Impact of Built Environment on Urban Mobility: A Case Study of Quebec City's Urban Development and Transport Policy Plan

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Introduction

The relationship between the built environment and transport has been the focus of research since the mid-20th century (*1*). Urban planning strategies, especially those focused on land use, play a pivotal role in achieving desirable transport outcomes, such as reducing car use and promoting public transport (*2*, *3*). Over the years, research has delved into various aspects, including integrated land use and transport models and the impact of land-use policies on transport demand (*4*). There have been ongoing debates about whether built environments directly influence travel behavior or if personal preferences lead individuals to choose where to live and how to travel (*5*).

Research has demonstrated that both built environment factors and personal attitudes influence travel behavior (*6*, *7*). A substantial body of research has examined the complex interrelationships between spatial planning, urban development, and transport to elucidate the impact of urban form on urban mobility. However, those studies frequently encounter difficulties in accurately capturing the relationship between the built environment and mobility behavior at the micro-individual level due to challenges related to interaction and integrity (*8*). To address this, the present study introduces variables that account for both land use and the spatial distribution of economic activities at the micro-individual level using Multi-Agent Transport Simulation (MATSim) (*9*).

This study proposes a Discrete Choice Model (DCM) to predict individual travel behavior, incorporating attitudes and spatial attributes as key factors. To this end, a large-scale origin-destination survey is applied. The developed DCM is then integrated with a MATSim model to simulate the influences of urban development plans in Quebec City at the individual level. This approach enables a more nuanced understanding of how individuals'-built environment influences their mode choices by estimating spatial parameters at both local and individual levels. The objective of the present study is to utilize simulations based on various urban development and transport policy proposals to identify the influence of the built environment on mobility behaviors in a North American city (i.e., Quebec City, Canada).

Methods

The current study utilizes MATSim (*10*) , a multi-agent modeling tool, to investigate the evolution of modal choices in the context of urban development plans and infrastructure. The MATSim model optimizes the movements of agents by simulating various iterations and considering the decisions of other agents. The objective is to ascertain a scenario that optimizes the individual utility of all agents. The simulations conducted with MATSim adhere to three distinct phases (see Figure 1).

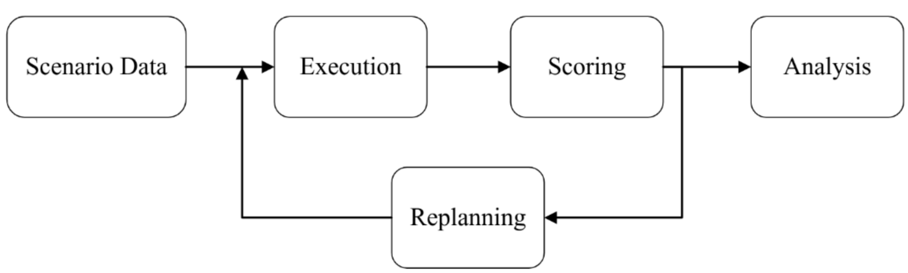

Figure 1: Structure of the simulation in MATSim (*14*)

First, the mobility simulation is executed. Second, the transport utilities are evaluated, and an overall score is calculated. Third, the behavior is replanned and optimized to achieve the greatest overall utility. A critical component of our analysis involves the incorporation of the Eqasim module (*11*), a sophisticated instrument that employs a DCM (*12*) during the replanning phase of MATSim, thereby associating utility with individual and spatial attributes. (Figure 2)

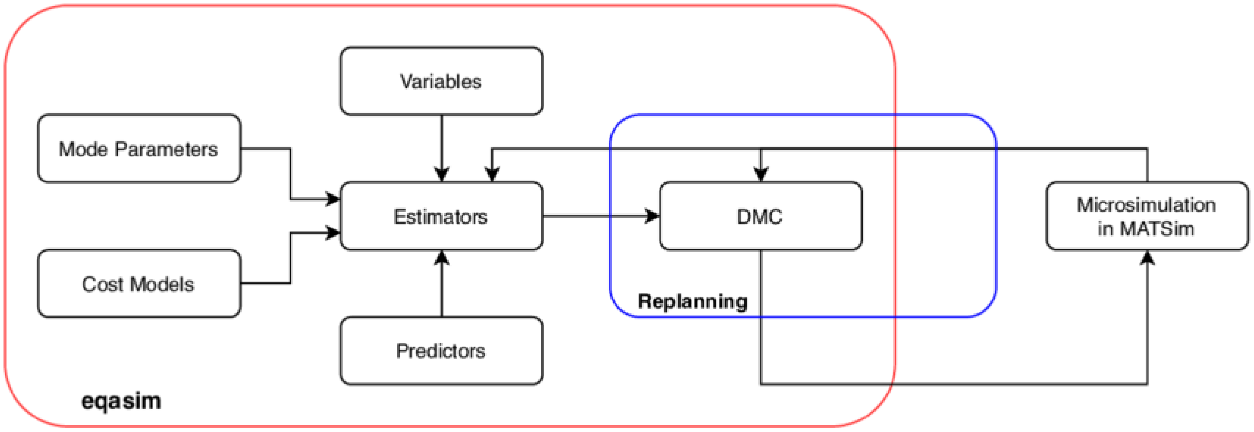

Figure 2: Structure of Eqasim in the replanning phase of simulation (*11*)

Figure 2 shows the core components of Eqasim, which establish a cohesive framework for the exhaustive examination of mobility options within MATSim simulations. These components include variables representing individuals, transport alternatives, and the spatial attributes of origins and destinations. Parameters enable customization of choices, while predictors calculate travel times. Finally, estimators assess the utility of each mode alternative. The final decision on mode choice is related to a utility equation computed based on a multinomial logit model (*13*).

At the core of the Eqasim framework, our objective is to demonstrate the impact of the built environment at the origin and destination on transport mode preferences incorporating the spatial variables. These variables consider a range of elements, from residential and commercial density to building environment diversity, as outlined by (*15*). Equation 1 illustrates the complex interplay between individual attributes, spatial variables, and their impact on a person's preference for different transport options within their immediate environment.

$$U_{ij} = \sum_{j=1}^{J} \alpha_j + \sum_{k=1}^{K} \beta_k \,.X_{ik} + \sum_{r=o\,,d} \quad \delta_r \,.D_{ir} + \quad \zeta_r \,.H_{ir} \qquad \alpha_1 = 0 \qquad 1)$$

In this equation, α_j represents mode-specific constants, capturing the inherent preference or bias toward each transport mode not explained by other variables. The term X_{ik} includes individual and trip-specific characteristics, such as travel time, age, income level, and employment status, each weighted by coefficients β_k , which measure their influence on utility. the variable X_{ik} in Equation (1) refers exclusively to individual or trip-level attributes and should not be confused with the variables used in the diversity calculation.

The final component of the equation incorporates spatial variables: D_{ir} denotes the density of the built environment (e.g., residential or employment density) at the origin or destination r, and H_{ir} represents the diversity of economic activities at those locations, calculated using the Herfindahl-Hirschman Index (HHI). These spatial variables are weighted by coefficients δ_r and ζ_r, respectively, to capture their influence on mode preference in both the origin and destination regions. The diversity measure H_r is computed using the HHI, defined in Equation (2) as**:**(*15*)

$$H_r = \sum_{s=1}^{S} p_{sr}^2 \quad \text{where} \quad p_{sr} = \frac{e_{sr}}{e_r} \qquad 2)$$

Here, e_{sr} denotes the economic activity in sector s within region r, and e_r is the total economic activity in that region. The index reaches its maximum when one sector dominates the entire economic landscape, indicating low diversity, and its minimum when activity is evenly distributed across sectors, signaling high diversity. Lower H_r values thus reflect a more heterogeneous and diverse economic structure.

Although Equation (1) presents the utility specification in general form, the actual model includes a comprehensive set of parameters that represent a detailed behavioral structure. This includes multiple age and income groups, employment types, non-linear travel time effects, and fine-grained density and diversity indicators at trip origins and destinations. As such, the model provides a robust basis for evaluating how individual characteristics and the built environment jointly influence transport mode selection within the MATSim-Eqasim framework.

Data

The MATSim simulation framework employs five primary XML files to represent road and public transit networks, population distribution, daily activities, and geographic locations. A synthetic population, based on the 2016 Census and 2017 origin-destination survey, reflects demographic and travel patterns in the Quebec census metropolitan area, encompassing over 540,000 individuals (focused on home-based activities) and 1,820,000 trips. Constructed using a Python pipeline (*16*), this synthetic population assigns trip locations using 2018 assessment roll data. Public transit networks are incorporated through pt2matsim integration.

Case study

The Quebec urban redevelopment project aims to create a more interconnected and sustainable environment. The primary objective is to transform the Dufferin-Montmorency Highway into an urban boulevard as part of the Samuel-De Champlain promenade development. This reorganization seeks to reconnect neighborhoods, reduce traffic, and support greening and densification. Similarly, the Laurentienne Highway, particularly the Wilfried Hamel sector, is being targeted for conversion into urban boulevards, accompanied by urban consolidation.

Results

The MATSim framework has been utilized to predict the future population and development, incorporating novel calculations of density and diversity within a 500-meter radius of each building, based on the recently devised development plan. The travel mode choice was estimated by the BIOGEME tool.

The DCM estimation results highlight several key insights across car, public transport, and walking modes. Travel time negatively impacts the likelihood of choosing walking and car modes, with a more pronounced effect for walking. Employment status is crucial, as non-working or full-time individuals are less likely to choose walking or public transport compared to students. Age also influences mode choice, with older age groups (35+) less likely to opt for walking or public transport. Higher income groups are more inclined to choose walking but less likely to choose public transport. Urban density at both origin and destination significantly increases the likelihood of choosing walking and public transport, with the highest density levels having the most substantial positive impact. Conversely, higher HHI (inversely related to diversity) decreases the likelihood of choosing public transport and walking, suggesting that areas with greater diversity may be more conducive to these modes.

This study conducts simulations under three scenarios. First, 6000 new individuals (1.5% of current population) are introduced into the target development area, adjusting home and work locations to observe the impact on travel mode choices in MATSim. Second, speed limits on the Laurentienne and Dufferin-Montmorency highways are reduced to 50 km/h, transforming them into urban boulevards to assess the effects. Third, urban development and urban boulevard scenarios are combined. Figure 3 compares mode ratios in the reference scenario and scenario 3 across different socio-demographic categories, highlighting which individuals and built environment characteristics are more likely to shift to sustainable transport modes.

Figure 3: mode ratios in reference scenario and scenario 3 across different socio-demographic categories.

Figure 3 heatmaps illustrate mode ratios among various age and income brackets, ranging from "12-19 years old" to "90+ years old" and "<$10K" to "$100K+". Mode ratios vary from 0.94 to 1.17 for age groups and 1.03 to 1.53 for income groups, indicating that urban development and population density impact travel behaviors differently across demographics. Individuals aged 38 to 55 years and higher-income households show a stronger preference for active transportation as density and diversity increase. This highlights the importance of considering demographic diversity in urban planning and policymaking, as shown in the MATSim agent-based simulation.

Conclusion

Using the MATSim framework integrated with Eqasim, the study evaluates various urban planning strategies, such as reducing speed limits, converting highways into boulevards, enhancing public transport, and introducing mixed-use spaces, to understand their effects on transportation choices. The findings highlight that middle-aged individuals with higher incomes are more inclined towards active transportation as density and diversity increase. However, it acknowledges limitations, such as the need for a relocation strategy in future developments. Future research could explore models generating new agents and incorporating job classifications to better understand the interplay between urban development and transportation planning.

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