Development Of Rapid Macroscopic Traffic Simulation Models

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Abstract

This research presents a simplified methodology to develop rapid macroscopic traffic simulation models that can be used study reduced areas or districts with high traffic congestion. In contrast to the classical macroscopic approaches that require large amounts of data and a large-scale implementation model, the proposed approach focusses on a manageable area instead to trying to cover the entire road network of a city. For the purposes of the investigation, the subject of study is an area of high demand with access to a bridge that connect two populated districts of Valdivia, Chile. Two virtual models were constructed, calibrated, and validated. The base model representing the actual situation and a second one with a double bridge to connect the districts. Simulation results revealed a significant difference in the rate of use of the bridge`s lanes in both directions during the peak hours. While the base model showed a use rate close 76% and 73% in each direction of the bridge, the double bridge model showed a use rate close to 38% in both directions. In conclusion, simulation results suggests that the proposed simplified methodology might be to be a useful tool for developing reliable models that produce consistent results.

Keywords
Macroscopic Traffic Simulation, Multimodal, Transportation Model, OD Matrix, Principle of Wardrop

1. Introduction
The concentration of the population in large cities and the growing number of vehicles in the streets inevitably give rise to traffic congestion in the zones of highest demand. Urban traffic planning is a complex and demanding task. Before a mayor infrastructure project is initiated, an extensive analysis of the current situation and the impact of any modifications on the dynamics of the city's traffic flow must be completed.

Classical travel forecasting models have been used by scholars and transport engineers during decades. These models are extremely complex and demand the collection of large amounts of data to characterize all the travels that take place in an area of study, usually a city or a metropolitan area. It is necessary to know the number of trips being made, their origin and destination, the reason and the means of transport used. Additionally, it is necessary to have information about the available infrastructure: direction of streets, number of lanes, and traffic control signals. The availability of any public transport network and city bus lines must also be incorporated along with travel made using private vehicles. In summary, to analyze the effect of any alteration to the existing infrastructure, for instance, a change of direction in an avenue or the addition of a new lane, it is necessary to have a complete model to forecast properly the future number of trips in the city.

This research is focused on the development of rapid macroscopic simulation models to evaluate modifications in the existing road infrastructure by means of applying a simplified methodology that considers models with a limited geographic scope to evaluate specific areas of interest.

1.1 Objective
Analyze the properness of a simplified methodology for the rapid development of macroscopic simulation models to study urban traffic flows by means of the construction and comparison of virtual models of areas with high traffic congestion.

2. Literature Review

2.1 Simulation

In the context of the present investigation, simulation can be defined as the process of creating virtual models to represent real systems that can be then studied under different conditions. The steps or stages of a simulation project generally include the analysis, design, development, calibration and testing, validation, experimentation, and the interpretation of the results.

2.2 Macroscopic simulation

In the field of urban traffic simulation there are three different types of simulation: microscopic, mesoscopic, and macroscopic, which basically differ in the approach used. While the microscopic simulation focuses on individual vehicles' behavior, the macroscopic simulation considers the traffic flows that take place in the entire city (Figure 1).

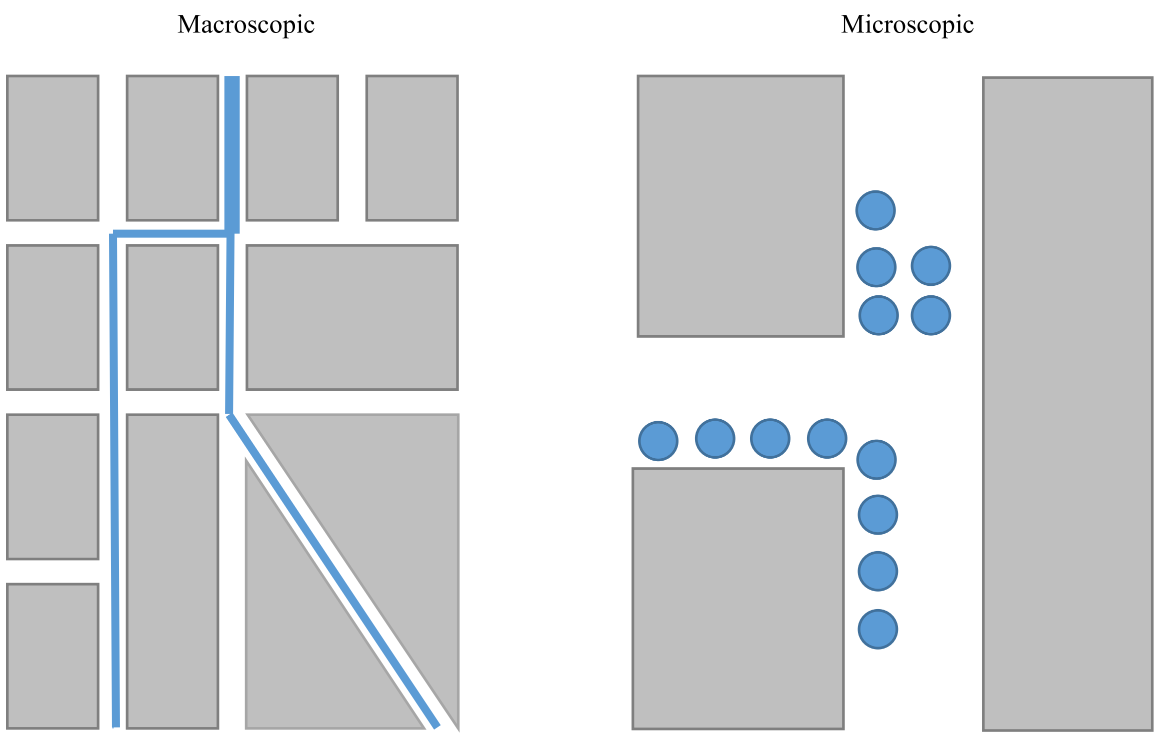

Figure 1. Macroscopic and microscopic simulation

2.3 Classical trip forecast model

An important part of the classical traffic simulation models is the Wardrop Principle, which states that in a road network, individuals make rational decisions choosing routes that minimize travel time. The travel forecast model uses the so-called origin-destination matrices, which contains all the information that characterizes the trip in a zone of interest. They indicate trips' origin and destination, its travel time and the means of transport used by travelers (Barceló 2010, Bocanegra 2005, Ortúzar Willumsen 2008). The construction of the OD matrices requires the previous zoning of the city under study. During the zoning, the city is divided into zones that will be used to symbolize the point of generation and attraction of trips. The 4 steps of the classical model are: generation / attraction, distribution, modal split, and allocation (Figure 2):

Step 1: Generation / attraction. In this stage, the number of trips generated and attracted to each zone in which the city has been divided is determined.

Step 2: Distribution. In this stage, the pair origin-destination is matched and then incorporated into the origin-destination matrix.

Step 3: Modal selection. In this stage, trips are classified according to the transport mode (public, private), generating an origin-destination matrix for each mode.

Step 4: Travel assignment. In this stage, the trips contained in the OD matrices are assigned to the available networks or routes.

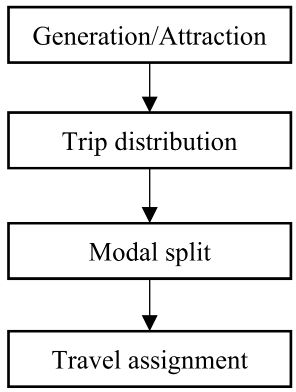

Figure 2. Classic 4-step transportation modeling

3. Methods

The present work was carried out following a traditional 4-stage approach (Figure 3): Analysis, Design, Construction, Validation.

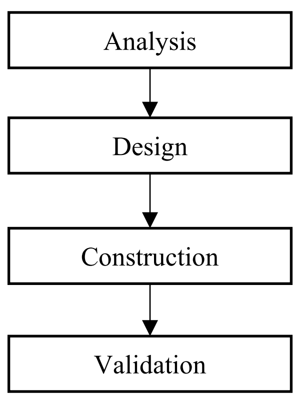

Figure 3. Tradicional 4-stage methodology

3.1 Analysis

During the analysis, existing bibliography and classical transport simulation methodologies are reviewed. The simulation software is also selected in this stage. District, avenues, or intersections of potential interest are then identified using existing traffic studies (Ministerio de Transporte y Telecomuncaciones 2014). The investigation will be entirely carried out in Valdivia, Chile. Once the area of interest has been identified, the needs for additional information assessed and the control points where in-situ observation will be made are defined (Figure 4).

3.2 Design

During the design, the requirements for a simplified modelling methodology based on the classical models are defined. The objective is the development of virtual models that allow to evaluate the impact of modifications to the existing infrastructure in a reliable way and yet quickly.

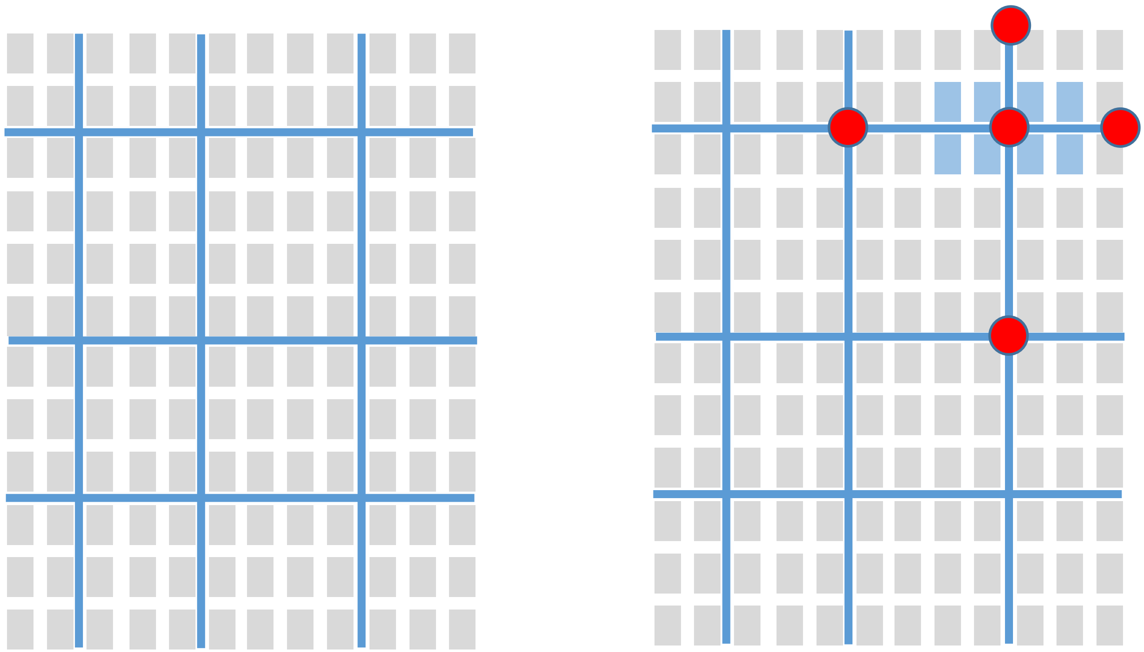

Figure 4. Zoning and district selection

The initial goal is the construction of a base model to simulate the actual traffic situation in the city considering both private and public transport networks. To do it, existing traffic studies containing the original zoning and the OD matrices of 2013 are used (Ministerio de Transporte y Telecomuncaciones 2014). For each zone, 12 in total, a centroid to represent the zone's geographic center is defined (Figure 5). Existing OD matrices are updated according to the projected annual growth of the number of trips.
Subsequently, based on the knowledge of the city, an area of interest is selected to evaluate the impact of an alteration in the actual road structure. Control points for in-situ traffic flow measurements are also defined in this stage . The measurements or counting will be used to validate the models.

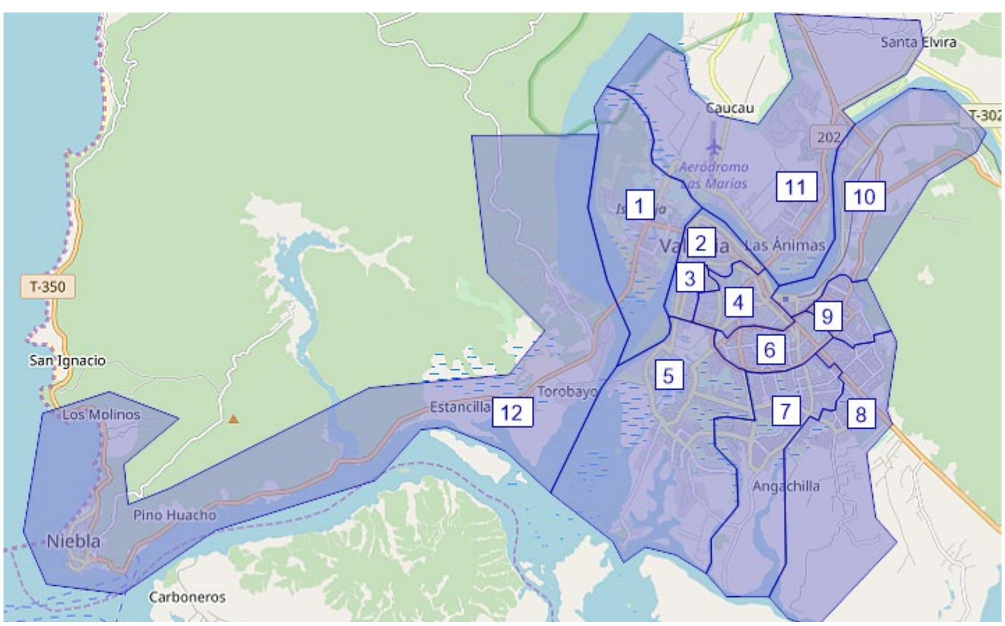

Figure 5. Valdivia's 12 zones

For the purposes of this research, the area of interest covers a bridge that connects two areas with high traffic demand (Figure 6). Considering the traffic congestion generated during peak hours in the morning and afternoon, the construction of a parallel bridge will double the number of lanes and consequently will help reduce the congestion problem (Figure 7).

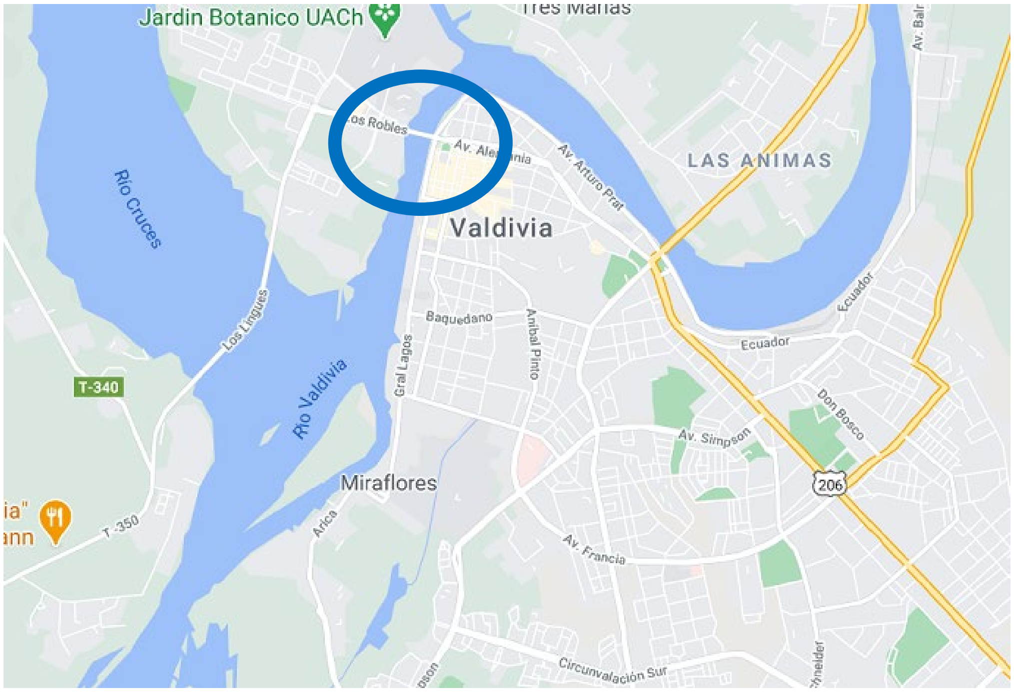

Figure 6. Study area – Bridge connecting districts

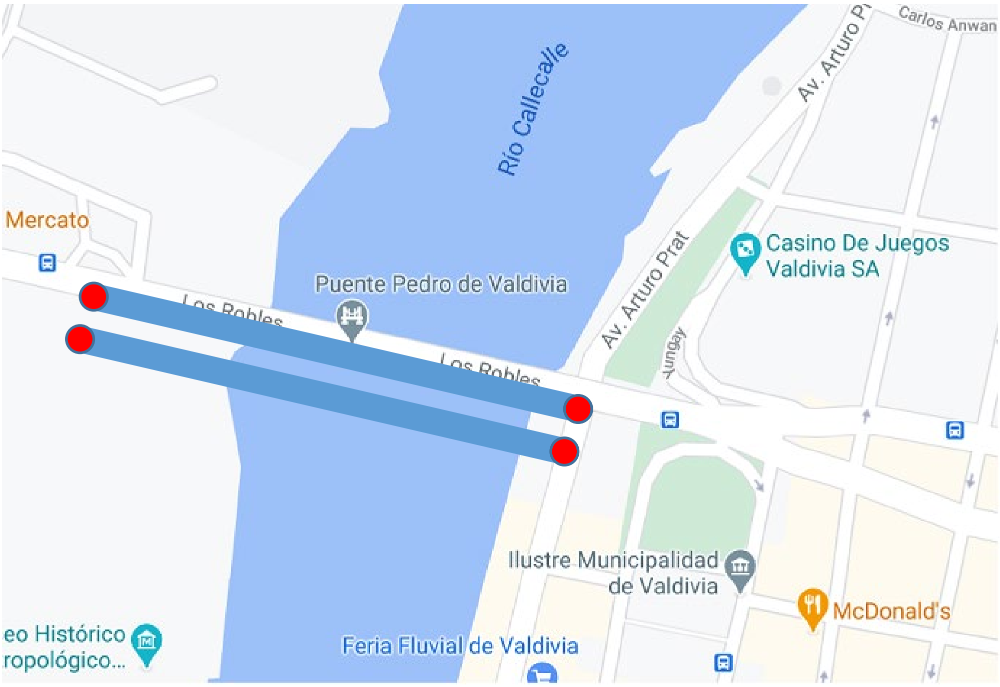

Figure 7. Proposed modification – Double bridge

To compare both the base model and the proposed model key indicators suggested in classical model are used. The theory of continuous traffic flows describes the spatio-temporal evolution of the variables that characterize macroscopic flows:

1. Flow q (x, t) (or also called volume), which corresponds to the number of vehicles that pass through a location x in a period of time t.
2. Average space velocity v (x, t), which corresponds to the instantaneous average speed of the vehicles in an increase in length.
3. Traffic density k (x, t), which corresponds to the number of vehicles per unit of length.

Figure 8 summarizes the mayor activities to be completed during the stage of design.

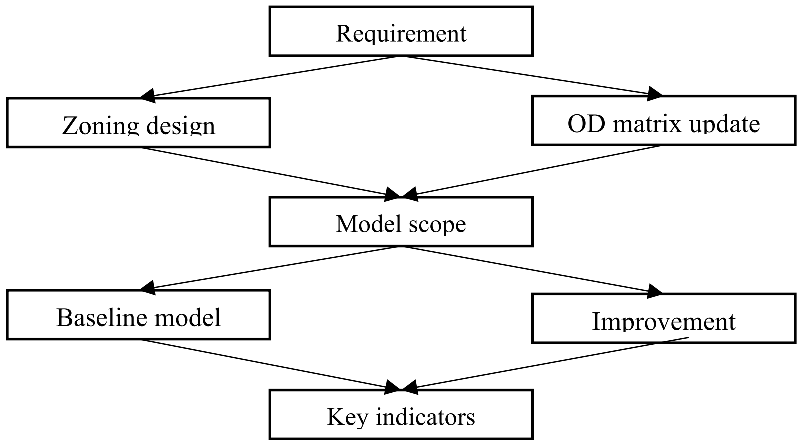

Figure 8. Design stage – Simplified Methodology

3.3 Construction

The construction carried out entirely using the world class traffic simulation software PTV Visum. The process begins with the configuration of the OD matrices and the creation of the objects of the transport network: zones, centroids, nodes, arcs, and connectors. Additionally, the modeling of public transport requires special objects such as bus stops and bus lines. PTV Visum uses graphical representations that include actual maps so that each arc really has a length proportional to the actual street that it models. Arcs are also defined by the number of lanes, the direction of flow, and the volume of vehicles that it can support.

During the model calibration several parameters must be set up so that the virtual network reflects the results of the OD matrices, which were originally created with information obtained from the population. The calibration of the virtual network is carried out within some tolerance range. The proposed simplified methodology does not require the implementation of streets of the actual road network. Just like the classic travel forecast model, the configuration of the transport modes must also be set up during this stage.

As aforementioned, for the purposes of this research two virtual models are built: the base model with the actual infrastructure and the proposed model with the second parallel bridge (Figure 9).

3.4 Validation

During the validation, a comparison between the flows generated by the virtual model and those observed in the control point is carried out. There is also a tolerance range when comparing the flow, which in this case can be attributed, on the one hand, to the update of the OD matrices, and on the other hand, to the infrastructure projects built after the creation of the original OD matrices. In case of the public transport network, additional differences can be created by variations in the bus lines' frequencies through the years.

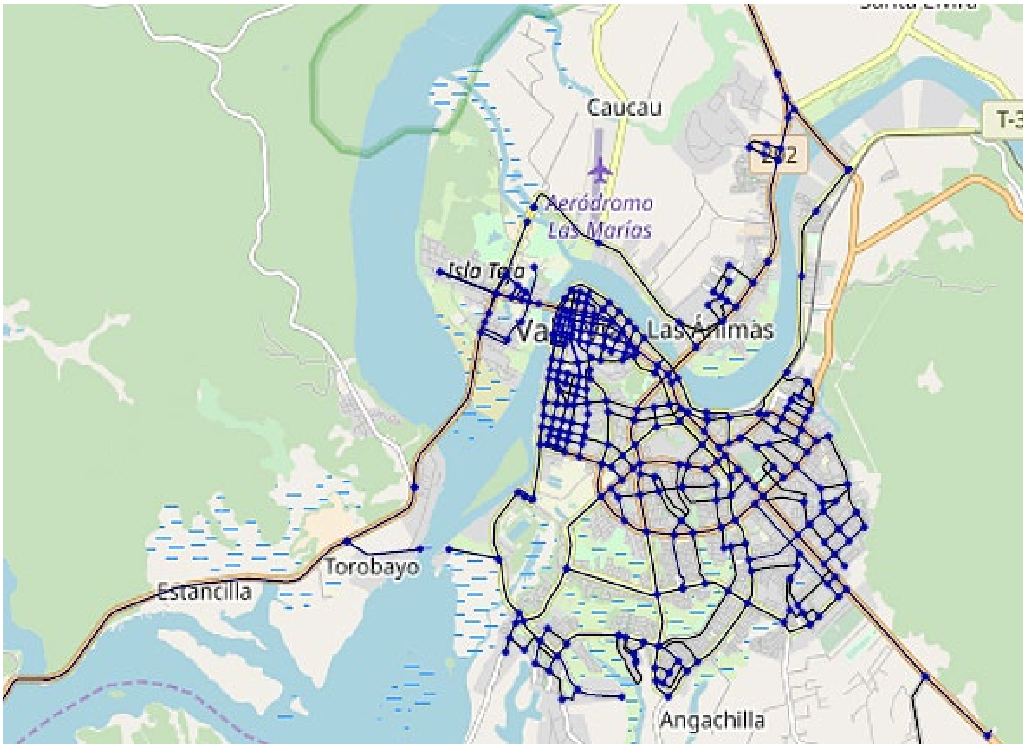

Figure 9. Base model – Transport network

4. Data Collection

Simulation results obtained during the calibration of the base model are summarized in Table 1, Table 2, Table 3 and Table 4. The simulated flows are presented in Figure 10.

Table 1. Private transport network – Calibration

	Flow [vehicles]		
	OD matriz - 2013	PTV Visum - Simulation	Error [%]
Bridge – West direction	1573	1573	0
Bridge – East direction	1502	1502	0

Table 2. Public transport network – Calibration

	Flow [vehicles]		
	OD matriz - 2013	PTV Visum - Simulation	Error [%]
Bridge – West direction	1747	1770	1.3
Bridge – East direction	639	662	3.6

Validation results of thew base model after comparing the measured flow in 2019 and the simulation results are summarized in the following tables.

Table 3. Private transport network – Validation

	Flow [vehicles]		
	Measured flow 2019	PTV Visum - Simulation	Error [%]
Bridge – West direction	1151	1314	14.2
Bridge – East direction	1290	1361	5.5

Table 4. Public transport network – Validation

	Flow [vehicles]		
	Measured flow 2019	PTV Visum - Simulation	Error [%]
Bridge – West direction	1872	1770	5.5
Bridge – East direction	655	662	1.1

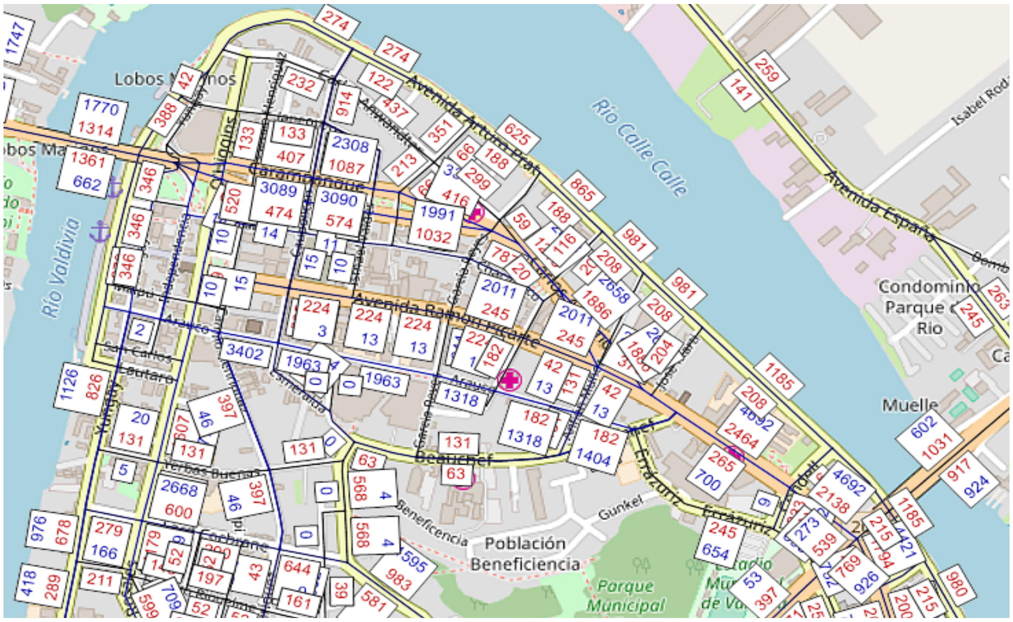

Figure 10. Simulated flows – Public and private networks

5. Results and Discussion

5.1 Numerical Results

As it might be expected, the construction of an additional parallel bridge would reduce the traffic flow though the original bridge. In the base model, the use of the original bridge at peak hours is 78% towards East and 735 towards West. The parallel bridge would reduce the utilization rate of the original bridge to 38% in each direction (Figure 11).

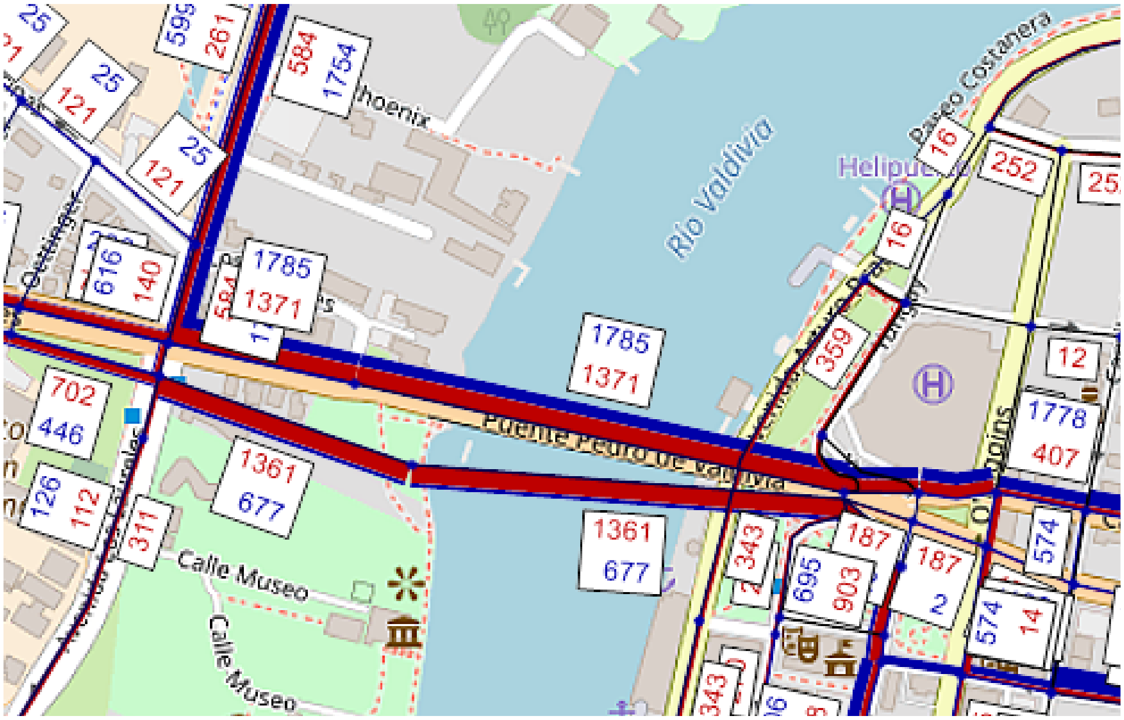

Figure 11. Simulation – Double bridge

6. Conclusion

Base model simulation results suggest that by means applying the proposed simplified methodology there is consistency between the volume flow generated by the model and the flow observed in-situ. Although necessary and helpful, updating the OD matrices may not be completely accurate as it does not consider the infrastructure projects that were built after the creation of the original OD matrices.

Even though it is based on the classical models, the main advantage of the proposed simplified methodology is the reduced effort (data, measurements, construction, calibration, validation) needed to construct virtual models thanks to the focus on rather reduces areas instead of the whole road network.

Finally, the comparison between the simulation results of the base model and the double bridge model are consistent with the expected result, which is a reduction close to 50% in the traffic flow. The results suggest that the proposed simplified methodology might be a useful tool to analyze the impact of alterations to the existing by means of developing rapid simulation models focused on small areas of interest.

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Biographies

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