

Applying Macroscopic Simulation Models To Evaluate River Crossing Alternatives

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Abstract

This research presents the analysis and comparison of two river crossing alternatives in terms of their impact on the on the city's urban traffic demand by means of implementing simulation models. While the first proposed alternative considers the construction of a bridge, the second one is limited to the use of medium-size ferry to transport vehicles across the river. The work is carried out following a 4-stage methodology: analysis, design, construction, and validation. The virtual models' construction is based on the classical 4-step travel forecast model. First, a base model to simulate the actual traffic flow is constructed, calibrated, and validated. Starting from it, two new models are developed, the first one to simulate the construction of a bridge, and the second one to simulate the implementation of a ferry line. Realistic restrictions are considered for each proposal: vehicle capacity, travel time, boarding time, and departure frequency, etc. Simulation results and statistical tests reveal that the bridge-based model has a significant impact on the travel time. Whereas the ferry-based model does not have such impact. In conclusion, the approach based on virtual models' simulations proved to be an useful tool to compare the impact of different river crossing alternatives.

Keywords

Macroscopic Traffic Simulation, Transportation Model, OD Matrix, BPR Function, ANOVA Analysis

1. Introduction

Modern cities always attract people looking for new opportunities and better living conditions. The concentration of the population in large cities is a phenomenon that has been observed during decades. Unfortunately, it is often common that the existing infrastructure is not prepared to satisfy the housing and mobility needs of the newcomers. The growing number of vehicles on the streets gives rise to traffic congestion problems in the busiest districts, usually in downtown and wherever private vehicles and city buses share routes. Of particular interest are the cities crossed by rivers, where the presence of bridges is crucial for connecting popular districts. The access to those bridges is typically where traffic jams will appear during the hour of high demand. This is the case of Valdivia, Chile. The city is crossed by rivers and counts with four bridges to interconnect the city. Since the construction of new bridges is currently under study, it is interesting to study different alternatives to interconnect the city across rivers using transport simulation techniques. The present work analyses two river crossing alternatives: a bridge and a ferry.

1.1 Objective

Analyze the effect of new river crossing projects on the urban traffic of Valdivia by means of developing and comparing macroscopic simulation models.

2. Literature Review

2.1 Traffic Simulation

There are three mayor approaches for simulating urban traffic: microscopic, mesoscopic, and macroscopic. The to be used will depend on the scope and motivation of the study. While microscopic simulation focuses on the behavior of individuals, the macroscopic simulation considers the entire flows (Figure 1).

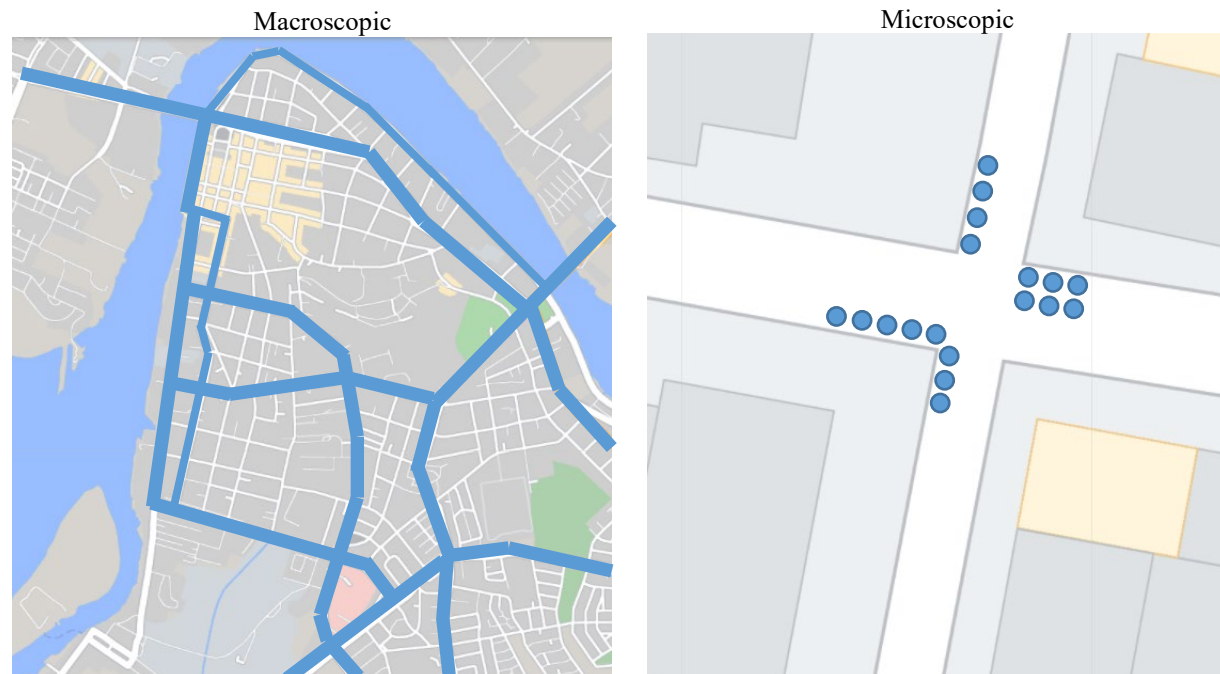


Figure 1. Traffic Simulation – Macroscopic and microscopic

2.2 Four-step travel forecast model

Classical traffic simulation models are based on the Principle of Wardrop, which states that individuals make rational decisions and will choose routes that minimize travel time. The travel forecast model uses origin-destination matrices to characterize the travels that take place in an area 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 step called zoning, in which the area under study is divided into zones to symbolize the origin and destination of the trips. Figure 2 presents the 4 steps of the classical modelling.

- 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, based on its residential and employment characteristics.
- Step 2: Distribution. In this stage, the pair origin-destination is matched and then incorporated into a squared matrix called OD matrix. The trips can be made within the same zone or different zones.
- 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.

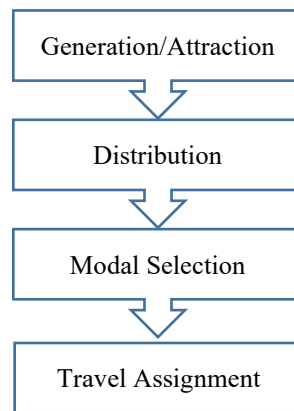


Figure 2. Four-step travel forecast model

The BPR function relates the travel time to traffic flow. It considers the time under free flow conditions (t_0) and the capacity of the arc representing the actual street (q/q_{max}). There are two parameters to set up in this equation α and β . The result (t_{cur}) is the travel time when there are vehicles circulating through the arc.

$$t_{cur} = t_0 \cdot \left(1 + \alpha \cdot \left(\frac{q}{q_{max}} \right)^\beta \right)$$

3. Methods

The investigation is carried out following a traditional 4-stage approach: analysis, design, construction, and validation (Figure 3).

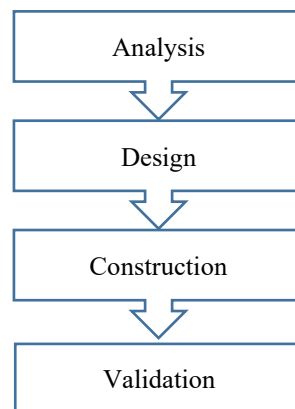


Figure 3. Four-stage methodology

3.1 Analysis

During the analysis, bibliography and existing studies are reviewed along with the selection of the simulation software PTV Visum. At this moment, possible river crossing points are identified and compared according to the needs of the population. The knowledge of the existing road infrastructure along with the local population's habits allowed identify the point where a river crossing project would help the most. For the purposes of the present investigation the two alternatives of interest are a new bridge and a ferry to connect the residential areas and the coastal towns with the access to downtown (CIS 2016). The implementation of such connection would allow residents avoid crossing bridges

1 and 2 when going to city center (Figure 4). Once the location of the crossing project is defined, several control points for making in-situ observations to calibrate and validate the simulation models were also defined.

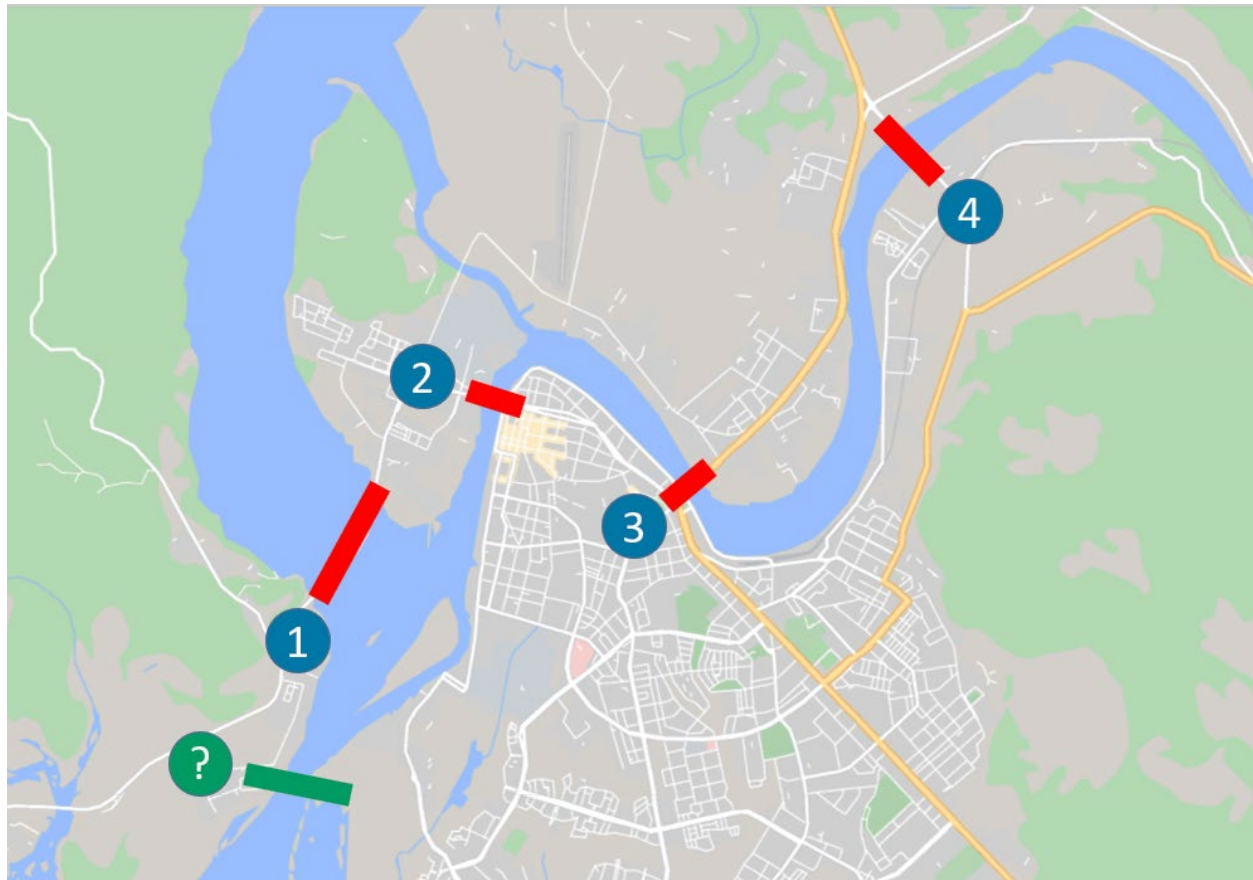


Figure 4. Four existing bridges and new river crossing alternative

3.2 Design

During the design, existing OD matrices from 2013 provided by the local urban planning are used to define the zones while setting up the virtual models (Traza Ingeniería 2014, Traza Ingeniería 2017). OD matrices are updated by means of incrementing the number of travels by 3.5% per year. A total of 12 zones are defined along with a corresponding centroid that represents the exact point of generation and attraction of trips from and to a given zone (Figure 5).

The first step is the construction of a base model to simulate actual traffic flows in the city making use of the existing information about public and private transport networks, which are usually treated in separated OD matrices.

Since the preparation of an OD matrix is based on data obtained from local people, its construction demands an enormous economic expense and plenty of time to process the surveys, therefore it is necessary to maximize its usability. As aforementioned, this can be achieved by means of applying certain update coefficients to express the annual growth rate of travels (Macro Ingenieros 2012). The main disadvantage, however, is assumption that only the number of trips varies through the years, while the road network will remain unaltered. Thus, all the infrastructure projects (e.g. bridges, avenues, etc.) built after the creation of the OD matrices are ignore. Although, they do have an impact on the number of travels.

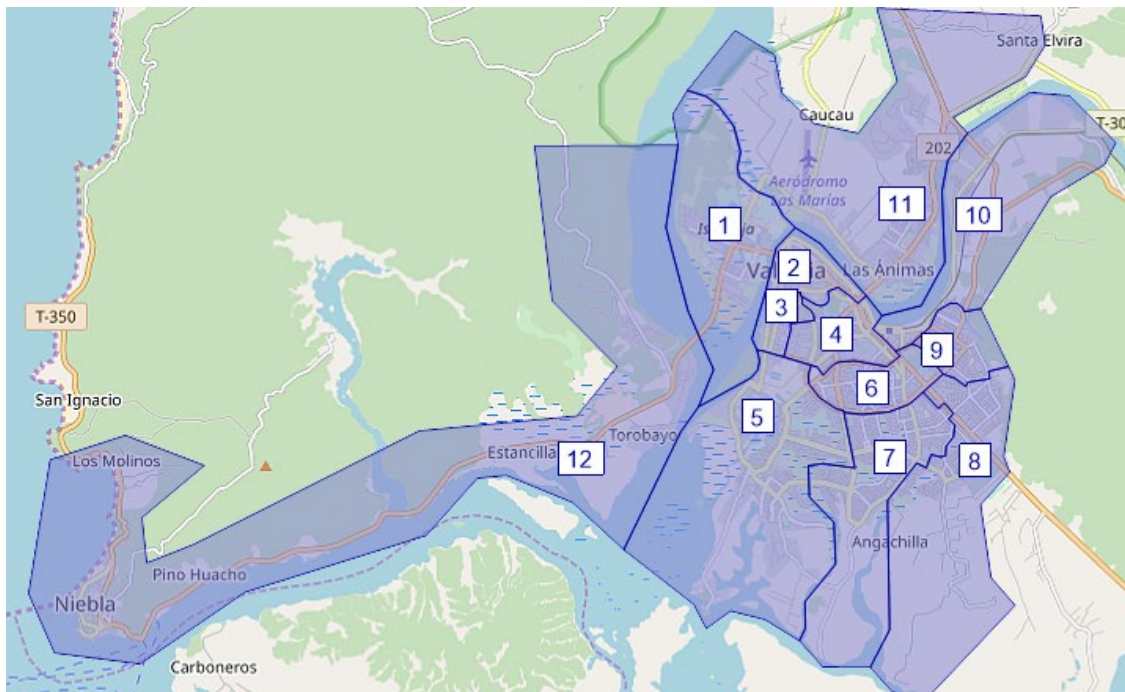


Figure 5. City zoning

Starting from the base model, two additional virtual models are built to simulate the proposed river crossing alternatives. Being the first one a bridge and the second one a ferry that will operate in the same location. Local people are not stranger to traveling by ferry since there have being ferries operating in the region for decades (Figure 6).



Figure 6. Existing (red) and proposed ferry line (green)

3.3 Construction

The construction of the virtual models is carried out using PTV Visum, a world class traffic simulation software. Firstly, all OD matrices corresponding to both the private and public transport networks are defined in the software.

Then, all modelling objects included as well. Among other: zones, centroids, nodes, arcs, connectors, bus lines and stops (Figure 7). Some of the arcs' attributes are length, lanes, direction of flow, and capacity. Once the base model is completed, calibrated, and validated using the in-situ observations, two new models are to be constructed.

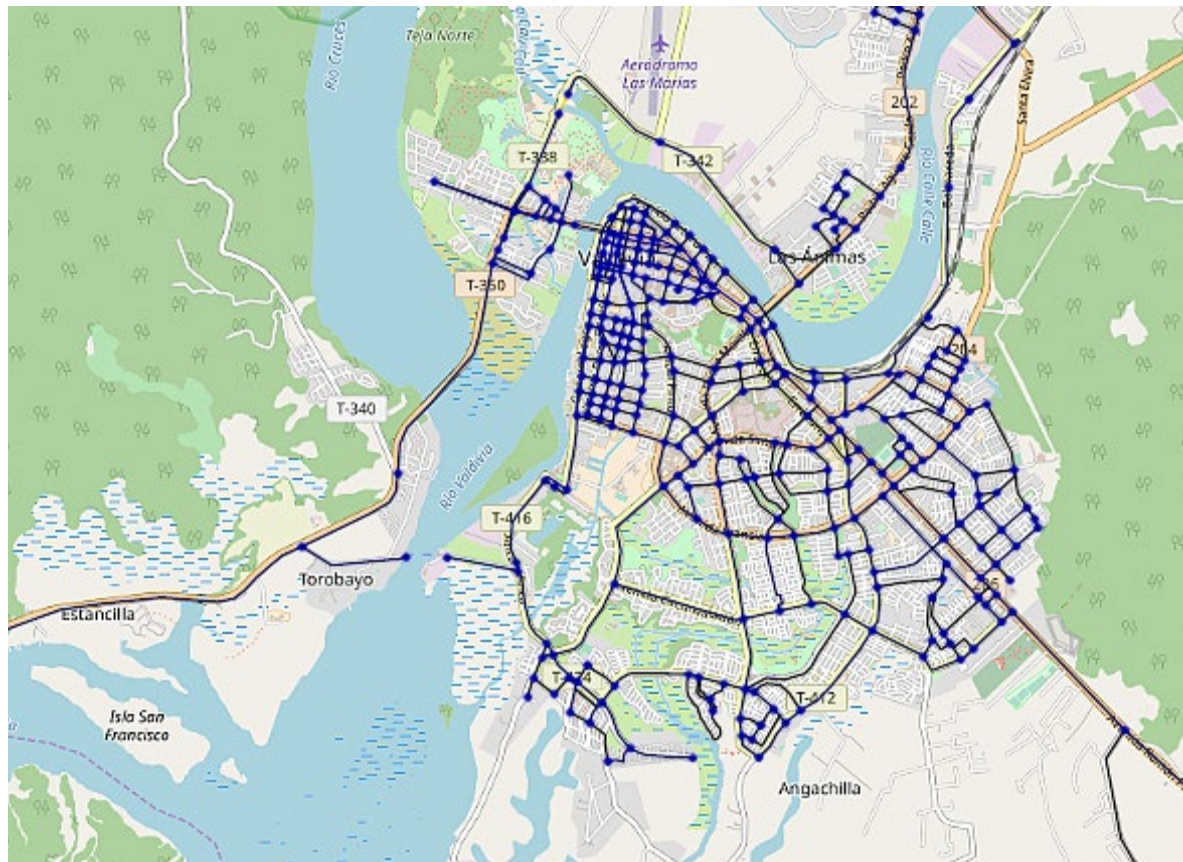


Figure 7. Base model

The proposed bridge-based model is assumed to count with 2 lanes and a limit speed of 50 km/h. The arc representing the bridge has a capacity of 1800 veh/h. The proposed ferry-based, instead, is assumed to have room for 20 small vehicles, a displacement speed of 10 nautical knots and departure frequency of 20 minutes. The arc representing the ferry has a capacity of 30 veh/h and a speed limit of 18.5 km/h (Table 1).

Table 1: River crossing alternatives implementation

	Bridge	Ferry
Type	arc	arc
Speed limit	50 km/h	18,5 km/h (10 knots)
Capacity	1800 veh/h	30 veh/h
Traffic light	no	40 min cicle

3.4 Validation

During the base model validation, a comparison between the flow generated the simulations and those observed at the control points is carried out. There is a tolerance range of tolerance when comparing flows. The causes for such differences are diverse: the update of the OD matrices from 2013 and new infrastructure projects built after the creation of the original OD matrices.

4. Data Collection

The base model's calibration and validation were both carried out using the observations made at specific control points (Figure 8).

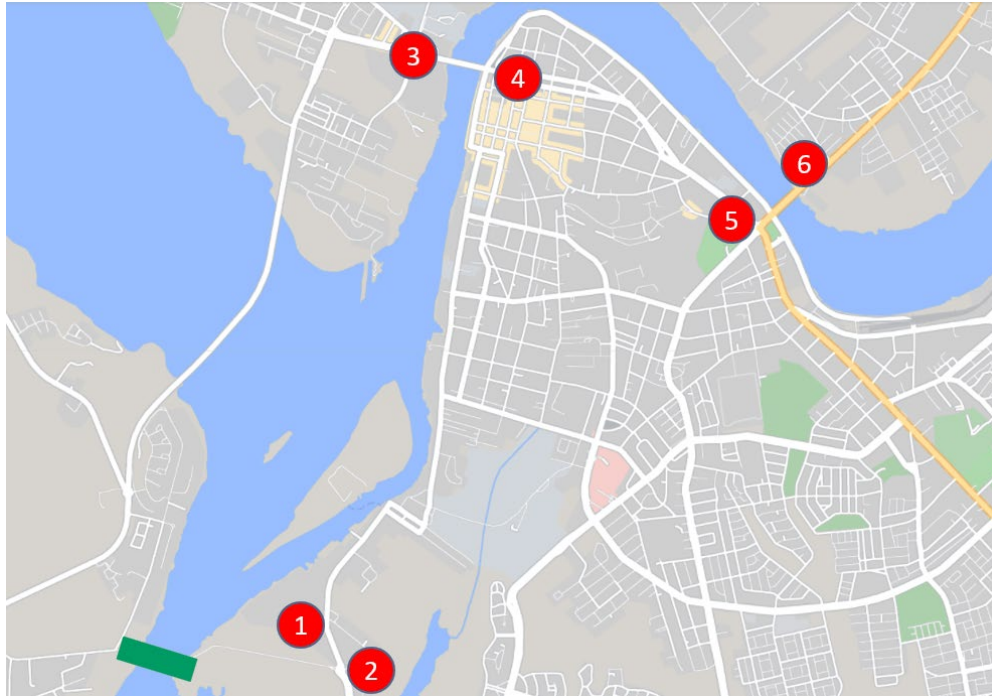


Figure 8. Control points. In-situ measurements

A comparison between the observations (flow counting) and simulation' results is presented in Table 2.

Table 2. Validation – Base Model

Control Point	Observed flow [veh]	Simulation – Base Model [veh]	Error [%]
1	672	648	3.6
2	295	325	10.2
3	1151	1257	9.2
4	1290	1275	1.2
5	1326	1061	20.0
6	1442	1260	12.6

5. Results and Discussion

5.1 Numerical Results

Considering that any mayor construction project usually takes a couple of years, to add some realism it was decided to project all OD matrices to 2025 by means of the annual growing rate coefficient of 3.5%. The expected variation in the travel demand is shown in Table 3.

Table 3: Travel time variation [%] – Comparison 2018-2025

Zone	1	2	3	4	5	6	7	8	9	10	11	12
1	27.9	53.0	46.3	42.5	39.9	37.0	32.3	30.9	35.6	35.9	35.8	-4.0
2	55.9	56.6	5.1	29.8	9.8	23.2	18.4	15.9	18.6	25.6	22.9	36.0
3	52.8	34.5	37.8	14.2	9.8	11.6	6.7	7.1	12.2	21.0	20.4	35.9
4	88.0	104.3	62.5	42.0	0.6	11.2	4.4	-0.2	-0.1	19.2	30.6	66.5
5	68.9	74.4	77.1	72.0	19.9	36.2	1.4	7.0	21.9	39.1	58.0	55.4
6	88.5	99.7	70.9	67.1	12.2	31.1	5.9	8.6	19.1	32.5	52.4	70.4
7	84.6	91.3	70.0	66.2	-0.5	40.9	4.3	13.1	24.8	31.9	54.9	69.5
8	83.3	89.6	70.2	53.9	4.3	23.5	3.6	11.0	22.0	32.3	48.2	68.2
9	90.5	103.8	78.6	57.6	9.3	21.7	7.9	4.8	17.8	31.4	49.7	71.4
10	63.9	71.6	56.5	32.0	17.0	19.6	6.0	3.4	6.3	24.5	52.3	52.1
11	52.0	62.6	45.0	26.7	24.4	27.1	20.4	5.2	7.5	-0.2	28.8	41.8
12	6.4	40.0	36.8	35.5	33.4	31.9	28.8	27.7	30.7	31.8	31.2	23.5

The percentual impact of the construction of the bridge in the travel time is shown in Table 4. Simulation results reveals that zone 12 and zone 5 would significantly reduce their corresponding travel time. It is though expected since they are located nearby the bridge.

Table 4. OD matrix variation [%] – Bridge-based model – Year 2025

Zone	1	2	3	4	5	6	7	8	9	10	11	12
1	-13.8	-19.8	-18.1	-14.8	-19.3	-12.9	-23.1	-11.8	-13.7	-15.0	-22.3	5.3
2	-39.0	-13.3	-2.9	-0.8	-1.9	-0.6	-1.6	-0.9	1.8	-7.2	-2.1	-30.7
3	-34.9	-6.3	-4.2	-2.9	-0.6	-3.9	-1.8	-1.8	-3.5	-10.0	1.4	-28.3
4	-33.4	-22.9	-4.4	-5.0	9.2	-6.4	-2.8	-0.2	-0.4	-12.0	-9.4	-37.2
5	-25.5	-11.6	-11.3	-7.7	-2.7	-7.6	0.3	2.7	-1.4	-13.1	-13.1	-56.2
6	-30.6	-22.0	-4.5	-7.2	-2.3	-4.1	4.0	2.8	-0.5	-12.5	-13.3	-43.5
7	-28.2	-18.9	-4.6	-3.5	2.0	-2.1	2.1	1.8	-3.5	-2.9	-11.8	-53.8
8	-26.2	-17.0	-12.2	-9.6	0.2	2.5	4.0	1.0	-0.1	-0.2	-9.3	-45.1
9	-26.2	-14.7	-9.9	-4.5	0.7	-2.5	2.3	-2.8	-1.4	0.4	-4.2	-33.6
10	-20.6	-12.8	-8.7	-3.4	0.3	0.0	2.2	0.9	2.1	-0.7	-3.6	-22.0
11	-20.1	-6.6	-1.6	-4.8	-5.0	-5.8	-4.5	-0.4	-0.1	0.5	-5.0	-17.8
12	14.3	-9.2	-8.9	-19.3	-61.8	-35.4	-56.8	-42.1	-22.7	-17.6	-14.0	-18.0

The results of the simulation of the ferry-based model are not so conclusive as they were in the previous case in which means of conducting an ANOVA analysis statistical evidence of differences in the travel time was found. Furthermore, Tukey post-hoc analysis confirmed a significant difference in the travel time. A similar Tukey post-hoc analysis does not show significant differences in the travel time when the ferry-based model is simulated (Table 5).

Table 5. OD matrix variation (%) – Ferry-based model – Year 2025

Zone	1	2	3	4	5	6	7	8	9	10	11	12
1	-2.5	1.6	1.4	2.5	0.7	2.0	1.4	2.2	3.1	0.4	-3.0	-0.3
2	-7.2	-28.7	-1.5	-5.9	-2.2	-6.8	-5.3	-3.9	-0.7	-4.0	1.6	-5.3
3	-4.1	1.7	-19.2	-5.2	-1.1	-2.0	0.6	0.4	-0.7	-4.0	6.4	-3.1

4	-32.7	-52.4	-34.0	-7.5	0.8	-4.6	-1.2	7.6	15.1	0.6	5.7	-28.2
5	-14.1	-17.8	0.0	-2.0	-5.7	-13.3	-0.3	0.2	1.5	-2.7	-1.6	-12.4
6	-29.5	-41.2	-24.6	-6.6	-2.1	-0.2	1.8	2.6	6.2	3.0	-2.6	-26.1
7	-27.7	-36.3	-22.9	-10.8	-2.8	-2.7	-0.2	1.9	6.0	4.2	-5.7	-24.9
8	-17.9	-22.6	-17.2	-3.2	0.3	2.7	0.3	0.0	-2.4	0.3	3.0	-16.1
9	-17.3	-22.8	-17.2	2.1	1.8	5.7	-0.2	0.5	2.7	1.9	4.4	-15.3
10	-12.1	-20.1	-15.2	1.6	1.5	0.3	-0.1	1.1	1.1	2.7	5.1	-10.7
11	-3.6	-18.9	-12.4	0.9	-1.0	-2.1	-1.2	1.4	1.5	0.9	3.5	-3.0
12	-3.6	-2.1	-2.0	-0.6	-6.3	-0.8	-12.0	-0.4	0.0	-1.6	-4.2	-3.2

6. Conclusion

Considering the effort involved in the preparation of OD matrices, the update coefficient is of great help to extend their useful life. However, it does not consider the impact of new infrastructure projects as it was seen during the validation of the base model. The selection of the right number and proper location of the control points is crucial to collect enough data for the calibration and validation of the base model.

Difference in the simulation results of the proposed river crossing alternatives suggests that the models can adequately forecast the travel demand between zones.

The ANOVA analysis reveals statistical evidence of differences in travel time when a new crossing structure is incorporated to the existing road network. However, a post-hoc analysis reveals that only in the case of the bridge-base model the travel time reduction is significant, whilst the ferry-based proposal does not.

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Biographies

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