its population (505 million people) living in cities within a diverse urban landscape.

It also has great concerns and challenges in terms of social inequality gaps; Latin America is arguably the most unequal region in the world. A recent study conducted from 366 cities in the region showed that 172 million (or 58% of the population studied) live in areas that have air pollution levels above the guidelines of the World Health Organization.

Another characteristic of the region is heavy traffic in its cities. In my city of Bogotá, Colombia, the increments in travel time due to this factor alone is about 50%; a 60-minute trip takes on average 90 minutes to complete. It is clear that citizens in Latin America have a complex landscape. Although we have learned to embrace chaos, the positive aspects of the region offset these challenges. But for industrial engineers, this is an invitation for improvement.

Sustainable development goals (SDGs) are a call for action by all countries to promote prosperity while protecting our planet and environment. The SDG 11 (The Global Goals for Sustainable Development, *globalgoals.org/11-sustainable-cities-and-communities*) focuses on making cities inclusive, safe, resilient and sustainable. In this context, Latin America has a lot to do to meet this goal by 2030, but also most of the countries in the global south.

To illustrate these challenges, only half the world's population has proper access to public transit. More than half the world's population does not have proper access to public spaces like parks. Air pollution causes a significant amount of untimely deaths. In addition, during the pandemic, more than 90% of COVID-19 cases have appeared in cities, putting even more social and economic pressure on urban settings. A lot of ISE wisdom could be put into service to make our world better.

On the bright side, several policies and programs have emerged from Latin America and perhaps may spread to other regions. We have systems that operate at a different scale or under other realities that have pushed us to develop creative solutions. In this article, I will cover challenges related to transportation, recreation in public spaces and air quality that have been partially tackled using ISE techniques in transdisciplinary teams. I will cover some of these stories where the ISE viewpoint has enriched the solutions in non-

A Recreovía hub in Bogotá provides physical activity classes in parks, mainly for vulnerable communities.

Photo courtesy of J.D. Pinzón

traditional settings for our profession.

Two key tools of ISEs are operations research and analytics, which focus on solving complex problems. Both share the idea that, through mathematical and computational models, we support better decision-making by transforming data into actionable advice. Descriptive models provide insight from historical data, predictive models try to view what will happen in the future and prescriptive models provide actions for decisions. More importantly, ISEs with their systemic view and holistic perspective derive methodologies by coupling, extending and integrating different models to provide complete analytics-based solutions to complex problems and systems.

To do so, it is important to articulate three pillars. First, it is important to identify the problem, its context, the stakeholders and the system's boundaries and its dynamics. Second, once we understand the problem, we can choose and build the right model. If there is no model that is a good fit for our problem, sometimes we need to extend these models through research. Third, as these models feed from data, it is necessary to extract, transform and load data in a systematic way.

These analytics-based solutions often require us to devise an ensemble of models and to explore multiple scenarios systematically, so programming is the glue that puts everything together. Finally, once we solve our model, we need to go back and interact with the stakeholders through a visual and actionable representation of the solution. So let us see how we have put these ISE tools to work.

Expanding recreation opportunities

In this case study, we worked in a public space program called the Recreovía program with the Institute of Sports and Recreation of the city of Bogotá (IDRD). The Recreovía program provides physical activity classes in parks, mainly for vulnerable communities. This type of program is present in nine countries in Latin America with more than 350 programs.

As the program grows, it is necessary to identify the best locations and schedules to expand the Recreovía hubs throughout the city. This challenge involves assigning public resources efficiently ("A robust DEA-centric location-based decision support system for expanding Recreovía hubs in the city of Bogotá (Colombia)," Sepideh Abolghasem, Felipe Solano, Claudia D. Bedoya, Lina P. Navas, Ana Paola Ríos, Edwin A. Pinzón, Andrés L. Medaglia and Olga L. Sarmiento, *International Transactions in Operational Research*, 2019).

To respond to this challenge, we developed RecreoBOG, a decision support system for the IDRD. RecreoBOG uses geographical data and information on locations, areas, theft records, schedules and historic attendance. At the descriptive layer, it is possible to visualize information through descriptive models. In this case, we built a data envelopment analysis model to classify programs according to their efficiency. At the predictive layer, we built a model based on random forest to estimate the number of potential participants in the new hubs. At the prescriptive layer, to select the best sites to expand the program, we used robust optimization models that maximize

A bike path in Bogotá. The Colombian capital has the largest network of bikeways in Latin America, with more than 550 km (more than 341 miles) of dedicated bikeways. Cycling trips accounted for 7% of the 13.3 million daily trips in the city in 2019.

Photo courtesy of C. Fernández

the number of participants in the program, taking into account the limited budget, that at most one schedule is selected per hub and that the sites are widespread throughout the city to adequately cover its population.

It is worth emphasizing that these analytics models are integrated – the output of one model is the input for another. ISEs are able to build these integrated models to solve these complex problems. In 2017, the IDRD used RecreoBOG for its expansion plan. Our team created different scenarios and conducted a "what if" analysis with IDRD officials. Our team recommended a set of 19 Recreovía hubs that consistently appeared in the solutions of our prescriptive analysis.

Of course, things are not always smooth and crisp as the output of our models. Considering new budget realities and gathering input from the community and local policymakers, the IDRD decided to open 10 new hubs out of the 19 initially recommended. After the implementation of the new hubs, attendance steadily increased. Total attendance data among all hubs from February to May 2017 showed a compound monthly growth of 28% and an average per event attendance growth of 7%.

Measuring cyclists' traffic stress

In this second study, we developed a methodology to estimate the level of traffic stress of cyclists in Bogotá. This work was funded by the Wellcome Trust of the UK and is part of a larger project called SALURBAL (a Spanish acronym for Urban Health in Latin America), which has a main goal of making cities healthier, more equitable and environmentally sustainable.

Bogotá has the largest network of bikeways in Latin America, with more than 550 km (more than 341 miles) of dedicated bikeways. Cyclists use this bike network, combined with the mixed-use road network, to complete their trips. In 2019, bike trips accounted for 7% of the 13.3 million daily trips in the city.

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It is important for the city to assess the level of stress that a cyclist experiences based on the physical and functional attributes of the streets. At the end, our city would like to know how to invest in infrastructure to have a bike network with lower stress levels for cyclists.

But first, how do we measure the level of traffic stress (LTS)? The LTS is an indicator that classifies the road segments according to the stress experienced by cyclists. To illustrate, if cars pass by your side, you might feel threatened and in danger. But if you ride on a segregated bike path, you might feel a bit more secure. These experiences create different levels of stress.

Under the LTS umbrella, depending on the characteristics of the road segment and its functional information, the street is classified as one of four levels. Typically, LTS 1 are streets that are the least stressful roads, even suitable for kids. On the other end of the spectrum, LTS 4 are streets generally more stressful and are suitable just for fearless cyclists.

Although LTS methodologies have been developed and applied to small- and medium-sized cities (such as Portland, Oregon, in the U.S.), our challenge was to extend the methodology to estimate LTS for a city of the size of Bogotá. Our analytics-based methodology starts with variable selection. After discussing with transportation experts, urban planners, and public health experts in our group, we identified two groups of variables: physical and functional. The physical variables were road width, number of lanes, presence of cycling infrastructure and heavy vehicles; the functional variables were vehicle speed, traffic density, traffic flow and congestion.

Once we calculated the variables for all the road segments, we used cluster analysis to identify the road segments that are similar to each other in terms of the eight variables ("Level of traffic stress-based classification: A clustering approach for Bogotá, Colombia, Colombia," Jorge A. Huertas, Alejandro Palacio, Marcelo Botero, Germán A. Carvajal, Thomas van Laake, Diana Higuera-Mendieta, Sergio A. Cabrales, Luis A. Guzman, Olga L. Sarmiento and Andrés L. Medaglia, *Transportation Research Part D: Transport and Environment*, 2020). Because Bogotá has about 170,000 road segments, the clustering algorithm takes a long time to run. For this reason, we had to adjust the classification algorithm to make it faster and scalable to the size of the city. We chose a representative area of the city, called a locality, and ran the clustering algorithm with the road segments of that single area.

After classifying the road segments into one of the four clusters (LTS low, LTS medium, LTS high and LTS extremely high), we trained a multinomial logistic regression to predict the probability of a new segment to belong to one of the four stress levels. With these probabilities, we classified the rest of the road segments in the city. Finally, based on this two-step classification, we developed a dashboard (Figure 1) to visualize these results. There we can see the LTS for a given neighborhood and that the busier, wider streets tend to be LTS extremely high (red) and the residential streets within the neighborhoods tend to be LTS low (green).

FIGURE 1

Measuring cyclists' road stress

A dashboard shows the level of traffic stress (LTS) classification in the Ciudad Salitre neighborhood of Bogotá.

Our LTS methodology provide useful information for city planning. We tested the hypothesis that more accidents occur on segments classified as LTS high and LTS extremely high. We overlapped the LTS layer with official reports of fatal and nonfatal collisions. As expected, the fatal and nonfatal accidents increased as the LTS level increased. Thus, we provided city officials strong evidence to help them find resources to lower the level of stress of the road network. Also, this methodology allows city officials to efficiently predict the impact of planned interventions on the LTS-based classification. When a new segment is planned, now we can anticipate how much stress it will impose on cyclists.

Measuring the multidimensional impact of the bicycle transport system

A third case focuses on the multidimensional impact of cycling as an active transportation mode that grew significantly as an alternative in the COVID-19 pandemic. This project is sponsored by Engineering X, an international collaboration funded

More than 10% of Bogotá deaths were attributed to air pollution in 2015, with an estimated cost to the city of $1.5 billion-plus.

by the Royal Academy of Engineering and Lloyd's Register Foundation ("Engineering X. Safer Complex Systems," *Royal Academy of Engineering*, case studies).

On March 20, 2020, the city of Bogotá entered a strict lockdown due to the global COVID-19 pandemic. The Mobility and Health Secretariats looked into innovative ways to guarantee mobility throughout the city while reducing the capacity of the public transport system complying with social distancing recommendations. Based on the city's established bike culture, local government targeted temporary bike paths as the primary solution, and by June 2020, it added 117 km (72.7 miles) of temporary bike lanes on top of the 550 km of existing dedicated bikeways. This expansion was planned and conceived by mirroring the corridors of the bus rapid transit, adding cycling infrastructure in areas with high volume of cyclists and adding more connectivity to longer bike trips.

With this context in mind, this project focuses on Bogotá's bicycle transport system and the measures taken by the city to manage the crisis. We evaluated the potential impact of the temporary bikeways in terms of safety, health, efficiency and flexibility. We designed a systems analytics methodology that combines systems modeling and analytics to analyze the bicycle transport (complex) system.

The systems analytics methodology is an innovative methodology for evaluating systems that combines actors' knowledge with data collected from possible interventions of the system. It uses analytics (descriptive, predictive and prescriptive) models to measure the system regarding specific performance indicators. The results of this case study are available at the Safer Complex Systems-Engineering X site, *raeng.org.uk/safer-complex-systems*.

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Tackling Bogotá's air quality

The fourth and last case focuses on air quality at a larger scale for Bogotá. This project, funded by the city, brought together researchers from environmental and industrial engineering, the business school and the school of economics to solve a critical environmental and health problem for the city.

Rapid urbanization has a direct impact on air quality and health-related problems. In 2015, the total cases of mortality attributable to air pollution reached 3,000 deaths, about 10.5% of the city's total deaths. The estimated cost due to air pollution has surpassed $1.5 billion ("Ambient fine particulate matter in Latin American cities: Levels, population exposure and associated urban factors," Nelson Gouveia, Josiah L. Kephart, Iryna Dronova, Leslie McClure, José Tapia-Granados, Ricardo Morales-Betancourt, Andrea Cortínez-O'Ryan, José Luis Texcalac-Sangrador, Kevin Martinez-Folgard, Daniel Rodriguez and Ana V. Diez-Roux, *Science of The Total Environment*, 2021).

We were part of a multidisciplinary project that proposed a 10-year decontamination plan for the city. The project provided a prescriptive optimization-based integrated assessment modeling tool to support a comprehensive urban air quality policy in Bogotá ("Optimization model for urban air quality policy design: A case study in Latin America," Jorge A. Sefair, Mónica Espinos, Eduardo Behrentz and Andrés L. Medaglia, *Computers, Environment and Urban Systems*. 2019). It provided city officials with a portfolio of mitigation actions for air quality policymaking including implementation cost, pollution goals, interdependencies between alternatives and managerial and regulatory constraints. It finally supported the design of an air quality plan to accomplish objectives on emission levels at the city level in a 10-year horizon.

The output of our model was a portfolio of mitigation actions and the optimal timing for execution of these strategies, given a set of constraints like budget, pollutant goals and regulatory constraints. This plan takes into account early and tardy dates for implementing each mitigation strategy, the capacity of the city to implement the policies, synergies between the strategies, economic costs and environmental impact (the reduction of pollutants). A key feature of this model is the fact that for each mitigation strategy, it is necessary to select a mode of implementation. These different modes have different resource consumption and more importantly, they have different environmental inputs.

A health benefit analysis of the proposed air quality plan estimated the health impacts and costs for the optimal plan (for 2010-2020), including 17,600 avoided deaths associated with long-term exposure to PM_{10} (solid and liquid particulate matter less than 10 micrometers in diameter); a decrease in 1,600 cases of child mortality; 30,100 avoided hospitalization cases linked to respiratory diseases in children under age 5; and a reduction in 11,900 hospitalization cases due to cardiovascular diseases.

Implementation of the plan has encountered multiple obstacles. Some measures were sanctioned as decrees; others were not applied. But all in all, it had partial impact on improving the air quality in the city. Since 2010, the fraction of days per year where PM_{10} concentration exceeded the national standard of 15 micrograms per cubic meter has decreased, showing a significant improvement in air quality. Again, we cannot argue that it is just the result of implementing the prescriptive model, but it is certainly one of the multiple causes of this positive effect.

IISE ANNUAL CONFERENCE & EXPO

Solutions featured in 2021 Annual keynote

Author Andrés Medaglia presented a summary of his team's findings in his keynote speech at the virtual 2021 IISE Annual Conference & Expo. His presentation and other conference content remains accessible to attendees with their site login at *iise.org/Annual2021*. To register and learn more about the 2022 conference scheduled for May 21-24 in Seattle, Washington, visit *iise.org/Annual*.

ISEs meeting the challenges

Latin America is a region full of challenges and opportunities. I have put an emphasis on the problems we need to solve, but there are many more positive aspects. In the region there are a lot of ISEs who are passionate about solving these problems. Throughout these projects, working in multidisciplinary teams, we have seen how professionals from other disciplines have seen the power of ISE and have embraced our tools to make them their own, allowing us to shift to truly transdisciplinary research. These sustainability problems are a constant call for innovation with other disciplines.

Solutions for complex problems often demand the integration of multiple models: descriptive, predictive and prescriptive. As ISEs, we are called to be analytics solution architects with a systemwide perspective. To impact our communities, it is necessary to engage policy and community actors in the co-creation of these solutions using systems-thinking methodologies. This takes time but builds a solid ground for long-term solutions. ❖

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