Applying Microscopic Simulation Models To Improve Existing Road Transport Infrastructure

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Abstract

This research analyzes the reorganization of the traffic control devices in the city's busiest avenue by means of implementing microscopic simulation models. The investigation focused on the development of alternatives to help reduce traffic congestion problems during hours of high demand. Initially, a base model to represent the actual situation in Valdivia's downtown is constructed and validated. Then a second model including the proposed reorganization of the existing infrastructure is developed. Both models are implemented in PTV Vissim. Simulation results revealed that the proposed modifications help the aggregate time travel by 32,9% and the aggregate delay times for vehicles by 49,5%. In conclusion, the results suggest that virtual models properly calibrated and validated can be used to evaluate and quantify the potential impact of a reorganization of the traffic control devices.

Keywords
Microscopic Traffic Simulation, PTV Vissim, Calibration, Traffic Congestion, Aggregate Time Travel

1. Introduction
The concentration of population in urban centers and the consequent increase in the number of vehicles reveal the precariousness of urban planning. Funding constraints often result in the city's infrastructure growing at a slower rate than the population's needs. This results in traffic congestion problems that deteriorate people's quality of life in large cities. To overcome this situation, many cities have rules that restrict the circulation of vehicles, access to certain districts, the use of lanes reserved for public transport, among others.
One of the greatest difficulties in vehicle traffic planning is to quantify the impact, positive or negative, of a specific project on the dynamics of vehicle flow. Fortunately, technology allows the development of highly complex simulation models that allow the current vehicular flow to be studied in detail and forecasting the impact of modifications to the existing infrastructure. The present work focuses on the development of virtual simulation models to analyze alternatives for the reordering of traffic control elements in the downtown of Valdivia, Chile.

1.1. Objective
Analyze and compare improvement alternatives to reorganize the existing traffic control elements in areas with high traffic flow through implementing microscopic traffic simulation models.

2. Literature Review

2.1. Transportation systems
Transportation systems can be conceptualized as the interaction between a demand and supply of travels. Travelers commute for work, study, and other reasons. Travel supply corresponds to the means of transport available at different times, the road network through which they circulate, the infrastructure and traffic control devices (Ortúzar & Willumsen, 2008).

2.2. Microscopic simulation
Simulation can be defined as the process of creating virtual models to represent the behavior of a real system and its subsequent study under different conditions. In the context of urban traffic simulation, there are two main types of simulation: microscopic and macroscopic, which differ mainly in the approach applied (Figure 1). Macroscopic

simulation considers the vehicular flows in the city network, while microscopic simulation is based on understanding and mathematically reflecting the individual behavior of each vehicle in the flow, in its route and speed decisions. Microscopic simulation relies on the modeling of frequent driving phenomena, such as the speed and distance at which a driver follows the vehicle preceding it, or the decision to change lanes (Barceló, 2010).

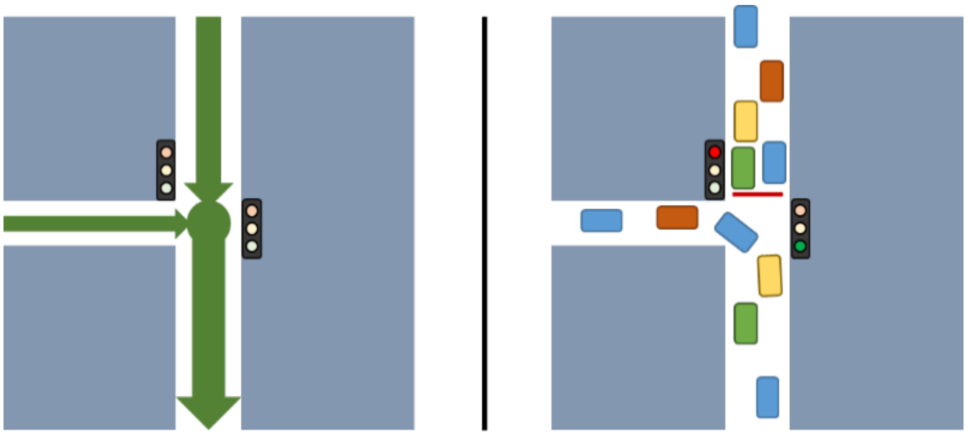

Figure 1. Macroscopic (left) and microscopic (right) traffic simulation.

2.4. PTV Vissim

One of the most versatile transport simulators is PTV VISSIM. It allows modeling multimodal transport private and public, pedestrians, taxis, and trams (Valladares, 2016).
In PTV Vissim, the road network is modeled as a series of links. Traffic flow is generated at the so-called input links, specifying the number of vehicles per unit of time. Their routes can be assigned dynamically or statically. In the first case the origin and destination of vehicles is defined by the traffic conditions. In the latter case, the routes are defined at specific decision-making locations (PTV Group, 2018).
City bus lines are modelled as public transport lines in PTV Vissim, whose flows enters the system according to predefined schedule. Other objects that must be modeled are traffic signs and conditions, such as traffic lights, intersections, exclusive lanes, allowed turns, speed restrictions, and public transport stops (PTV Group, 2018).

3. Methods

The investigation is carried out following the methodology shown in Figure 2, based on the methodologies described by Dowling et al (2002) and Sharma et al (2015):

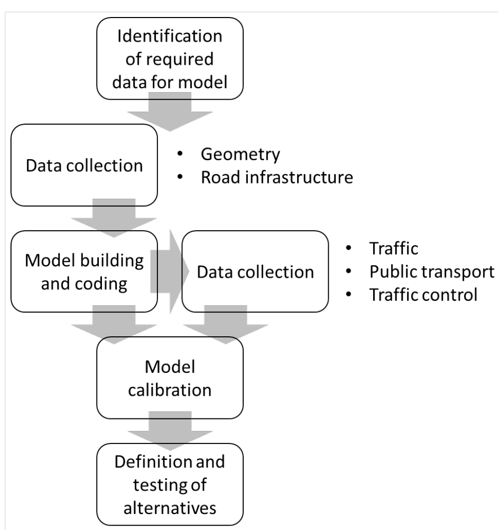

Figure 2: Modelling methodology

Initially an extensive review of the existing literature and previous studies was carried out. Additional data were obtained by means of direct in-situ observation at control points. These data is to be used afterwards during the calibration and validation stages.

4. Data Collection

4.1. Scope definition

For the purposes of the present work, Valdivia's busiest avenue is to be the subject of the analysis (Figure 3). The selected area is known for having high traffic congestion problems during peak hours, from 18:00 to 19:30 h (Subsecretaría de Transportes, 2017).

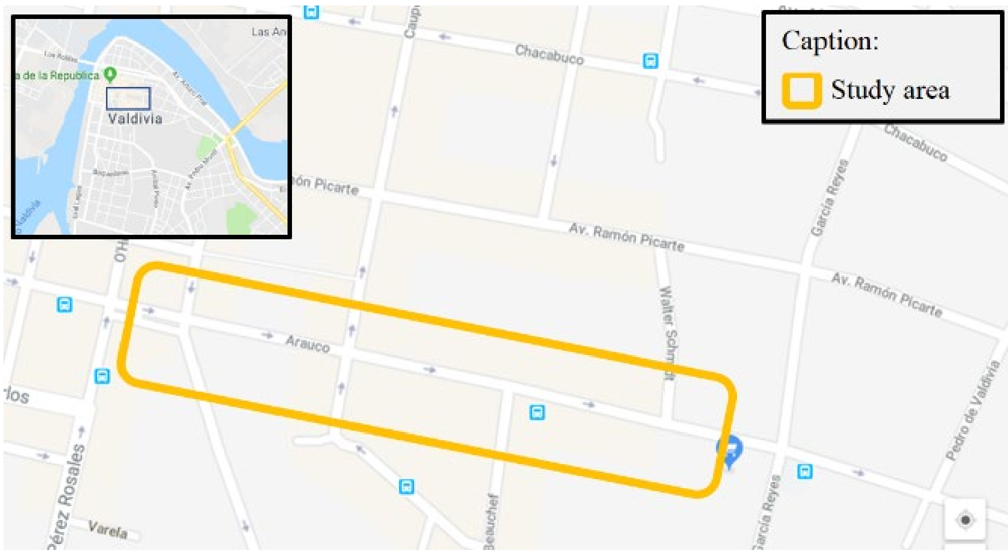

Figure 3. Area of study. Source. Google Street Map

The length, intersections and location of links were obtained from the Open Street Map. Other platforms such as Google Street View were also consulted. Both city bus lines and private vehicle flow forecasts were also included during the modelling (Subsecretaría de Transportes, 2017).

4.2. In-situ observations

Observations (vehicle counting) are made at certain control points (Figure 4). Arrivals of buses and line taxis are also considered. Measurement on the traffic lights frequencies and synchronization were made too (Table 2). All collected data and data coming from previous studies are considered during the construction of the base model (Gutiérrez, 2018).

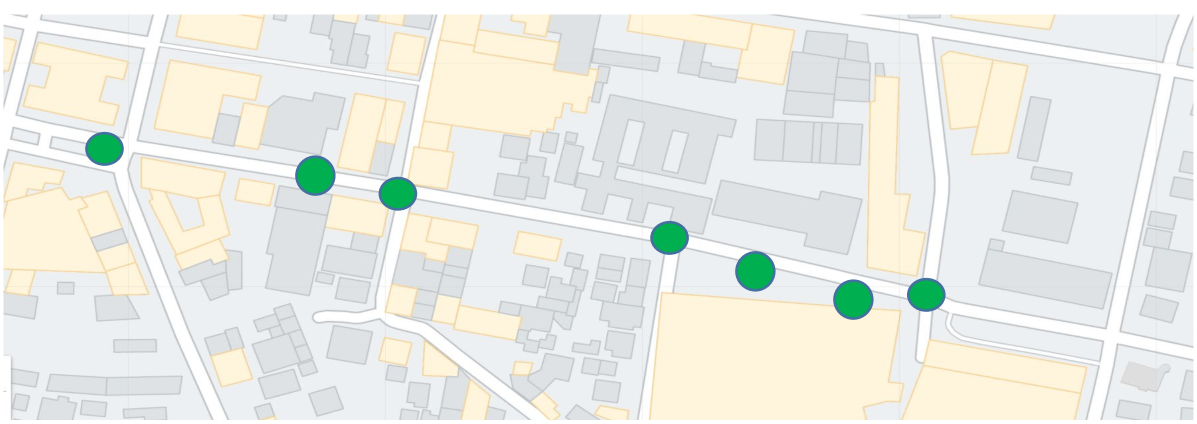

Figure 4. Control points for in-situ observations.

Table 1. In-situ data collection

Measurement	Description
Vehicle flow at intersections	Intersection, source link, time interval, vehicle type, vehicle movement
Vehicle flow at entry/exit point	Flow direction, time interval, vehicle type
Arrival of city buses	Bus stop, arrival time, bus line, occupation level, boarding/alighting passengers, time period
Arrival of line taxis	Bus stop, arrival time, taxi line color, occupation level, boarding/alighting passengers, time period
Traffic light frequency	Intersection, traffic light direction, duration of each light signal
Traffic light synchronization/lag	Intersection, synchronization/lag with other traffic lights
City buses' travel times	Bus line, stop time at buses and between defined measuring spots

4.3. Base model construction

Since the research is focused on the vehicle flow, none of the virtual models consider the pedestrian flow. In the virtual model, traffic lights are modelled by means of flow signal controllers at intersections. Bus stops are modelled including points for generation and destination of passengers. Nine city bus lines are included in the model. Line taxis have separate lines. In all cases the displacement speed is set according to 50 km/h, which is the legal speed limit.

4.4. Calibration and validation

During the calibration, the parameters of the virtual model are set to replicate the traffic flow observed in the real system (Sharma et al, 2015). As shown in Table 2 , two calibration variables (dependent variables) and two calibration parameters (independent variables) were chosen for model calibration (PTV Group, 2018).

Table 2: Calibration

Parameter	Average distance between two vehicles (a_x)	Coefficient for the additive part used for the calculation of the safety distance between vehicles in Wiedemann 74 model used by VISSIM (bx_{add})
Variable	Total vehicle flow per hour	Average travel time of public transport microbuses through the whole Avenue in the study area

According to Wiedemann 74 car following model, vehicles in an urban setting adjust their speed and acceleration dynamically to achieve the desired following distance. This calculation is made for every vehicle in the system at every time step (PTV Group, 2018).

$$\mathrm{d} = \mathrm{a_x} + (\mathrm{bx_{add}} + \mathrm{bx_{mult}} * \mathrm{z}) * \sqrt{\mathrm{v}}$$

Where, d is the desired distance for each following vehicle in relation to the vehicle ahead of it, which is re-calculated in each simulated instant (time step). The parameter a_x is the average desired stopping distance between two vehicles, while the second term calculates a safety distance using two parameters: the additive coefficient bx_{add} and the multiplying coefficient bx_{mult}. Lastly, z is a random value between 0 and 1, and v is the instant velocity, in meters per second (PTV Group, 2018). These parameters were calibrated until the vehicle behavior reflects the observation data, as measured in the system performance metrics.
For a 95% confidence level, the confidence interval mentioned results in a minimum number of 23 repetitions for each model to be simulated and analyzed (Dowling et al, 2002).

4.5. Simulation results

Simulation results reveal that the longest queues happen in the links where the current public transport stops are located. Additionally, the greatest aggregate delays take place at entry and exit intersection where a bus stop is located (Figure 5).

Figure 2. Base model simulation

4.6. Reorganization proposal

The reorganization considers an additional bus stop in the area, the fixed allocation of the existing ones and the exclusion of line taxis. Several configurations were preliminarily tried, each having a specific configuration, before the final proposed model is defined.
Actual traffic signals operate with frequency. The proposal considers an optimization algorithm to maximize the aggregate flow and minimize vehicles' total delay.
Simulation results reveal a statistically significant improvements in the performance indicators with respect to the base model.

5. Results and Discussion

5.1. Reorganization summary

Average results from several simulation runs (replications) reveal the longest queue (Figure 6), considering intervals of 3 simulation minutes, takes place where the actual bus stops are located (Figure 7).

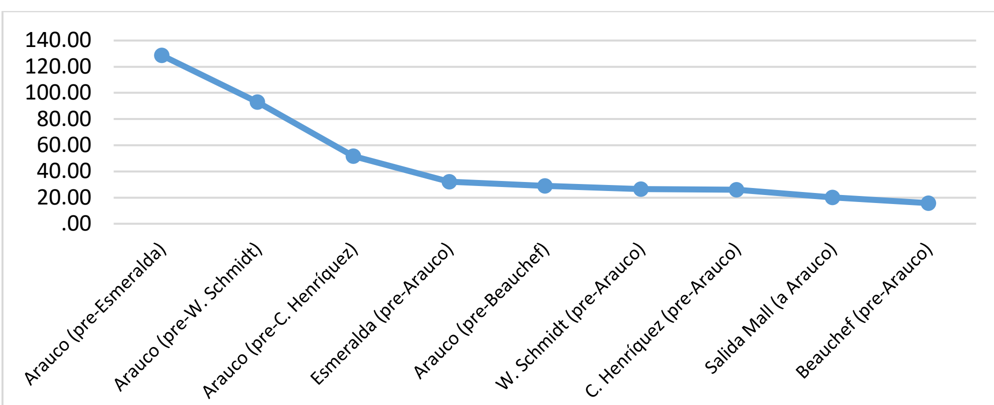

Figure 3. Base model - Queues' length [m].

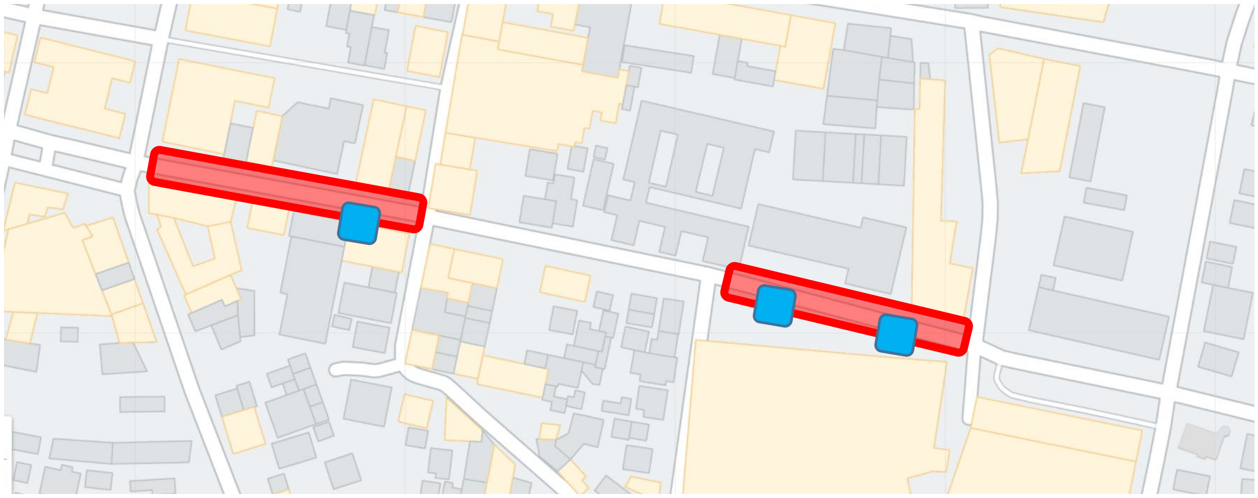

Figure 7. Base model - Longest vehicle queue location**.**

Base model simulation results suggest that additional bus stops and dynamic traffic light frequency might help reduce the traffic congestion. The proposed model considers an additional bus stop and the fixed allocation of city bus lines to specific stops (Figure 8)). The dynamic frequency of traffic light is considered too (PTV Group, 2018). The traffic light management algorithm help maximize the total vehicular flow through the intersection and minimizes the aggregate delay time experienced by the vehicles.

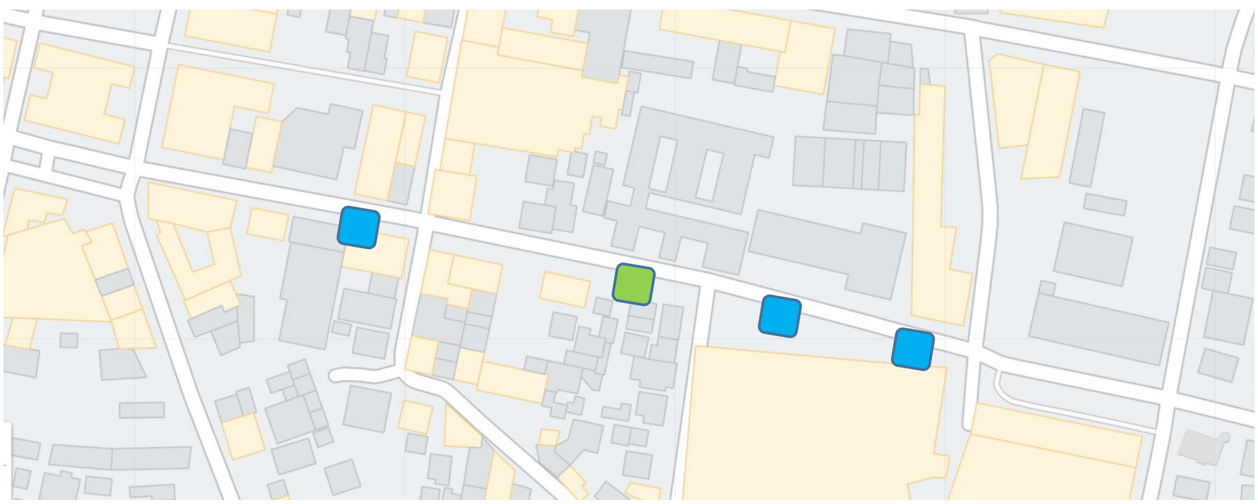

Figure 8. Proposed model – Existing (blue) and additional bus stops (green).

5.2. Numerical Results

A summary of the simulation results is presented in Table 3.

Table 3: Comparison – Base and proposed model

	Aggregate travel time (vehicle-hours)	Aggregate delay time (vehicle-hours)
Base model	172,6 hours	122,7 hours
Proposed model	115,9 hours	62,0 hours
Difference	-56,7 hours (-32,9%)	-60,7 hours (-49,5%)

5.2. Graphical Results

The maximum queue lengths (multiple runs' average) for simulated interval of 3 minutes are presented in Figure 9.

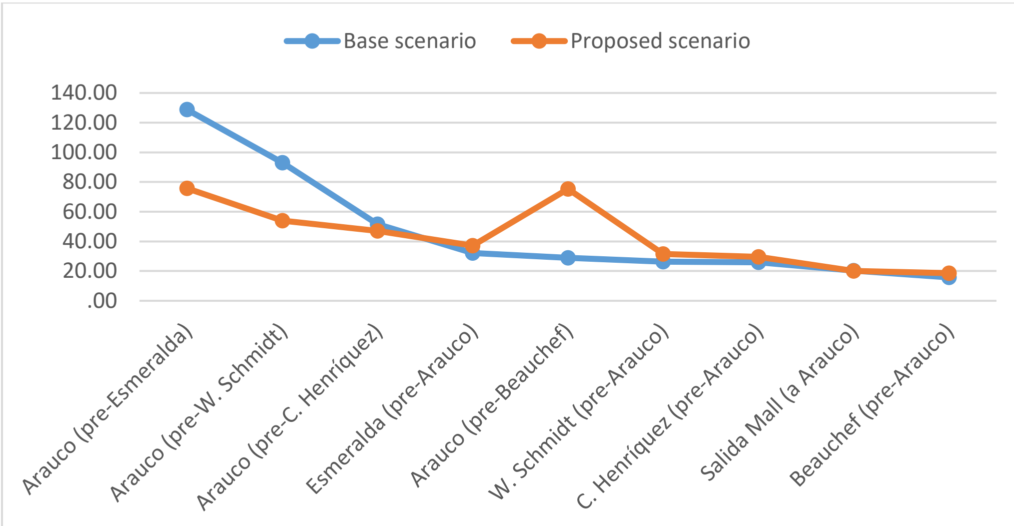

Figure 9. Longest queues [m] – Multiple runs – Base (blue) and proposed (red) model

A comparison of the aggregated delays during one hour of the vehicles that cross the nodes (intersections) is presented below. Total delay decreased in each intersection, especially at the most critical intersections of the existing system, where the largest drops occur.

Finally, Figure 9 shows the average level of service per intersection in the system, according to the notation defined by PTV Group (2018), both for the base situation and for the final proposal. Lower scores correspond to shorter wait times and therefore better service levels (1 is "A", 2 is "B", etc.).

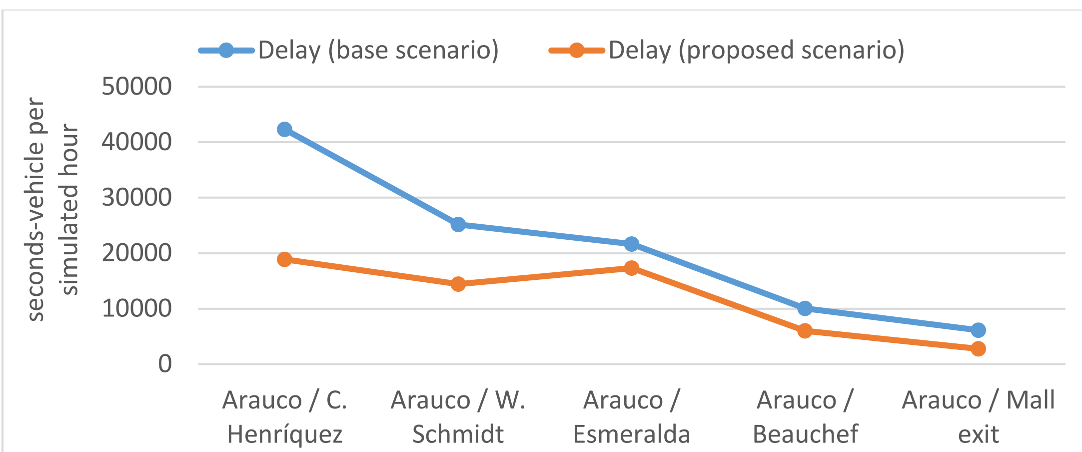

Figure 10. Aggregate delays – Multiple runs – Base (blue) and proposed (red) model

5.3. Proposed model summary

The simulation screenshot of proposed model is presented in Figure 11. The only visible change is the new bus stop, while the redistribution of bus lines along the bus stops and the new programs for the traffic control lights are not visible.

Figure 11. Proposed model screenshot.

5.4. Virtual model validation

The validation is carried out to verify that the simulation results are consistent with the observations of the actual system. There is an acceptable tolerance range as it is shown Table 4, Table 5, Table 6, and Table 7.

Table 4: Calibration guides for vehicle flows in micro-simulation models (Dowling et al, 2002).

Criterion and measures	Acceptation goals
Hourly flows, modeled vs. Observed	
Individual link flows	
Error under 15%, for flows between 700 and 2700 vehicles per hour	> 85% cases
Error under 100 vehicles per hour, for flows under 700 vehicles per hour	> 85% cases
Error under 400 vehicles per hour, for flows above 2700 vehicles per hour	> 85% cases
GEH Statistic for flows in individual links: GEH < 5	> 85% cases
Total link flows	
Total link flows: error under 5%	All input vehicles
GEH Statistic for total link flows: GEH < 4	All input vehicles

Table 5: Calibration guides for travel times and visual evaluation in micro-simulation models (Dowling et al, 2002).

Criterion and measurements	Acceptation goals
Travel times, modeled vs. Observed	
Travel times network: error under 15% (or one minute, if higher)	> 85% cases
Visual auditions	
Individual speeds in links: relationship of speed and flow is visually acceptable	To the analyst's satisfaction
Bottlenecks: queue formation is visually acceptable	To the analyst's satisfaction

Table 6: Base model – parameters calibration values (Gutiérrez, 2018).

Calibration parameter used	Used value	Default value
Average stopping distance (ax)	1,5 m	2,0 m
Additive part for the calculation of security distance bx_{add}	1,5	2,0

Table 7: Base model calibration (Gutiérrez, 2018).

Calibration variables used	Estimated final value	Observed value	Percent error	Acceptation criterion
Total vehicle per hour flow that enters the system in the evening peak hour	2259 vph	2370 vph	-4,7%	Error under 5%. Value is acceptable.
Average travel time for microbuses when flowing through the system	260,4 s.	272,4 s.	-4,4%	Error under 15% (or under a minute if higher). Value is acceptable.

6. Conclusion

The proposed model containing the installation of an additional bus stop for public transport in the study area, located between the existing ones; the reorganization of the use of bus stops for the stopping of different minibuses lines, and the restriction of the use of some stops by line taxis; and the definition of optimal schedules of green light times and synchronization between traffic control lights – help reduce the traffic congestion, delays, and travel times. Specifically, the improvements proposed would result in reductions of 32.9% in total aggregate travel times and of 49.5% in total aggregate delay times, by vehicles that drive through the study area during the time period that was modelled (5pm to 8pm in workdays, under conditions comparable to those studied and simulated).This research is, thus, one example of the usability and capabilities of microscopic traffic simulation for the analysis of transportation problems, particularly for the modeling and analysis of complex interactions between vehicles of different types and behaviors, and the definition and proposal of alternatives for the improvement of transportation systems. These simulation tools have several more capabilities and uses, which may strengthen the analytical and data-driven definition and backing of public policy initiatives and projects in transportation and road infrastructure.

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Biographies

Isaac Gutiérrez is an Industrial Engineer and former lecturer in the Institute of Industrial Engineering at Universidad Austral de Chile, Valdivia, Chile. He earned B.S. and Licentiate Degree in Engineering from Universidad Austral de Chile. He has taught lectures in Optimization for engineering students. He currently works as an analyst in the Digital Strategy Department at the multinational sport company Sparta. His research interests include urban traffic and transportation systems simulation, supply chain management, e-commerce business processes, automated reporting development, customer service platforms.

Carlos Hernández is an Industrial Engineer and professor in the Institute of Industrial Engineering at Universidad Austral de Chile, Valdivia, Chile. He earned Licentiate Degree in Engineering from Universidad de La Frontera, Temuco, Chile, Master of Sciences in Computational Engineering and Doctor of Engineering from Technische Universität Braunschweig, Brunswick, Germany. He is the author of several scientific and engineering articles. He has taught lectures in Discrete Event Simulation, Supply Chain Management, Engineering Economics, Corporate Finances, Financial Engineering, Business Analytics, Data Mining and Machine Learning for engineering students. He has developed a professional career working for large multinational companies (PricewaterhouseCoopers, BHP Billiton, and Merck Sharp & Dohme). He also worked as a scientific researcher in the Institut für Produktionsmesstechnick at TU Braunschweig, Germany. His research interests include assembling process techniques, manufacturing process simulation, urban traffic and transportation systems simulation, supply chain design and management, machine learning for finances. He is a member of IEOM.