Understanding Urban Mobility: Dynamics of Transport Planning and Modal Preferences

Sara Gharavi, Jean Dubé and Francesco Ciari

March 12, 2024

Understanding Urban Mobility: Dynamics of Transport Planning and Modal Preferences

Sara Gharavi [1,2]; Jean Dubé[1]; and Francesco Ciari[3]

[1] Department of Regional Planning and Regional Development (ÉSAD), Faculty of Planning, Architecture, Art, and Design, Laval University, Quebec City, Quebec, Canada G1V 0A6,
[2] sara.gharavi.1@ulaval.ca

[3] Department of Civil, Geological and Mining Engineering (CGM), Faculty of Engineering, Polytechnique Montréal, Montreal, Quebec, H3T 1J4, Canada.

Abstract

Over the years, studies have revealed that the implications of adopting one or the other of transport infrastructure strategies are not neutral on urban planning, sustainability, and landscape development. Studies consistently highlight that expanding highway often results in increased traffic, known as induced demand. As a direct consequence, comparative analysis of various scenarios resulting from introduction or change in transport infrastructure is essential to understand how mobility behavior can be related to spatial aspects and individual preferences in urban transportation.

This study aims to evaluating individual transportation choices following the implementation of diverse transport planning proposals for Quebec City, a city oriented on the use of private car and the high supply of highway infrastructure. Based on the MATSim multi-agent simulation model and integrating Eqasim for modal choice analysis, this research adopts a microeconomic perspective. It aims to measure shifts in modal share across different spatial scales, emphasizing localized nuances stemming from changes of the development of a new road link between Quebec City and Lévis introduces by government. The assessment focuses on how different planning scenarios impact modal shares between private vehicles and public transport.

Through this research, we simulate three different propositions of the third link through west, center and east of Quebec including the car, public transport, and mixed allowed mode policy for each scenario of single proposition.

The findings indicate that the implementation of the proposed third link has minimal impact on reducing car usage. Notably, only the scenario prioritizing public transport shows a substantial change in modal choices. The originality of this research lies in its comprehensive exploration of the intricate connections between transport planning changes and the dynamics of individual travel choices within urban environments.

1 Introduction

The debate on transportation and infrastructure priorities has been raging for several years in Québec City (Dubé et al., n.d.; Dubé, Aubry, et al., 2021; Dubé, Mercier, et al., 2021; La Presse Canadienne, 2022; Simard, n.d.). These tensions have been exacerbated since the provincial elections of 2018, where the winning party had campaigned for the development of a new road link between Quebec City and Lévis. Originally, this project aimed to address traffic congestion. However, voices have risen, claiming that this choice would encourage car use over public transportation.

Several studies have established a link between the expansion of road infrastructure and an increase in traffic (Downs, 1962; Duranton et al., 2014; Duranton & Turner, 2011; Tennøy et al., 2019; Thompson, 1977) . This phenomenon, known as "induced demand," tends to promote urban sprawl (Baum-Snow, 2007). Recent studies have also highlighted the opposite phenomenon, i.e. where the removal of highway infrastructure results in a reduction in car modal share (Graham-Rowe et al., 2011). This phenomenon is referred to as evaporated demand and confirms, from an inverse proof perspective, the presence of induced demand.

To identify the potential impact of adding transport infrastructure on individual modal choice in the Quebec City region, this study aims to evaluate the impact of different land planning scenarios. The analysis relies on a multi-agent simulation model known as MATSim (Horni et al., 2016) . In addition to the simulation model, the analysis integrates a module concerning econometric modal choices model, called Eqasim (Hörl & Balac, 2021). The module proposes a discrete choice model to explain individuals' modal choices. The contribution of the work lies in its ability to estimate changes in modal choices by adopting a microeconomic approach.

The model allows evaluating specific hypotheses. Firstly, we aim to verify that the construction of a new road infrastructure between Quebec City and Lévis lead to a reduction in travel times for motorists, thus prompting an increase in car usage and the reveal the induced demand (Mann, 2014; Schneider, 2018; Speck, 2018). Secondly, we seek to check if the hypothesis of evaporated demand, by dedicating this new infrastructure solely to public transportation, can be confirmed in the context of Quebec City. The study is based on three different proposals regarding the location of a third link, based on different proposition presented in the media, as well as three different scenarios regarding the modes of transport permitted on this new infrastructure. The results show that the proposed third link construction has a limited effect on reducing car usage. Only the scenario dedicated to public transport significantly altering modal choices, particularly for inter-shore trips, representing approximately 11% of all trips. For the remaining trips, modal choices are marginally impacted.

The article is divided into five distinct sections. The first section examines the impact of changes in road infrastructure and public transportation on mobility behaviors using agent-based simulation models. The second section details the methodology used to simulate these travel behaviors. The third section presents the data used to construct and adjust the simulation model. Results from the simulations and their analysis are discussed in the fourth section, highlighting the observed implications. Finally, the article concludes with a summary of the main points addressed in the study.

2 Literature Review

The use of multi-agent systems (MAS) for transportation simulations proves to be an effective means of modeling individual behavior in various situations. In MAS, individuals, represented by agents (Russell et al., 1995), seek to maximize their respective utilities based on their preferences (Balmer et al., 2008). One way to achieve this goal is by opting for the fastest mode of transportation to reach their destinations. MAS posit that agents can modify their route, through an iterative process, to avoid traffic or choose faster modes of transport (Turing & Haugeland, 1950). MAS provide a dynamic way to simulate transportation choices and travel times based on a multitude of individual agents (Huang et al., 2022).

The significant advantage of MAS is their ability to handle complex scenarios (Hermellin et al., 2015). This method is widely used in the transportation domain for its capacity to synthesize complex systems (Sanford Bernhardt, 2007) and solve various problems. Over the years, agent-based modeling (or Agent-Based Model - ABM) has become an efficient and recognized method for understanding the impact of transportation infrastructures, in general, and road networks, in particular, on modal choices (Sanford Bernhardt & McNeil, 2008).

Several ABM models have been designed to address these challenges (Bastarianto et al., 2023). Among these frameworks, notable ones include SimMobility (Lu et al., 2015), TRANSIMS (Lee et al., 2014; Smith et al., 1995), and AnyLogic (Castle & Crooks, 2006). Other open platforms such as MobiTopp (Schnittger & Wittowsky, 2002) and Polaris(Auld et al., 2016) offer users the opportunity to adapt or replace modules to explore specific aspects of transportation projects (Chen & Cheng, 2010). However, MATSim (Balmer et al., 2008) MATSim is known for robustness flexibility, and modularity in modeling transportation systems. The model was designed to assist planners in making informed decisions. MATSim can also be used to manage and compare different scenarios involving millions of travelers (Meister et al., 2010) and detailed networks. Thanks to its modular nature (Bösch & Ciari, 2015), it can easily be extended with custom features and integrated into other tools to work in various fields of study.

The development of MATSim (Multi-Agent Transport Simulation) traces its origins back to the work of Nagel (Nagel & Rickert, 2001). Its primary motivation was to create a more efficient and adaptable transportation system model. Before MATSim, Nagel had actively contributed to the development of the TRANSIMS platform (Nagel, 1997), which utilized cellular automata-based traffic modeling for various scenarios, including multi-lane traffic and intersections.

MAT Sim’s evolution started with simulations of single-lane road traffic (Nagel & Rickert, 2001; Nagel & Schneckenberg, 1992) before progressing to large-scale network-based scenarios. Under Balmer's leadership (Balmer et al., 2008), the project transitioned to Java programming, enhancing its versatility and independence. This pivotal shift marked a significant milestone in MAT Sim’s trajectory (Nagel & Axhausen, 2016), laying a robust groundwork for its continuous advancement and improved capabilities in transportation modeling and simulation.

More recently, the integration of the Eqasim module (Hörl & Balac, 2021) into MATSim has strengthened the consistency between observed data regarding transport modal choices and simulation results. This integration relies on discrete choice models (DCM -McFadden, 1978) that explicitly consider agents' preferences and utilities associated with different transportation modes (Manski, 1977). The module enhances MAT Sim’s overall capabilities and its relevance for better understanding and analyzing real-world transportation systems, in addition to offering improved computational performance.

MATSim has been used in studies to evaluate the outcomes of different transportation projects. One such example is the assessment of the Westumfahrung highway project in Zurich (Ballmer et al., 2009; Disler, 2009; Mattes et al., 2007; Sauter et al., 2014). This study adopted a different approach by seeking to identify who benefited from the project. The primary finding was that certain measures, such as modifications to the Westtangente (Zurich city center bypass) and adjustments to traffic signal systems in the Wollishofen district, proved effective in managing traffic flow and redirecting it to new highway sections (Westumfahrung). The simulation indicates that the addition of the highway does not generate traffic congestion in the city of Zurich, even when considering potential future changes in land use and population distribution over time (Balmer, 2009).

MATSim has also been employed by the Communauté d'Agglomération Paris-Saclay (CPS) (Chouaki et al., 2022; Gall et al., 2023), a region with 27 municipalities located south of Paris, near the Métropole du Grand Paris. The objective of the study was to evaluate the impact of the Grand Paris Express (GPE) (Anas & Chang, 2023; Bouillaut et al., 2020; Egal, 2023), and more specifically the introduction of Autonomous Shared Electric Vehicles (VESPA) as a mobility-on-demand service. This initiative aims to facilitate access for rural and peri-urban households to existing public transportation systems (Réseaux Express Régionaux) as well as future systems (Metro Line 18, Tram 12) in the region. The study demonstrated that future transportation scenarios can influence individuals' preferences, including factors related to car ownership. It underscored the importance of adapting infrastructure based on where people will live and work in the future.

In another study, MATSim was used to assess the impact of constructing the 2nd Stammstrecke (2nd main line in the railway transport system) on Munich's regional railway network (Sheikh, 2018). The analysis conducted from 2012 to 2050 suggests that the 2nd Stammstrecke has a modest impact on public transportation use by 2026, with similar effects across all scenarios by 2050. Areas served by the Express line experienced increased public transportation usage, while areas not served experienced decreased usage. Car preferences decreased while public transportation accessibility increased in 2026 across all scenarios. By 2050, car accessibility improved in the reference situation but continued to decrease in the scenario involving the construction of the 2nd Stammstrecke.

3 Methodology

MATSim offers flexibility, enabling exploration of a variety of urban transport scenarios and policies (Axhausen & Gärling, 1992). By using real data such as travel demand information and transportation supply (network data), MATSim contributes to a better understanding of urban mobility and aids in making informed decisions regarding urban planning and transportation policies.

Our approach aims to consider a crucial factor in modal choice, namely travel time. We seek to understand how modifications in travel time, facilitated by new infrastructure and changes in individuals' habits, influence individuals' mode choice (Hörl et al., 2019). These factors are crucial in explaining how travel preferences evolve following the implementation of each scenario, particularly concerning preferences for time savings during travel.

To analyze changes in transportation preferences resulting from the Third Link proposals, we utilize a version of MATSim equipped with the new discrete choice modeling (DCM) module called Eqasim (Hörl & Balac, 2021; Pereira et al., 2022). Discrete choice models, statistical tools assigning probabilities to various travel options, enable individuals to weigh the benefits and drawbacks of each option, selecting the one maximizing their satisfaction. Employing a microeconomic approach, we estimate transportation trips and examine spatial variations in transportation decisions compared to a reference scenario, aiming to assess the potential impacts of the Third Link proposals on travel behavior.

To model transportation choices, we employ the principle of Random Utility Maximization (RUM) (Walker & Ben-Akiva, 2002).In the model, various modes of transportation are considered as alternatives, each associated with characteristics such as travel time. This utility model enables estimation of mode choice probabilities based on these characteristics. We use origin-destination (OD) survey data or GPS data to estimate the model parameters (Hörl et al., 2019). Assigning utility functions to different modes of transportation is crucial in determining agents' mode choices during their trips (Pereira et al., 2022) (Equation 1).

$$U_{ij} = \sum_{j=1}^{4} \alpha_j + \sum_{k=tt} \beta_k X_{kj} \tag{1}$$

The model links the utility for an individual i to transportation mode j (car, passenger, public transport, walking), based on the travel time X_{kj} in minutes from the origin to the destination using transportation mode j. In the model, α_j is the intercept (where walking mode serves as the reference mode), and β_k represent the parameters to be estimated, weighting the importance of travel times.

To estimate the model, we utilize Biogeme, a Python-based tool (Bierlaire, 2018), to maximize the likelihood function of the multinomial logit model (McFadden, 1978).

Once the parameters are estimated, it is possible to simulate modal choices based on observed data. This initial simulation serves as the reference scenario, which can be compared with observed choices to calibrate the model. Once calibration is done, the reference scenario becomes the benchmark against which other scenarios are compared, obtained by modifying travel times associated with changes in infrastructure provision. This approach enables the analysis of transportation projects' impacts on individuals' mode choice, thereby contributing to urban planning and transportation policies (Axhausen et al., 2016). Given that the route optimization method relies on travel times, any alteration to the highway infrastructure may have varying impacts on these times and, consequently, on mode choices.

3.1 Data

MATSim utilizes multiple files to store the various datasets it mobilizes for simulation. Typically, MATSim includes files describing the existing road system, as well as files outlining the spatial distribution of populations and activities, along with existing travel patterns (Table 1).

Files	**Description**	**Data source**
config.xml	Configuration options for MATSim.	-
Network.xml	Road network descriptions.	OpenStreetMap[*]
Population.xml	Agents and their daily activities.	Census data (2016)[†], Origin destination survey (2017)[‡]
Facility.xml	The locations of activities.	Assessment roll (2018)[§]
Transit_Schedule.xml	Stops and public transport services	General Transit Feed Specification (GTFS) Québec[**] et Lévis[††]
Transit_Vehicle.xml	Description of public transport vehicles.	

Table 1 : Input data necessary for simulation in MATSim

To generate the 'population.xml' file containing synthetic agents with their daily activities, as well as the 'facilities.xml' file detailing the locations of these activities, three main sources of data are mobilized. These sources include: i) the 2016 Population Census for individual-level socio-demographic information, ii) the 2017 Origin-Destination Survey characterizing travel habits within the Québec Census Metropolitan Area (CMA), and iii) the 2018 assessment roll, providing accurate information regarding the location of properties and major trip generators in the Québec CMA.

To process these essential data sources and produce the 'population.xml' and 'facilities.xml' files compatible with the MATSim model, we have developed a population generation pipeline using Python. This pipeline consists of distinct steps (Figure 1), enabling the integration and transformation of these various data sources into formats suitable for MATSim simulation.

---

[*] The networks for MATSim are typically created from OpenStreetMap (OSM), a free and editable map of the world published under an open content license.

[†] Census Profile 2016 for Quebec, Census Divisions (CD), Census Subdivisions (CSD), and Dissemination Areas (DA).

https://www.transports.gouv.qc.ca/fr/ministere/Planification-transports/enquetes-origine-destination/quebec/2017/Pages/enquete-2017.aspx

[§] https://www.mamh.gouv.qc.ca/evaluation-fonciere/evaluation-fonciere-municipale-au-quebec/role-devaluation-fonciere/

[**] https://www.rtcquebec.ca/donnees-ouvertes

[††] https://www.stlevis.ca/stlevis/donnees-ouvertes

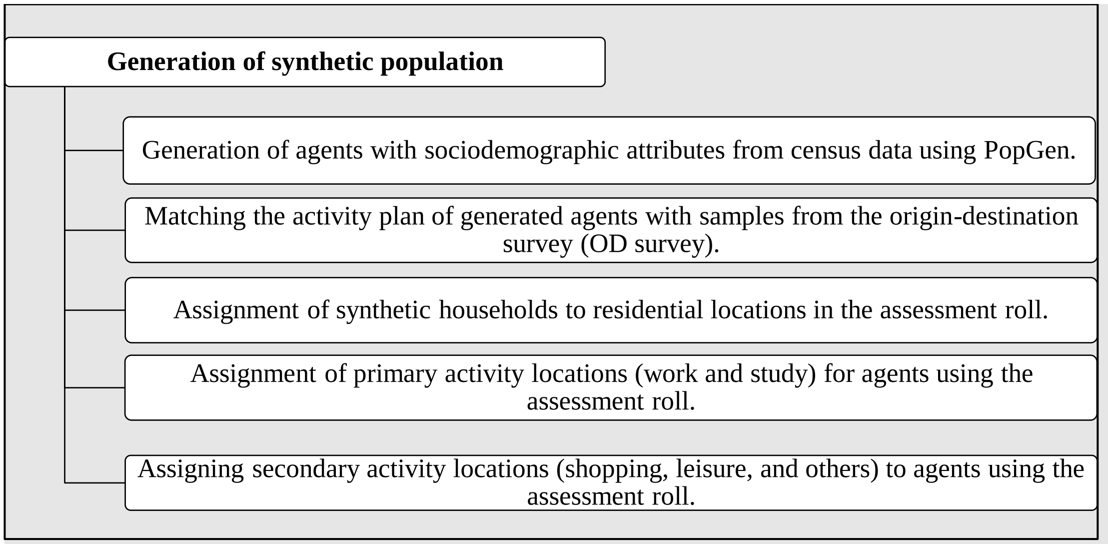
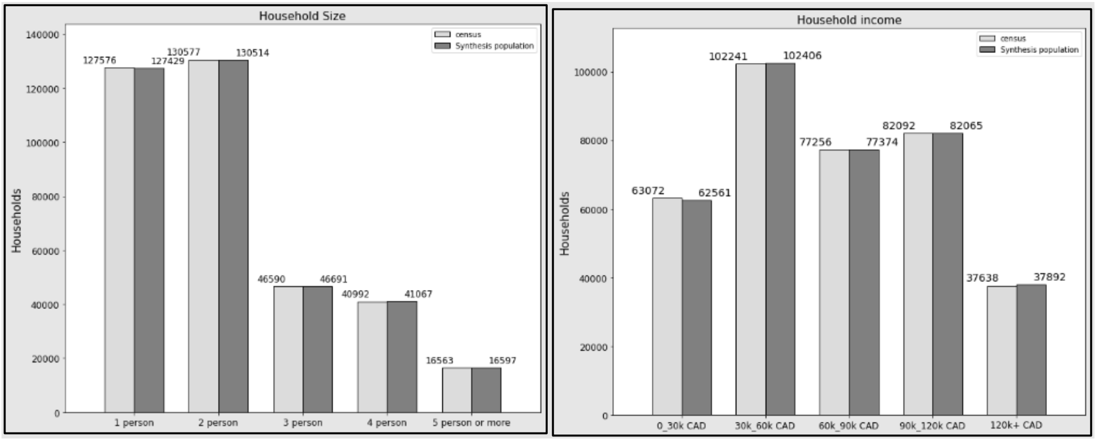


Figure 1 : Overview of Synthetic Population Generation.

The data from the Census (2016) and the Origin-Destination Survey (2017) allow for the reconstruction of a synthetic population. To achieve this, the PopGen module along with Iterative Proportional Fitting (IPF) and Iterative Proportional Updating (IPU) algorithms are used to create synthetic populations based on the 2016 Census data. The method used is detailed to ensure an accurate reproduction of the sociodemographic distribution from the census within the synthetic population, achieving a coefficient of determination (R²) of 0.99 (Figure 2).



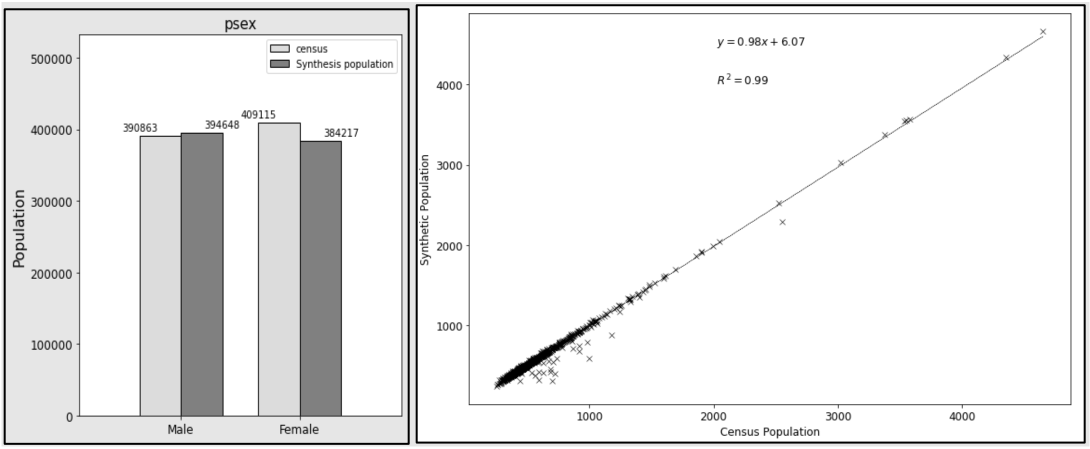


Figure 2 : Comparative analysis of IPF-adjusted marginals and joint distribution of synthetic agents compared to the actual census population.

After the initial processing, we filtered the origin-destination survey data to focus on individuals with complete information on their trips, particularly those starting their daily activities at home and returning home at the end of the day. The synthetic population generated in PopGen is matched with trip and daily activity data from the 2016 origin-destination survey. This matching process ensures consistency between the synthetic population and the actual travel patterns observed in the OD survey.

Additionally, using the origin-destination matrix, we linked real establishment points listed in the 2018 assessment roll to the origin and destination points of these activities. This step contributes to accurately assigning real-world facilities to activities performed by the synthetic population, enriching the simulation with realistic origin and destination points for these activities.

To generate the 'network.xml' file, describing the transport networks and private vehicles in Québec, as well as the 'Transit_Schedule.xml' and 'Transit_Vehicle.xml' files specifying the stops, services, and vehicles of public transit networks, we use an open-source Java tool called pt2matsim[‡‡]. This tool utilizes OpenStreetMap data to extract comprehensive information about the network, including road layouts, intersections, and other transport-related details. Furthermore, pt2matsim leverages the General Transit Feed Specification (GTFS), a standard format for public transit schedules and associated geographic information. By interacting with GTFS feeds, this tool translates transit schedule data into 'Transit_Schedule.xml' and 'Transit_Vehicle.xml' files, providing details on transport stops, service schedules, and vehicles operating in the Québec public transit network.

4 Estimation and calibration

The estimates of the discrete choice model used in MATSim are conducted based on five thousand randomly sampled observations from the Québec origin-destination survey (2017). The estimated parameters respect theoretical expectation, with higher time travel reducing the probability of using specific mode (Table 2).

[‡‡] https://github.com/matsim-org/pt2matsim

Parameters	Value	Std.Err	T-test	Calibration
α_{car}	-0.4676	0.0656	0.1121	**-1.35**
α_{pt}	-3.3803	0.0886	0. 1379	**-3.05**
α_{walk}	0.0000	0.0000	0.0000	**Reference mode**
β_{tt-car}	-0.1595	0.0066	0.0084	-
β_{tt-pt}	-0.0547	0.0030	0.0037	-
$\beta_{tt-walk}$	-0.1716	0.0045	0.0085	-

Table 2: Estimated parameters in the DCM logit model with calibration

Note that this simplified approach may not always accurately reflect real decision-making. As (Balac & Horl, 2021) points out, a single set of utility functions rarely precisely predicts everyone's choices from survey data. This discrepancy arises from potential shortcomings in the model's complexity and the fact that human behavior is not always rational.

Adjusting the values of αj aims to partially bridge this gap by refining the model's prediction, better reflecting the diverse and sometimes unpredictable nature of real decision-making. This involves fine-tuning the constants specific to the car and public transport alternatives to better represent how individuals make travel decisions. This final calibration method allows for obtaining a simulation portrait that is closer to real data (Figure 3). Once the model is estimated, individual choices can be simulated by varying the initial conditions of certain variables, including travel time.

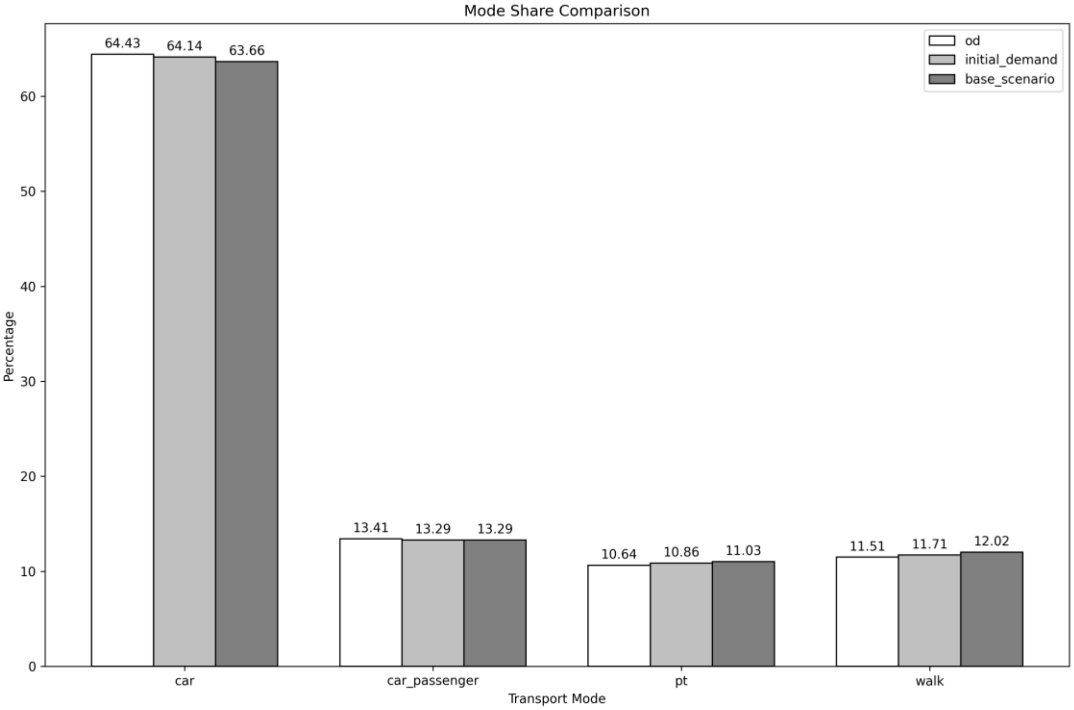


Figure 3 mode share comparison of real data (OD), initial demand (synthetic population) and base scenario.

5 Simulation

In this study, we aim to determine the impact of different scenarios on modal share (car, public transport, and active modes). The scenarios seek to establish, once the infrastructure is installed, what is the impact of modifying the infrastructure supply, and thus travel time, on modal choices. Three scenarios (S1, S2, and S3) are considered for the location of the third road link (Figure 4). The first (S1) propose a passage through both historical downtown areas connecting highway 973 Laurentides to Quebec City and the Trans-Canada Highway to Lévis. The second (S2) proposes the link connect the east part of québec, Levis and ‘Île-d'Orléans. The third scenario (S3), proposed by two engineers, considers linking Chemin des Îles in Lévis to Boulevard Charest in Quebec City.

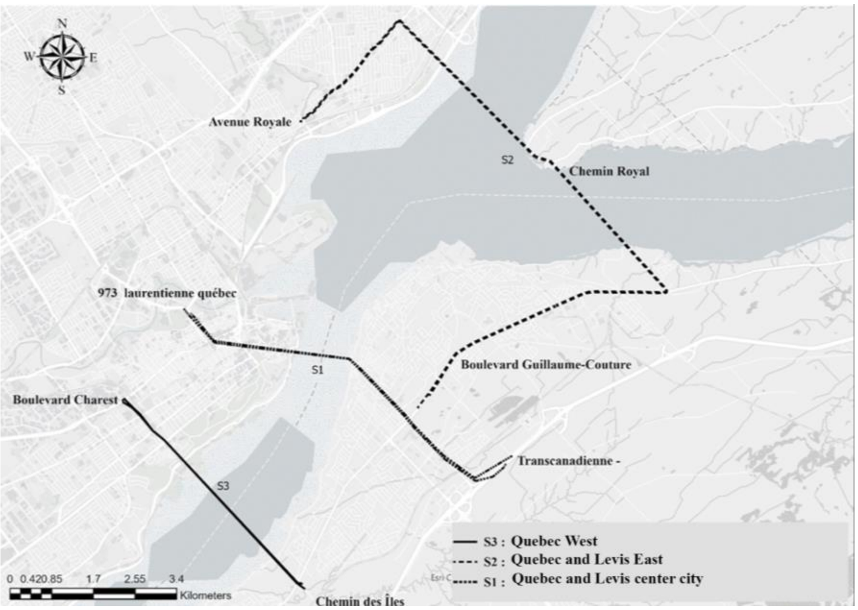


Figure 4: Proposed Scenarios for the Third Link between Québec and Lévis

Each of these scenarios is then split down into three possibilities (Table 3). The first strategy is to make the infrastructure available for both private cars and public transportation. The second strategy focuses on exclusive use for public transport. Finally, the third proposal is exclusively for car use.

Scenarios	Zone of changes	Allowed Mode
S_0	Base scenarios, no changes	-
$S1_{mixed}$	Autoroute 972 laurentienne Québec _ Autoroute Transcanadienne - Lévis	Car + passenger + pt + walk
$S1_{pt}$		Pt + walk
$S1_{car}$		Car + passenger
$S2_{mixed}$	Quebec - L'Île-d ‘Orléans - Lévis	Car + passenger + pt + walk
$S2_{pt}$		Pt + walk
$S2_{car}$		Car + passenger
$S3_{mixed}$	Chemin des Iles Lévis _Boulevard Charest	Car + passenger + pt + walk
$S3_{pt}$		Pt + walk
$S3_{car}$		Car + passenger

Table 3 : Scenarios for the three proposals of the third link with different strategies of allowed modes of transportation.

5.1 Scenarios

To better understand the number of trips made between Quebec City and Lévis compared to the entire metropolitan region, we conducted simulations based on 10% of the total trips in the Quebec Metropolitan Area (Llorca & Moeckel, 2019). This simulation considered limited personal activities starting and ending at home, disregarding trips outside the metropolitan area. Our simulation encompassed 54,753 individuals, representing 182,263 trips recorded in the origin-destination survey. It is worth noting that out of the total, 6,074 individuals, or 11% of the trips, made cross-river trips between Quebec City and Lévis. These individuals generate a total of 13,700 trips, accounting for 7.52% of the total trips.

The results show truly minor change in the overall trips in the Quebec Metropolitan Area (Figure 5). In fact, the modal shares of different options remain overall remarkably similar to those observed in the reference scenario. These results mean that the behavioral changes target those crossing the river.

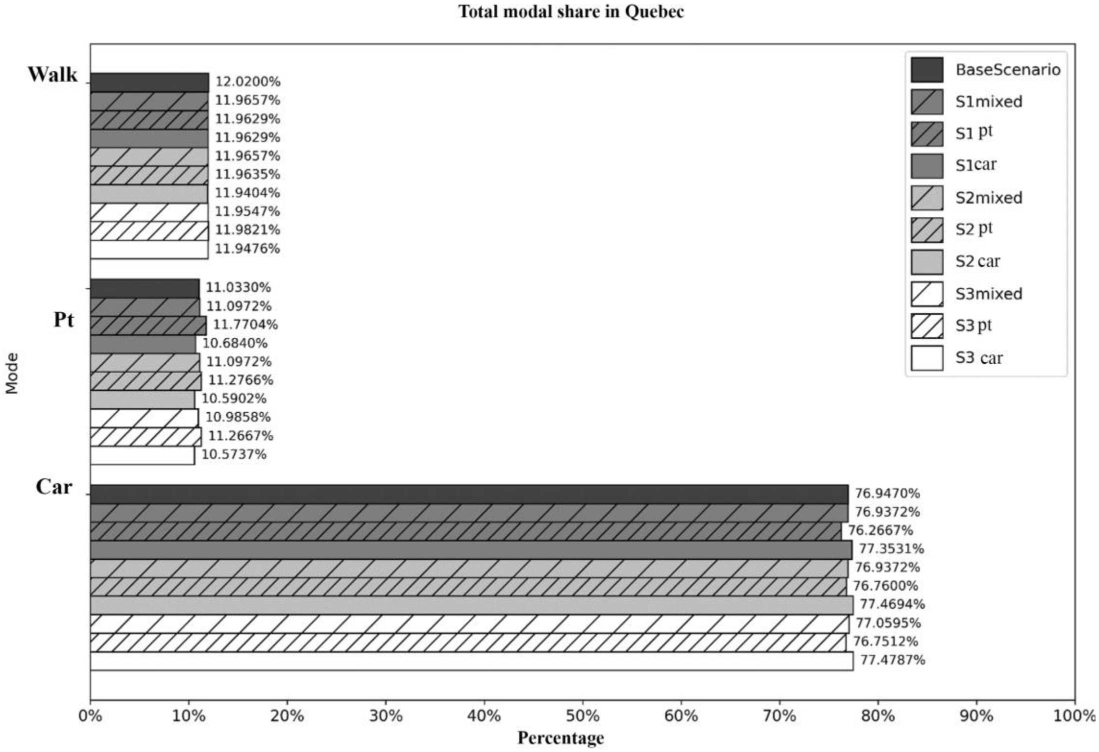


Figure 5: Modal Shift Analysis: Quebec Metropolitan Area

By focusing on the river-crossing trips between Quebec City and Lévis (Figure 6), the conclusion is more nuanced. This targeted analysis aims to provide an in-depth understanding of the changes in trips that could be most affected by this new infrastructure, as well as to envision how new trips between the two shores could be influenced by the new infrastructure.

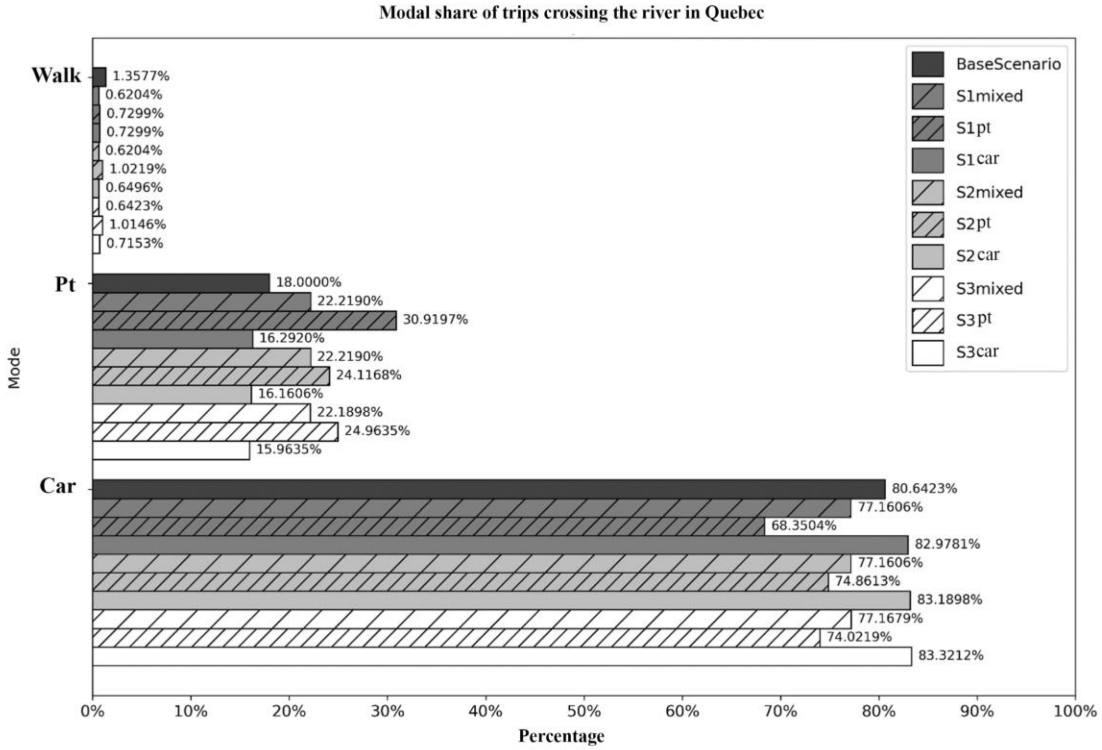


Figure 6: Modal Shift Analysis for Trips Crossing the River between Quebec City and Lévis

In the case of infrastructure for both car and public transport mode, the increase in the modal share of public transport comes at the expense of the car. The car's modal share stands at 77.16%, a decrease of almost three percentage points compared to the reference scenario (80.64%). In contrast, the modal share of public transport increases by almost four percentage points, rising from 18% in the reference scenario to just over 22% in the various third-link location scenarios. The results are similar for all proposed routes.

When the infrastructure is entirely dedicated to public transport, the results suggest a significant increase in public transport modal share. Compared to the reference scenario, the modal share increases by twelve percentage points for the scenario where the infrastructure is located further west. For the two scenarios to the east, namely the passage between downtowns and the one via Île-d'Orléans, the increase in modal share is almost six percentage points, or about 24%. This increase comes at the expense of the car's modal share, which decreases, in the most significant case, by twelve percentage points, dropping below the 70% mark.

Unsurprisingly, the scenario linking the new infrastructure for car use only suggests an increase in the car's modal share (S3). Although modest, between 2 and 3 percentage points, this increase suggests that adding infrastructure may hardly solve the problem of urban traffic congestion. This increase in modal share comes at the expense of public transport, which sees its modal share decrease from 18% in the reference scenario to almost 16%.

In all cases, this variation in modal share is localized near the imagined infrastructures (Figure 7).

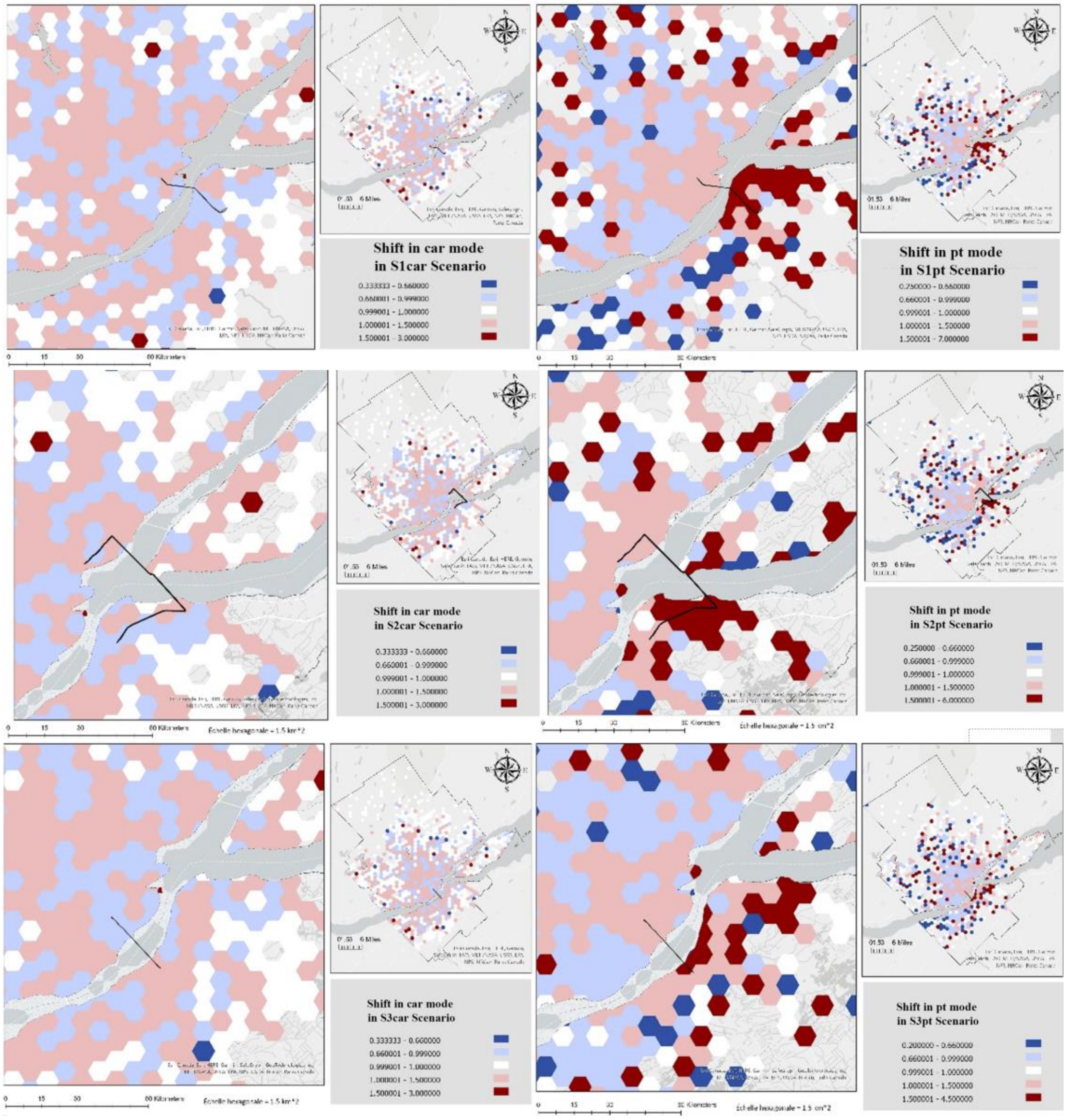


Figure 7: Modal Changes in Specific Zones (1.5 km *2) for the Proposals.

Unsurprisingly, the increase in the modal share of public transit occurs in close areas from the infrastructure, as travel time is more strongly influenced in these locations. Conversely, the change in modal choice for these users negatively influences those located a little further away. For these commuters, a reduction in the intensity of infrastructure use translates into reduced travel times by car and, consequently, favors the use of this mode.

The spatial distribution of the variation in modal share depends on the availability of existing public transport infrastructure, but also on the availability of highway and road infrastructure. The overlap of blue and red colors clearly shows the areas where public transport infrastructure is well developed (in red) and where road and highway infrastructure are better developed (in blue). The fact that the proposal for a third link to the west brings about greater changes is attributable to the existing infrastructure supply in that area. The public transit supply is better developed there than in the west. Conversely, the relative dominance of highway infrastructure in the east explains why the variation in the modal share of public transit is lower for a scenario where the third link would be exclusively dedicated to public transit. Travel times by car are almost unaffected by the implementation of the third link, which explains the limited variations in the results for the car modal share (Figure 4).

Travel time shifts in the crossing river trips.

	Mean (minutes)		Median (minutes)	
Mode	**car**	**pt**	**car**	**pt**
S1m	-2.272	-12.704	-1.683	-10.542
S1pt	-1.948	-26.218	-1.742	-21.2
S1car	-2.229	-4.872	-1.867	-3.858
S2m	-2.272	-12.704	-1.683	-10.542
S2pt	-1.306	-13.132	-0.95	-9.492
S2car	-1.773	-3.589	-1.1	-2.267
S3m	-2.725	-13.516	-2.667	-12.383
S3pt	-1.134	-12.763	-1.017	-11.358
S3car	-1.96	-2.828	-1.983	-2.258

Table 4: Changes in travel times between the reference scenario and the proposals for the third link.

In contrast, the results suggest that a significant variation in travel time for public transportation is necessary to affect the modal share. This conclusion stems from the fact that Quebec City is well-served by highways and residents are attached to this mode of transportation.

In summary, based on a constant population structure, the study suggests that the third link would result in marginal global change compared to the current situation. The statistics related to the use of the third link suggests a ridership three times lower than on existing infrastructure. The reduction in car travel time is marginal, and although it is more significant in the case of public transportation, the reduction in bus travel time is not important enough to result in a major change in travel habits, mainly because car travel time remains constant. The option that has the most significant impact is the addition of infrastructure based to the west dedicated solely to public transportation, where the use of public transportation is easier. In all cases, the results obtained hardly seem to justify such a large project for the rather limited benefits of adding a third link between Quebec City and Levis. One interesting avenue for research would be to calculate the Transportation Time Savings (TTS), which quantifies the benefit gained by adding a third link compared to the estimated project budget. This calculation would help to clearly explain these findings in numerical terms.

6 Conclusion

This study aims to evaluate the impact of developing a third link connecting Quebec City to Levis on modal shares across different scenarios regarding its location and the various modes that can use the structure. To do so, simulations are conducted using data available through MATSim, an agent-based simulation model, and Eqasim, a module that integrates a discrete choice model regarding modal choice. The simulations stem from microeconomic analysis and revealed preferences.

The results reveal a limited impact of the third link construction scenarios on the modal share of cars. Moreover, the use of the new infrastructure represents only one-third of the usage for inter-river travel, while the car travel time savings is marginal, i.e. less then 3 minutes. Only the scenario where the third link is dedicated to public transportation significantly reduces car usage in favor of public transportation. Furthermore, the changes are primarily limited for inter-river travelers, which represents about 11% of total trips. For the other trips, modal choices are only marginally impacted.

In terms of public policy, the analyses suggest that adding a third link would have marginal benefits for commuters crossing the river. This result raises concerns about the cost-benefit ratio of such infrastructure. Even for the potential gains in terms of the number of trips taken by public transportation, the results suggest that dedicating the new infrastructure to this type of travel would be necessary to significantly change travel habits. However, once again, the cost-benefit ratio of such an option does not ensure an optimal decision, at least economically speaking.

Certainly, the conclusions must be interpreted considering certain limitations. Firstly, the forecasts assume a constant demographic structure and do not account for adjustments related to various changes, such as shifts in generational preferences and optimization of the public transportation network. Additionally, the study assumes that the locations of residence and employment remain unchanged after the construction of the third link, thereby limiting the comparative scope of the study. Furthermore, regarding the car passenger mode, we exclude them from the mode choice process in the MATSim replanning stage. We assume that car passengers depend on other people or agents for their mode choice, thus they cannot switch modes themselves. This assumption is made due to limited data in the origin-destination survey, where respondents declare their travel companions in their daily activities. Consequently, this mode remains constant during simulation. Finally, the study primarily focuses on intra-metropolitan travel and therefore does not include trips originating from outside the Quebec City metropolitan area. However, it's worth noting that many outer city trips via the Transcanadienne highways (20) cross the river to Levis, which are excluded from our study. Nonetheless, the study's results offer an interesting comparative overview from a static perspective.

7 References

Anas, A., & Chang, H. (2023). Productivity benefits of urban transportation megaprojects: A general equilibrium analysis of «Grand Paris Express». *Transportation Research Part B: Methodological*, *174*. https://doi.org/10.1016/j.trb.2023.03.006

Auld, J., Hope, M., Ley, H., Sokolov, V., Xu, B., & Zhang, K. (2016). POLARIS: Agent-based modeling framework development and implementation for integrated travel demand and network and operations simulations. *Transportation Research Part C: Emerging Technologies*, *64*, 101–116.

Axhausen, K. W., & Gärling, T. (1992). Activity-based approaches to travel analysis: conceptual frameworks, models, and research problems. *Transport Reviews*, *12*(4), 323–341.

Balac, M., & Horl, S. (2021). Simulation of intermodal shared mobility in the San Francisco Bay Area using MATSim. *2021 IEEE International Intelligent Transportation Systems Conference (ITSC)*, 3278–3283. https://doi.org/10.1109/ITSC48978.2021.9564851

Ballmer, M. ;, Horni, A. ;, Charypar, D. ;, Meister, K. ;, Ciari, F. ;, Axhausen, K. W., Balmer, M., Horni, A., Charypar, D., Meister, K., & Ciari, F. (2009). *Wirkungen der Westumfahrung Zürich Analyse mit einer agentenbasierten Mikrosimulation Schlussbericht Wirkungen der Westumfahrung Zürich: Analyse mit einer agentenbasierten Mikrosimulation*. https://doi.org/10.3929/ethz-a-005763454

Balmer, M. (2009). Case Studies and Analysis with MATSim. *1st MATSim Users' Group Meeting*.

Balmer, M., Meister, K., Rieser, M., Nagel, K., & Axhausen, K. W. (2008). Agent-based simulation of travel demand: Structure and computational performance of MATSim-T. *Arbeitsberichte Verkehrs-Und Raumplanung*, *504*.

Bastarianto, F. F., Hancock, T. O., Choudhury, C. F., & Manley, E. (2023). Agent-based models in urban transportation: review, challenges, and opportunities. *European Transport Research Review*, *15*(1), 19. https://doi.org/10.1186/s12544-023-00590-5

Baum-Snow, N. (2007). Did highways cause suburbanization? *The Quarterly Journal of Economics*, *122*(2), 775–805.

Bierlaire, M. (2018). Biogeme. *Ecole Polytechnique Fédérale, Suiza*.

Bösch, P. M., & Ciari, F. (2015). A Multi-Modal Network for MATSim. *15th Swiss Transport Research Conference*.

Bouillaut, L., François, O., Putallaz, Y., Granier, C., & Cieux, C. (2020). A hybrid approach for the evaluation of rail monitoring and maintenance strategies for the grand paris express new metro. *International Journal of Performability Engineering*, *16*(11). https://doi.org/10.23940/ijpe.20.11.p1.16851697

Castle, C. J. E., & Crooks, A. T. (2006). Principles and concepts of agent-based modelling for developing geographical simulations. *CASA Working Paper Series*, *110*(0).

Chen, B., & Cheng, H. H. (2010). A review of the applications of agent technology in traffic and transportation systems. In *IEEE Transactions on Intelligent Transportation Systems* (Vol. 11, Issue 2). https://doi.org/10.1109/TITS.2010.2048313

Chouaki, T., Hörl, S., & Puchinger, J. (2022). *Agent-based simulation of future mobility systems in the Paris area-MATSim User Meeting 2022*.

Disler, K. (2009). Westumfahrung zürich und die n4 konaueramt: tunnellüftungsanlagen. *Felsbau Magazin*, *4*.

Downs, A. (1962). The law of peak-hour expressway congestion. *Traffic Quarterly*, *16*(3).

Dubé, J., Aubry, G., Beaudoin, C., Carrier-Morissette, A., Fecteau, J., & Herbuvaux, A. (n.d.). *I TA I R E*.

Dubé, J., Aubry, G., Beaudoin, C., Carrier-Morissette, A., Fecteau, J., & Herbuvaux, A. (2021). Vers une utilisation accrue du transport en commun à Québec ? Analyse des impacts de scénarios pour les personnes fréquentant le campus universitaire. *Canadian Journal of Regional Science*, *42*(2), 140–153. https://doi.org/10.7202/1083623ar

Dubé, J., Mercier, J., & Scanu, E. (2021). *Comment survivre aux controverses sur le transport à Québec?* Septentrion.

Duranton, G., Morrow, P. M., & Turner, M. A. (2014). Roads and Trade: Evidence from the US. *The Review of Economic Studies*, *81*(2), 681–724. https://doi.org/10.1093/restud/rdt039

Duranton, G., & Turner, M. A. (2011). The Fundamental Law of Road Congestion: Evidence from US Cities. *American Economic Review*, *101*(6), 2616–2652. https://doi.org/10.1257/aer.101.6.2616

Egal, E. (2023). New elements on the lithostratigraphy of the Paris Eocene series based on the observation of hundreds of core drillings (Eole and Grand Paris Express projects). *Geologie de La France*, *2023*(1).

Gall, T., Chouaki, T., Yannou, B., Vallet, F., Gall, T., Chouaki, T., Yannou, B., & Vallet, F. (2023). *Un cadre basé sur les scénarios du futur au service de la simulation multi-agents de la mobilité urbaine de demain*. https://hal.science/hal-04012211

Graham-Rowe, E., Skippon, S., Gardner, B., & Abraham, C. (2011). Can we reduce car use and, if so, how? A review of available evidence. *Transportation Research Part A: Policy and Practice*, *45*(5). https://doi.org/10.1016/j.tra.2011.02.001

Hermellin, E., Michel, F., & Ferber, J. (2015). État de l'art sur les simulations multi-agents et le GPGPU: Évolution et perspectives de recherches. *Revue d'Intelligence Artificielle*, *29*(3–4). https://doi.org/10.3166/RIA.29.425-451

Hörl, S., & Balac, M. (2021). Introducing the eqasim pipeline: From raw data to agent-based transport simulation. *Procedia Computer Science*, *184*, 712–719.

Hörl, S., Balać, M., & Axhausen, K. W. (2019). Pairing discrete mode choice models and agent-based transport simulation with MATSim. *2019 TRB Annual Meeting Online*, 19–2409.

Horni, A., Nagel, K., & Axhausen, K. W. (2016). Introducing matsim. In *The multi-agent transport simulation MATSim* (pp. 3–7). Ubiquity Press.

Huang, J., Cui, Y., Zhang, L., Tong, W., Shi, Y., & Liu, Z. (2022). An Overview of Agent-Based Models for Transport Simulation and Analysis. In *Journal of Advanced Transportation* (Vol. 2022). https://doi.org/10.1155/2022/1252534

La Presse Canadienne. (2022, December 5). Pont-tunnel Louis-Hippolyte-La Fontaine: bilan mensuel positif du gouvernement. *La Presse Canadienne*.

Lee, K. S., Eom, J. K., & Moon, D.-S. (2014). Applications of TRANSIMS in transportation: A literature review. *Procedia Computer Science, 32,* 769–773.

Lu, Y., Adnan, M., Basak, K., Pereira, F. C., Carrion, C., Saber, V. H., Loganathan, H., & Ben-Akiva, M. E. (2015). Simmobility mid-term simulator: A state of the art integrated agent based demand and supply model. *94th Annual Meeting of the Transportation Research Board, Washington, DC*.

Mann, A. (2014). *What's Up With That: Building Bigger Roads Actually Makes Traffic Worse*.

Manski, C. F. (1977). The structure of random utility models. *Theory and Decision*, *8*(3), 229.

Mattes, H. N., Braun, H. M., & Amstad, C. (2007). Unterirdische Autobahnabzweige der Westumfahrung Zürich. *Felsbau, 25*(5).

McFadden, D. (1978). Estimation techniques for the elasticity of substitution and other production parameters. In *Contributions to Economic Analysis* (Vol. 2, pp. 73–123). Elsevier.

Meister, K., Balmer, M., Ciari, F., Horni, A., Rieser, M., Waraich, R. a, & Axhausen, K. W. (2010). Large-Scale Agent-Based Travel Demand Optimization Applied to Switzerland , Including Mode Choice. *12th World Conference on Transportation Research, 11 - 15 July 2010, Lisbon, Portugal*, *1*.

Nagel, K. (1997). TRANSIMS traffic flow characteristics. In *PREPRINT October* (Vol. 26, Issue 1).

Nagel, K., & Axhausen, K. W. (2016). Some History of MATSim. In *The Multi-Agent Transport Simulation MATSim*. https://doi.org/10.5334/baw.46

Nagel, K., & Rickert, M. (2001). Parallel implementation of the TRANSIMS micro-simulation. *Parallel Computing*, *27*(12). https://doi.org/10.1016/S0167-8191(01)00106-5

Nagel, K., & Schneckenberg, M. (1992). Nagel, Schreckenberg 1992 2221. *Journal de Physique I*, *2*(12).

Pereira, A. M., Dingil, A. E., Přibyl, O., Myška, V., Vorel, J., & Kříž, M. (2022). An Advanced Travel Demand Synthesis Process for Creating a MATSim Activity Model: The Case of Ústí nad Labem. *Applied Sciences*, *12*(19), 10032. https://doi.org/10.3390/app121910032

Russell, S., Norvig, P., & Intelligence, A. (1995). A modern approach. *Artificial Intelligence. Prentice-Hall, Egnlewood Cliffs, 25*(27), 79–80.

Sanford Bernhardt, K. . (2007). Agent-Based Modeling in Transportation. *Transportation Research Circular*, *E-C113*(January).

Sanford Bernhardt, K. L., & McNeil, S. (2008). Agent-Based Modeling: Approach for Improving Infrastructure Management. *Journal of Infrastructure Systems*, *14*(3). https://doi.org/10.1061/(asce)1076-0342(2008)14:3(253)

Sauter, D., Kunz, M., Eggenschwiler, E., & Lang, M. (2014). Wirkungsanalyse Flankierende Massnahmen Westumfahrung: Fuss- und Veloverkehr. In *Schlussbericht*.

Schneider, B. (2018). CityLab University: Induced Demand. *Bloomberg CityLab*.

Schnittger, S., & Wittowsky, D. (2002). *mobiTopp–ein verhaltensorientiertes Verkehrsplanungsinstrumentarium, Tagungsband Heureka 02, Optimierung in Verkehr und Transport*. FGSV Verlag GmbH, Köln, or: http://inst. ifv. uni-karlsruhe. de/dl/Report ….

Sheikh, S. (2018). *Evaluation of the Impact on Land Use and Transport Flows with the Construction of second Stammstrecke in Munich*. www.msm.bgu.tum.de

Simard, M. (n.d.). *ESPACE LIBRE Québec et ses dilemmes urbanistiques : les enseignements du terrain et des débats médiatiques*.

Smith, L., Beckman, R., & Baggerly, K. (1995). *TRANSIMS: Transportation analysis and simulation system*. Los Alamos National Lab.(LANL), Los Alamos, NM (United States).

Speck, J. (2018). Understand Induced Demand. In *Walkable City Rules* (pp. 64–65). Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-899-2_27

Tennøy, A., Tønnesen, A., & Gundersen, F. (2019). Effects of urban road capacity expansion – Experiences from two Norwegian cases. *Transportation Research Part D: Transport and Environment*, *69*. https://doi.org/10.1016/j.trd.2019.01.024

Thompson, V. A. (1977). *Modern organization* (Vol. 12). University of Alabama Press.

Turing, A. M., & Haugeland, J. (1950). Computing machinery and intelligence. *The Turing Test: Verbal Behavior as the Hallmark of Intelligence*, 29–56.

W Axhausen, K., Horni, A., & Nagel, K. (2016). *The multi-agent transport simulation MATSim*. Ubiquity Press.

Walker, J., & Ben-Akiva, M. (2002). G eneralized random utility model. In *Mathematical Social Sciences* (Vol. 43). www.elsevier.com/locate/econbase