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Examining the influence of urban form and land use on bus ridership in Montreal

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Abstract

The prevalence of sub-urban life in North American cities in the recent decades has resulted in increased private vehicle usage while reducing public transportation system usage. An oft-suggested alternative to reduce the negative externalities of the personal vehicle use is the development of an efficient public transportation system that provides equitable service and accessibility to the population as well as contributes to the reduction of air pollution and GHG emissions. The emphasis of this study is on a systems perspective where transit ridership is studied from the perspective of the transit provider, with the objective of quantifying the influence of transit system operational attributes, transportation system infrastructure attributes and built environment attributes on the disaggregate stop level boardings and alightings for the bus network in the Montreal region. A Composite Marginal Likelihood (CML) based ordered response probit (ORP) model, that simultaneously allows us to incorporate the influence of exogenous variables along and potential correlations between boardings and alightings across multiple time periods examined is employed. Our results illustrate that headway impacts ridership negatively, while the presence of public transportation around the stop has a positive and significant effect. Moreover, parks, commerces, and residential area, amongst others, impact boardings and alightings at different bus stops. The results can provide transit agencies a mechanism to study the influence of transit accessibility, transit connectivity, transit schedule alterations (to increase/reduce headway), and land-use pattern changes on ridership.

Selection and peer-review under responsibility of International Scientific Committee.

Keywords: Bus ridership; land use; boarding; alighting; ordered regression; composite marginal likelihood;

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1. Introduction

An oft suggested alternative to reduce the negative externalities of the personal vehicle use is the development of an efficient public transportation system that provides equitable service and accessibility to the population as

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well as contributes to the reduction of air pollution and GHG emissions. Not surprisingly, many urban regions are either enhancing or considering improvements to public transportation infrastructure to address the private vehicle use challenge. In this context, a number of research efforts in transportation have been focusing on promoting public transportation use. Many studies focused on gaining an understanding of the primary determinants of public transit system usage from two perspectives: (1) User perspective – What makes individuals opt for transit mode, and (2) Transit system perspective – What attributes at a system level contribute to transit usage. In the first group of studies the focus is on examining how individual level socio-demographics, transit accessibility measures, and built environment affect transit ridership choice. In the latter group, the emphasis is on a systems perspective where transit ridership is studied from the perspective of the transit provider.

The current study belongs to the latter category with the objective of quantifying the influence of transit system operational attributes (such as headway, transit accessibility indices, etc.), transportation system infrastructure attributes (such as road network characteristics, bicycle lanes, etc.) and built environment attributes (such as presence of parks, residential area, etc.) on the disaggregate stop level boardings and alightings for the bus network in the Montreal region. To be precise, the emphasis is on the quantification of the influence of various attributes on boardings and aligthings using econometric models. The results will provide transit agencies a mechanism to study the influence of transit accessibility, transit connectivity, transit schedule alterations (to increase/reduce headway), and land-use pattern changes on ridership. Further, the framework developed can be applied to predict ridership at potential new stop locations. At the same time, the ridership information at the stop level provides the transit agency an effective mechanism to predict transit bus occupancy - an important measure for vehicle fleet allotment for various lines.

2. Literature Review

Several studies examine ridership across different contexts in an attempt to link transit ridership with socioeconomic characteristics, built environment, and transit attributes. Earlier research has focused on understanding the different factors that affect transit ridership at a macro-level (region or country). Taylor et al. (2009), for example, have undertaken a country-wide study for 265 U.S. urbanized areas and concluded that transit ridership is influenced by the regional geography, the metropolitan economy, the population characteristics, and the auto/highway system characteristics. The authors have classified the factors that affect transit ridership as internal (fare, level of service) or external (income, parking policies, development, employment, fuel prices, car ownership, and density levels) variables. They have observed that external factors generally have a greater impact on ridership than internal factors.

Some studies examined the effect of trip costs, such as fares, fuel price, and parking price. The elasticity of transit ridership with respect to the fare is negative and inelastic for all transit, and even more so for bus ridership compared to other public transportation modes (Hickey, 2005; Wang and Skinner, 1984). There is also a general consensus that the elasticity of transit ridership with respect to gasoline price is positive and inelastic, especially in medium sized cities (Matson, 2008; Currie & Phung, 2007). The price of parking also affects transit ridership, where imposing a daily parking fee for commuters will significantly increase the transit patronage (Hess, 2001).

On the other hand, a distinctive body of literature focuses on the effect of transit attributes and built environment on its patronage. Most of these studies examine the station or stop features affecting ridership or station choice for the rail mode (Brown & Thompson, 2008; Debrezion, Pels, and Rietveld, 2007, 2009; Fan, Miller, and Badoe, 1993; Frank & Pivo, 1994; Sung & Oh, 2011; Wardman & Whelan, 1999; Weizhou, Shushen, and Fumin, 2009). Debrezion, Pels, and Rietveld (2009) have found that the availability of parking spaces and bicycle standing areas have a positive effect on the choice of the railway station. Brown and Thompson (2008) observed that rail ridership decline in Atlanta could be explained by the employment decentralisation, while Shoup (2008) observed that Transit Oriented Development (TOD) comprised of high commercial intensity positively affects transit ridership at the rail station. In fact, Sung and Oh (2011) have also determined that some TOD factors have a positive effect on transit ridership. They found that the most important factors affecting ridership at rail stations are land use mix, street network, urban design, and an overall pedestrian friendly area around the stations. To a lesser extent, the ridership has also been analyzed at metro stations (Chan & Miranda-Moreno, 2013; Gutiérrez, 2001; Lin & Shin, 2008). Chan and Miranda-Moreno (2013) found that commercial and governmental land uses, bus connectivity, and transfer stations are all associated with station attraction ridership during morning peak hours for metro stations. Lin & Shin (2008) observed that transfer stations affect ridership positively. Moreover, the authors found that retail and service area and walkability around the stations (sidewalk length, 4-way intersection) have positive impacts on ridership.

The relationship between bus ridership and built environment has been explored with the use of routes or route segments as the unit of analysis (Stropher, 1992; Peng, Dueker, Strathman, and Hopper, 1997). This type of analysis has certain limitations, such as unequal route lengths, representation of transit service variable, and inter-route relationship analysis. Peng, Dueker, Strathman, and Hopper (1997) suggest that although a stop level model requires more detailed data that may not have been available at the time, it may prove to be more appropriate. Few papers have analyzed ridership as a function of the urban environment at a stop level for the bus mode. Ryan and Frank (2009) have studied the influence of pedestrian environments on bus ridership. The authors found that the built environment, specifically the walkability of an area, is a useful tool for predicting transit ridership at a bus stop level. However, they examined total ridership (no distinction between boarding and alighting) and only consider a limited amount of built environment variables. Johnson (2003) also examined ridership at a bus stop level using an ordinary least squares regression, finding that land-use and density have the most important impacts on ridership. More specifically, it was found that multifamily residence, mixed-use, and retail-commercial land uses affect bus boardings. This study focuses its analysis solely on boardings at bus stops, neglecting any possible interactions with the alightings. Moreover, Chu (2004) noted that the presence of bus or trolley stops around a particular bus stop exerts a positive effect on ridership using a standard poisson regression. Finally, Estupiñán and Rodríguez (2008) explored the effect of the built environment on boardings at Bus Rapid Transit (BRT) stations in Bogotá while accounting for the simultaneity of transit demand and supply. The authors highlight the importance of urban environmental interventions to support transit use.

2.1. Current Study in Context

There is emerging recognition on quantifying the influence of built environment, transit and transport infrastructure on transit usage. However, a majority of the studies exploring this relationship focus on the rail or metro mode (as described above). The analysis for the rail and metro modes are computationally less intensive as the number of stations rarely amount to more than 50. The focus of this paper is to examine this relationship specifically for the bus mode, at the bus stop level. In our empirical context, we focus our evaluation on a transit stop system of about 8000 stops.

A number of studies explored the association between built environment and bus ridership, but have either considered daily ridership as a sum of boardings and alightings or have only explored boardings (Chu, 2004; Estupiñán & Rodríguez, 2008; Johnson, 2003; Ryan & Frank, 2009). The analysis is adequate for an overall picture of transit ridership in the region but is inadequate to comprehensively examine the influence of various attributes highlighted earlier. Moreover, to draw any conclusions on vehicle fleet decisions a daily ridership measure is inadequate. Of course, incorporating the stop level boardings and alightings along various time periods provides us with unique challenges of its own. For instance, the consideration of four time periods for boardings and alightings result in eight dependent variables for each stop. It is important not only to consider different time periods in the analysis, but also to assess the possible unobserved interactions between them. The dependent variables are all reported for the same stop and hence are likely to be affected by common unobserved factors. Our analysis quantifies the dependencies between the eight dependent variables using an innovative

Composite Marginal Likelihood (CML) method that has recently been employed in transportation literature (Ferdous, Eluru, Bhat, Meloni, 2010; Seraj, Sidharthan, Bhat, Pendyala, and Goulias, 2012; Sidharthan, Bhat, Pendyala, and Goulias, 2011). In summary, the main contributions advances transit literature by are: (1) considering temporal dimension (categorized as am peak, pm peak, off peak day, and off peak night) (2) differentiating between boarding and alighting (3) examining of the interactions between boarding and alighting with a comprehensive set of exogenous variables and (4) incorporating potential unobserved correlation across the stop level dependent variables.

3. Data

Montreal is the second most populous metropolitan region in Canada with 3.7 million residents. According to the 2008 Montreal origin-destination (OD) survey (AMT, 2008), 67.8% of trips are undertaken by car, 21.4% by public transit, and 10.8% by active transportation (walking and bicycling). On average, residents of Montreal make 203 transit trips annually as opposed to 141, for major American cities. Its relatively high share of transit ridership (for a North American city) can be attributed to its multimodal transit system, including bus, metro, and commuter train. There are 4 metro lines, 5 commuter train lines, and over 200 bus lines, managed by different travel agencies. The Société de transport de Montreal (STM), which serves bus and metro on the Island of Montreal, has reached a high record of transit ridership in 2011 with 405 million trips, exceeding the previous record of the year 1945 (STM, 2011). In the last 15 years, the transit patronage (bus, metro, train) has increased by over 25% for the Montreal Metropolitan Region.

The data employed in this study is drawn from data collected by the STM. Approximately 15% of STM bus fleet is equipped with infrastructure that counts boardings and alightings with specific information, such as the location, time of day, and bus number. The sampling procedure allows us to obtain an accurate average of ridership for each bus stop across the Island for a typical weekday. The STM has also provided data on bus frequency for each bus stop for all time periods.

The original data has been processed in order to generate total ridership for each bus stop, for each time period. The dependent variable data compiled for the purpose of this analysis consists of bus boarding and alighting for different time periods for about 8000 bus stations across the Island of Montreal. The time periods considered in our analysis (as limited by data collection approach) are the am peak (6:30 – 9:30), pm peak (15:30 – 18:30), off peak day (9:30 – 15:30), and off peak night/morning (18:30 – 6:30). The average boarding and alighting numbers per bus stop for the entire day amount to 110. The corresponding values for various time periods are: (1) am peak period – 28, (2) off peak day – 35, (3) pm peak period – 28 and (4) off peak night – 20. Across the 8000 stops the ridership varies significantly from 0 to 8000 riders. To accommodate for the large variability in boarding and alighting at the stops, we categorize the various stops into three groups – low, medium, and high ridership. The demand profile for the stops in the three groups is expected to be very different and warrant group specific analysis. The thresholds for the low, medium, and high groups are less than 50, 50 – 250, and more than 250 respectively (boarding + alighting for 24 hours). The finalized groups have the largest sample of stops in the low category (3574), and the lowest sample of stops in the high category (1813).

3.1. Variables Considered

The analysis quantifies the influence of various exogenous factors including *stop level transit operational variables* (average headway for time period, number of lines passing through the stop, night bus passes through stop), *public transit accessibility indices* (number of bus/metro/train stops around each stop, length of bus/metro/train lines, length of exclusive bus lanes), *transportation infrastructure attributes* (road length by functional classification, bike lane lengths, distance to central business district, (CBD), and *stop level land use measures* (number of parks and their areas, residential area, number of commerces and their area, government and institutional area, resource and industrial area, employment density, walkscore). The attributes highlighted are computed for various buffer sizes (200m, 400m, 600m, 800m, 1000m) and for Traffic Analysis Zones (TAZ) drawn around the bus stop using Geographic Information Systems (GIS).

3.2. Summary Statistics

A large variance exists between average boarding and alighting for the different stop categories and time periods, confirming the necessity to analyze them separately. Naturally, more lines pass through high ridership stops than medium or low, on average. Moreover, average headway for a time period varies from 10 minutes to 100 minutes, where peak periods and high ridership stops have lower headway. The number of bus stops and metro stations in different buffer sizes consistently decrease from higher ridership to lower ridership stops. Naturally, the total length of bus routes in a 600 meter buffer around the stops decreases from the higher to the lower ridership categories, but the opposite can be observed for the same variable at a TAZ level. The explanation is quite simple: TAZ size varies throughout the Island of Montreal, where larger TAZs are generally located far from the city center, where higher ridership exists. The bus route length will be higher in the larger TAZs not because of demand and ridership, but rather because of the area analyzed. The same logic applies to train line length in TAZ, while metro line length in TAZ decreases since metros are only present close to the city center. Finally, on average, high ridership stops are located in areas with more reserved bus lanes.

The length of major roads and bicycle paths around the stops decreases for lower categories, whereas length of highway remains relatively constant. The number of parks and commerce and their respective areas decrease for lower categories, while government and institutional area, residential area, park and recreation area, and resources and industrial area all increase for lower ridership stops. Once again, the size of the TAZs has a large role to play in these values.

4. Results

The analysis of bus stop level boarding and alighting is undertaken by developing a CML ordered response model of the bus stop specific boarding and alighting hourly rates by time of day. Due to considerations of space, the detailed description of the methodology is not provided in this paper. The readers are referred to Ferdous, Eluru, Bhat, Meloni, (2010) for a detailed description. The empirical analysis in the study involves estimating the effect of the built environment and urban design on ridership at a stop level using an ordered regression model. We are examining the ridership in different dimensions. First, we are analyzing three categories of stops; high, medium, and low ridership. For each of these, boardings and alightings are modeled separately. Further, each time period (am peak, pm peak, off peak day, off peak night) is considered. Therefore, we are estimating an 8 dimensional multivariate ordered logit model using the CML approach for each category (low, medium and high). The final specification was based on a systematic process of removing statistically insignificant variables. For the sake of brevity, we have focused on the results of the high category of stops. The results for the medium and low category are available with the authors.

Prior to examining the high ridership category in more detail, some general trends that appear throughout the models will be discussed. First, we notice that in each category, the AM Boarding and PM Alighting models have similar specifications. The same applies for PM Boarding and AM Alighting. In each case, both models present similar significant variables with the comparable effects. Evidently, they capture the morning and afternoon commutes. This is along expected lines because an individual boarding at stop A near his residence in the morning is likely to alight at that same stop A in the afternoon. Tables 1 and 2 provide the final model specification for the “high” category, for which all stops have a total ridership (boarding + alighting) of more than 250 for a given day. Note that for all specifications, length variables are in kilometers, and area variables are in kilometers squared.

Table 1: Correlation Matrix for High Ridership Stops

		Boarding				Alighting			
		AM	PM	Off-Peak Day	Off-Peak Night	AM	PM	Off-Peak Day	Off-Peak Night
Boarding	AM	1	0.5974	0.7104	0.7359	-0.1602	0	-0.0949	-0.1494
	PM		1	0.8369	0.7862	0.1439	0	0	-0.0797
	Off-Peak Day			1	0.7974	0.1368	-0.0838	0.0643	-0.1264
	Off-Peak Night				1	-0.0915	-0.0711	0	-0.0663
Alighting	AM					1	0.5052	0.7046	0.5104
	PM						1	0.8549	0.8789
	Off-Peak Day							1	0.8191
	Off-Peak Night								1

4.1. Unobserved correlations across the dependent variable

Table 1 provides the correlation matrix for the eight dimensions of the high ridership stop models, where values of 0 represent an insignificant correlation effect. All the non-zero elements in the table are statistically significant at the 95% level. We notice that boardings for all time periods are positively correlated to each other (top left corner of Table 1), as are the alightings (bottom right corner of Table 1). The AM Boardings have a negative correlation with alightings for the same time period, whereas the PM Boardings and AM Alightings have the opposite relationship indicating that unobserved factors that result in an increase in boardings are likely to contribute to a reduction in alightings. Finally, the results indicate that ridership in Off Peak Day and Off Peak Night time periods also exhibit significant dependencies. These results clearly highlight the presence of dependencies across the eight dependent variables for each stop.

4.2. Transit Operating Attributes and Indices

The headway (in minutes) has a negative and very significant effect for all ridership models. In other words, stops with higher frequency, have higher ridership. The presence of public transportation around the stop has a positive and significant effect on the ridership. This holds true especially for presence of bus stops and metro stations in a 200 meter buffer, effectively showing that most high ridership stops are located in an area with substantial public transportation facilities. The number of surrounding train stations has an effect only on AM Boarding, suggesting that individuals board high ridership stops after traveling by train in their morning commute. Specifically in the context of Montreal, this most likely represents individuals boarding buses at stops near the central station, where the largest train station is located, in the CBD. Overall, these high ridership stops seem to be transfer points, close to metros and located in areas with strong public transportation facilities.

Table 2: Ordered Logit Models for High Ridership Stops

	Boarding				Alighting			
	Am peak B (t-stat)	Pm peak B (t-stat)	Off peak day B (t-stat)	Off peak night B (t-stat)	Am peak B (t-stat)	Pm peak B (t-stat)	Off peak day B (t-stat)	Off peak night B (t-stat)
- Stop level variables								
Lines through stop		0.139 (3.73)			0.17 (4.73)		0.118 (3.16)	
Night bus through stop				0.387 (4.34)				0.575 (6.45)
- Transit indices								
Bus stops in a								
200m buffer	0.083 (5.58)	0.112 (7.54)	0.08 (5.43)	0.109 (7.2)	0.043 (2.99)	0.033 (2.25)	0.047 (3.17)	0.051 (3.52)
Metro stations in a								
200m buffer	0.548 (4.28)	0.851 (6.16)	0.412 (2.53)	1.345 (9.41)	0.738 (5.88)	0.298 (2.15)	0.861 (6.61)	0.675 (5.36)
Train stations in a								
200m buffer	0.928 (3.32)							
Reserved bus lane length in								
200m buffer	0.724 (4.58)		0.653 (4.19)	0.384 (2.37)		0.796 (5.06)	0.372 (2.29)	0.394 (2.51)
Metro line length TAZ			0.474 (2.16)					
Train stations TAZ						0.327 (3.51)		
- Infrastructure								
Major roads length in a								
400m buffer		0.079 (2.63)		0.105 (2.99)	0.128 (4.33)		0.072 (1.99)	0.098 (2.8)
Hway length 800m buffer	-0.038 (-2.3)		-0.037 (-2.31)	-0.064 (-3.48)		-0.034 (-2.11)	-0.076 (-4.02)	-0.049 (-2.73)
Straight line distance to CBD								-0.019 (-2.24)
- L-U measures								
Park area in a								
200m buffer					-8.222 (-2.16)			
600m buffer	-1.378 (-2.27)					-1.279 (-2.1)		
Parks in a								
200m buffer					0.066 (2.45)			
600m buffer	0.021 (2.79)					0.022 (2.88)	0.012 (2.21)	
Commerces in a								
200m buffer		0.003 (2.67)						
600m buffer	-0.001 (-5.43)					-0.001 (-2.87)		
800m buffer			-0.001 (-3.49)					-0.001 (-3.97)
Comm. area TAZ	-1.24 (-1.94)	1.496 (2.47)	1.388 (2.23)	2.239 (3.55)		1.661 (2.67)	3.462 (5.53)	
Gov&Inst areaTAZ		1.32 (2.57)			2.612 (4.11)		0.952 (2.35)	
Residential area in the TAZ		-0.715 (-4.56)			-0.838 (-5.22)			
Reso&Ind TAZ	-0.812 (-2.64)	-0.643 (-2.09)	-1.318 (-3.9)			-0.905 (-2.98)		
Threshold 1	-0.292 (-2.47)	0.349 (2.39)	-0.006 (-0.06)	0.331 (2.78)	0.554 (3.75)	-0.644 (-5.44)	0.603 (4.11)	-0.293 (-1.93)
Threshold 2	0.886 (7.43)	1.951 (12.72)	1.287 (11.76)	1.508 (12.24)	1.713 (11.22)	0.656 (5.58)	1.911 (12.52)	0.608 (3.99)
Threshold 3	2.135 (16.45)	3.055 (18.52)	2.04 (17.43)	2.911 (21.03)	2.707 (16.69)	1.952 (15.4)	2.727 (16.91)	1.774 (11.25)

4.3. Built Environment and Infrastructure

The presence of major roads around the stop exerts a positive effect on ridership and is significant only for Off Peak Night Boarding and AM Alighting. This may be due to higher transit stops that tend to be located on major roads. The length of highways in an 800 meter buffer exerts the opposite effect, indicating that stops in the vicinity of highways are more likely to have fewer riders. Again, this effect is only significant for Off Peak Night Boarding. Finally, the further the stop is to the CBD, the fewer alightings there will be for the Off Peak Night period.

4.4. Land Use Measures

The variables capturing the presence of parks offer interesting results. The area of the parks around the stop has a significantly negative effect, whereas the number of parks exerts a contrasting effect. This suggests that ridership is likely to be higher in an area with several parks of small dimensions, as the walkability of the area would benefit from the presence of parks without constraining road areas for transit to operate. Nevertheless, the net effect is positive overall. To demonstrate this overall positive effect, the average park area in a 600 meter buffer for the "high" category is 0.086 km^2, and the average number of parks for the same buffer size is 8.41. Therefore, in the AM Boarding, the overall park effect can be calculated as $-0.632*0.086 + 0.014*8.41 = 0.0633$. There is a similar equilibrium effect between the number of commerce locations and their areas. In fact, their interaction impacts in an overall positive manner, effectively demonstrating that stops in these areas are more likely to have high ridership. Government and institutional area near the stop is likely to increase the ridership, notably for the AM Alighting time period. The presence of residential area is expected to have the opposite effect on the stops for that same time period as well as PM Boarding, illustrating the presence of the commuting pattern in which individuals alight buses in the morning and board them in the afternoon near their workplace. We observe that the employment density at the TAZ level exerts a negative effect on boardings and the opposite effect on alightings. Finally, the resources and industrial area exerts a negative effect on ridership, particularly on boarding.

5. Conclusion

In this paper, we explore the influence of urban form and land use factors affecting bus ridership at the stop level in Montreal. The main contributions of our study are: (1) consideration of the temporal dimension (categorized as am peak, pm peak, off peak day, and off peak night) in our analysis (2) explicit distinction between boarding and alighting (3) examination of the interactions between boarding and alighting for several time periods and (4) incorporation of stop level and zone level land-use variables. The study quantified the effect of the overall built environment on bus ridership. The impact of land use and urban form on bus ridership at a bus stop level in the Montreal Island were explored, using a CML ordered probit model. Transit facilities (such as presence of metro stations, bus stops, and reserved bus lanes) and the presence of parks have a positive impact on ridership, while presence of highway has a negative impact. The impact of certain land use indices (commercial area, government and institutional areas, and residential areas) is time dependent and varies with period of day.

This paper attempts what has seldom been attempted in literature: to quantify the effects of land-use and built environment on ridership at a stop level. The study is not without limitations. We recognize that capturing the effects of the urban design is a delicate process, which can occasionally provide results which are difficult to explain. Further research can be carried out to develop more comprehensive set of land use variables in order to model ridership more adequately. Moreover, an elasticity analysis could prove to be worthwhile in order to explore the policy implications from our results.

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