Direct Ridership Model of Rail Rapid Transit Systems in Canada

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A direct ridership model for Canadian rail rapid transit systems is presented. The goal of the study was to produce a ridership model to evaluate the specific context of Canadian rapid transit: no comprehensive model existed. Data were collected for Canada's five largest cities, including 342 stations with an average weekday ridership of more than 3 million passengers. Using bootstrapped ordinary least squares regression with station boardings as the dependent variable and 44 socioeconomic, built environment, and system attributes as potential explanatory variables, which were chosen after a review of the direct ridership model literature, the study yielded one model with an adjusted R^2 value of .8033. The results are similar to those of models constructed in the United States with respect to densities, land uses, and station amenities, and socioeconomic variables do not appear to be significant. The absence of socioeconomic variables in the final model indicates that planners and policy makers have significant scope to exert influence over transit use through land use planning, design, and service features.

A direct ridership model (DRM), or offline estimation, of demand for rail rapid transit systems in Canada using ordinary least squares (OLS) regression is proposed. DRMs estimate transit demand (measured as station boardings) as a function of stop amenities, catchment area factors, and transit network characteristics and aim to explain how these elements, at a local level, can influence it. DRMs utilize local variations in land use and socioeconomic characteristics at a microscopic level, variations not taken into account by traditional four-stage travel demand modeling (*1*). To date, few studies on ridership generation at the station level have included Canada's cities, and those that have, have examined only one system in each study. The overall goal of this research is to understand which local factors can influence transit ridership and the implications for policy and the planning of new rail rapid transit stations in Canada.

There is a widespread desire to increase the transit mode share in Canada from the current level of approximately 20% for work trips in the five largest metropolitan areas and to reduce the number of automobile trips into the city centers (*2–5*). Currently six of Canada's cities have some form of urban rail rapid transit, three of which also have regional rapid transit lines extending to the suburbs. Increasingly, there are calls for the expansion of existing transit infrastructure and the creation of new services, often in suburban and lower-density settings. Across Canada, four new light rail transit lines (in Kitchener–Waterloo, Ottawa, Toronto, and Vancouver), two new regional rail lines (a suburban train line in Montreal and an airport connector in Toronto), and one subway line extension (in Toronto) are currently under construction, with several others at various stages of the planning process. Providing a better understanding of what drives transit ridership in Canada's cities will help to assess the potential implications of these new projects and their potential to influence mode share. It will also provide guidance to municipal politicians and planners with the power to influence station locations and the uses of the land around them.

A number of interrelated elements are associated with transit ridership: transit supply and fares, socioeconomic factors, and the built environment. Although influencing the socioeconomic character of the population surrounding stations is largely out of the control of governments, transit system elements and land uses can be altered to generate ridership. In fact, there is evidence to suggest that the built environment and factors outside the control of transit agencies may play a larger role in encouraging transit ridership than simply increasing supply or reducing fares (*6*). Through a review of the DRM and travel demand literature, a set of variables was selected to represent these elements in five Canadian cities (Montreal, Toronto, Calgary, Edmonton, and Vancouver) using ridership figures and data from 3 years close to the time of writing: 2006, 2011, and 2012. These data will be used to analyze which factors explain the station-level variation in ridership across Canada.

LITERATURE REVIEW

The question of what generates demand for travel continues to be a major motivation for research on transport. Researchers have examined links between travel behavior and the built environment, socioeconomic characteristics, and transport network attributes through measurements of vehicle miles traveled, station boardings, mode choice, and frequency of walking trips, among others (*7*). The built environment affects travel decision making (*7*) and land use planning that incorporates the five Ds (density, diversity, design, destination accessibility, and distance to transit) can encourage nonautomobile travel (*8, 9*). There is also evidence to suggest that internal factors under the control of transit agencies (e.g., fares, service quality and quantity, integration) also influence ridership (*10, 11*). Finally, socioeconomic factors (e.g., race, income, and age) also influence travel decision making and are thus used as control variables in studies seeking to identify the influence of transit system factors and land use factors (*7*).

DRMs are methodological tools that have grown in popularity owing to their ease of implementation and interpretation of results. Fundamentally, DRMs estimate ridership, typically measured at the station, line, or system level, and are frequently used in the assessment of transit infrastructure proposals and in investigations of the

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effects of built form, station amenities, and service supply on transit use. Eighteen DRMs were surveyed for this study: 11 from the United States, 2 from Spain, and 1 each from Canada, Colombia, Mexico, South Korea, and Taiwan. Some studies examine only one form of transit (*1, 12–22*), whereas others combine several (*23–27*); they cover bus, bus rapid transit (BRT), trolley, light rail, heavy rail, and subway systems. The majority employ OLS regression and others use two-stage least squares, geographically weighted regression, and structural equation modeling. The diversity of locations, methods used, types of transit, and variables considered in the models have resulted in a range of potentially significant factors. In order to simplify the large number of variables used in other studies and considered in this one, four categories are used: socioeconomics, station attributes, service attributes, and neighborhood urban form and street network.

Socioeconomics

The majority of reviewed DRMs found associations between socioeconomic variables and transit usage. These variables have been tested in other contexts and have been shown to exert an influence on ridership (*13–15, 18, 20, 22, 24–29*). It is assumed that as income decreases and the number of renters and unemployment rise transit ridership will increase. The wide range of variables tested in the models and likely high collinearity among them makes it difficult to isolate one or even several factors. What were generally found to be significant predictors in DRMs were income, economic status [e.g., population below the poverty line (*26*)], employment rates, housing tenure, and car ownership. Several studies in the United States found significant relationships between variables representing ethnicity (or race) and transit use (*15, 24, 26, 27*), whereas those conducted elsewhere did not find these factors to be significant. Several studies found negative associations between income and transit ridership (*13, 15, 26–28*), whereas the inverse was true for unemployment (*18, 24*). Car ownership was shown to influence transit ridership in both DRMs (*14, 15, 20, 22, 24, 26, 28*) and the travel demand literature (*6, 11, 30*). Finally, age groups in a station area were found to influence boardings, with higher proportions of youth and seniors positively related to ridership (*15, 22, 26, 27*). Again, it is likely that these variables exhibit a high degree of collinearity and are effectively tied to the price of travel. These effects may also vary depending on location owing to better transit service and attitudes toward transit use (*10*).

Station Attributes

Small-scale station features such as shelters, cleanliness, safety, and information displays were often not included in DRMs and other ridership models because of the difficulty of data collection. Nevertheless, service quality factors are likely to play a role in generating transit demand (*10, 31*). Estupiñán and Rodriguez used a pedestrian environment audit and found that immediate station-area amenities that support walking had a strong positive impact on BRT boardings in Bogotá, Colombia (*18*). One station attribute that is easier to measure is parking supply, which was found to be positively associated with ridership in several DRMs (*1, 14, 19, 25, 26, 32*). Driving is the most important access mode for regional or suburban rail transit in North American metropolitan areas. In Montreal and Toronto, Canada, driving accounts for approximately 60% of the access mode share to regional rail stations, although the total ridership at these stations is low in comparison with stations with little parking but a densely built-up area and frequent all day-service (*3, 33*).

Also included in station attributes are network location factors such as whether or not it is a transfer, terminal, intermodal, or central business district (CBD) station as well as the distance to the CBD and the bus connections serving the station. Transfer, terminal, intermodal, and CBD stations are often, by virtue of their position on a network, special attractors for ridership and have been associated with increased boardings (*1, 13, 14, 17, 19, 21, 26, 28, 32*). Distance to the CBD, or average travel time to the downtown, is also linked to transit use likely as a result of greater differences in travel times between automobiles as distance from the center of the city increases. Like parking, bus connections often serve as an important means of access for rail rapid transit users. Intermodal access variables appear frequently in the DRMs surveyed for this study (*1, 12, 14, 16, 17, 19, 21, 25, 27, 28, 32*); in Montreal, surface transit accounts for 46% of access mode share for the urban metro system and 12% for the Agence Métropolitaine de Transport regional rail system (*3*).

Service Attributes

Researchers have examined the relative effect of increasing transit capacity or supply and have found that supply is positively associated with ridership (*24, 34, 35*). In a single-equation approach to estimating demand, service supply is potentially endogenous and as a result violates the endogeneity assumption of OLS regression. A violation of this assumption is likely to bias the estimates of the model. Chu outlines three alternatives when the potential for endogeneity in ridership models is evaluated: (*a*) estimate a reduced-form model without the endogenous variable, (*b*) account for the endogenous problem within the model, or (*c*) include the endogenous variable and ignore the problem (*27*). Among the DRM studies surveyed, some, such as the ones by Estupiñán and Rodriguez (*18*) and by Taylor et al. (*24*), explicitly account for the nature of this relationship through the use of two-stage least squares, where supply and demand are estimated in a system of equations. Others use supply (*12*) or average headways (*26, 32*) directly in a single regression equation, whereas still others forgo the use of supply variables altogether. Whether supply variables are estimated directly or in a separate equation, it is generally found that they increase ridership, likely by making service more convenient and accessible. In the United States, both Lane et al. (*25*) and Taylor et al. (*24*) find that fares are significantly negatively associated with transit ridership.

In Canada, Kohn demonstrated that revenue vehicle hours, a measure of transit supply, was positively associated with transit ridership in the period from 1992 to 1998; data from 85 transit agencies across the country were used (*23*). Other research also points to this relationship and the potential for increased supply to increase ridership (*24, 34, 35*). Transit supply, however, is likely to have a reciprocal relationship with transit demand; this factor makes estimates of its effects difficult to discern. Kohn also found that another internal factor, fares, was negatively associated with ridership in Canada (*23*). Overall, however, this effect is small, and he concluded that demand for transit in Canada is relatively inelastic to changes in price.

Neighborhood Urban Form and Street Network

The set of variables for urban form and the street network includes the elements that elected officials and land use planners at the local level can influence through regulatory tools such as land use zoning or street design. Dense, mixed-use neighborhoods with permeable street networks should encourage the use of transit by facilitating access to stations and providing destinations. Transit-oriented neighborhoods are associated with higher rates of transit trip making (*7–9*) as are mixed land use and street network variables with transit ridership (*15, 18, 19, 26, 28*). Active modes of transport make up a large proportion of station access mode share, especially for urban systems, for example, 46% for Montreal's Metro (*3*). In the DRMs surveyed, street network characteristics and pedestrian accessibility in station catchment areas were associated with increased ridership through measures of intersection density (*28*) and the ratio of intersections to streets (*26*) as well as through the use of a composite walkability index (*26*). Positive associations between ridership and land use mix (*22, 26*), employment level (*14, 17–21, 25–27, 32*), and population density (*1, 12–14, 16, 17, 22, 24–27, 32*) indicate that density and diversity both play a role in transit use.

METHODOLOGY

Data were collected for a series of variables at the station level for 342 rail rapid transit stations in Canada in 2006 (jobs), 2011 (residents), and 2012 (station boardings, infrastructure, land use), depending on the variable. Some transfer stations were excluded because unique station boarding counts were not available; one persistent outlier (the airport station at Vancouver, British Columbia, Canada) was removed. Covering Canada's five largest cities, the systems in this study counted more than 3 million trips on an average weekday in 2012. Basic system and ridership characteristics can be found in Table 1.

Multiple regression was chosen for this study since it is the most commonly employed method for direct ridership models, and it can be used to assess the influence of a number of factors at the same time and produce intuitive and easily comparable results. Attention was paid to the basic assumptions of OLS regression: linearity, exogeneity, multicollinearity, and constant error variance. A variety of tests were conducted in order to ensure that the model and data satisfied these criteria and that corrective measures were undertaken (i.e., logarithmic transformations, corrected covariance matrices, and bootstrapping) if they did not. Model selection proceeded in a forward stepwise process that aimed to maximize the fit of the model while minimizing information loss. Akaike's information criterion was used to assess the various iterations of all models and those that scored the best (i.e., had the lowest AIC score) were chosen.

Catchment Areas

Several methods of measuring station catchment areas include fixed boundaries, either network based or circular, or without fixed boundaries through the use of geographically, or distance-decay, weighted regression (*19–21*). For this study a fixed boundary network buffer was selected. It is generally accepted that 800 m (≈½ mi) is the distance within which most walking trips to rail rapid transit occur and is an adequate representation of a person's willingness to walk to access transit, and there is some evidence to suggest that boundary size and shape have little influence on station-level predictions of transit ridership (*36*). However, El-Geneidy et al. point out, by using origin–destination survey data for Montreal, that willingness to travel on foot to access transit varies on the basis of location, personal characteristics, and service type (*37*). They find that the mean walking distances to Montreal's Metro stations are 565 m (0.35 mi) and 873 m (0.54 mi) at the 85th percentile. For suburban train stations the mean walking distances were 818 m (0.5 mi) and 1,259 m (0.78 mi) at the 85th percentile; this finding suggests that larger service areas for suburban train stations are more suitable. Therefore, for this study the 800-m (0.5-mi) catchment area for urban rapid transit stations and the 1,000-m (0.62-mi) catchment area for suburban train stations are used.

Network-based walking distances were chosen over circular buffers since network distances more accurately reflect the pedestrian accessibility of stations. In order to properly capture station accessibility a combination of DMTI Spatial's RouteLogistics road shapefiles for Canada were used and then manually edited to include missing footpaths and pedestrian access. This process was accomplished through the use of satellite imagery and the Google Maps base layer accessed through ArcGIS Version 10.2. This manual addition process resulted in the expansion of some catchment areas that the initial road network did not accurately capture. Since walking access is measured, highways were excluded from the network. Finally, a nonoverlapping buffer, or exclusive catchment area, was chosen for this analysis to prevent overlapping catchment areas. If boundaries were to overlap, certain features such as land use, amenities, and road network features might be double-counted. Boundaries were determined automatically by using the service area tool in ArcGIS. When exclusive service areas are chosen and buffers overlap, ArcGIS automatically determines the midpoint between the stations and draws the boundary.

TABLE 1 Rail Rapid Transit System Characteristics

System	Name and Type	Daily Passengers (2012)	Length	Stations (stations/km)	Average Passengers per Station
Calgary C Train	Surface and elevated LRT	210,495	49 km (30 mi)	36 (0.73)	5,847
Edmonton LRT	Surface and underground LRT	72,422	21 km (13 mi)	15 (0.71)	4,828
Montreal Metro	Underground	845,718	69 km (43 mi)	68 (0.99)	12,437
Toronto subway	Underground and surface heavy and elevated LRT	881,160	76 km (47 mi)	75 (0.99)	11,749
Vancouver SkyTrain	Elevated and underground LRT	327,625	69 km (43 mi)	47 (0.68)	6,971
Montreal AMT	Heavy railway	68,887	204 km (127 mi)	51 (0.25)	1,351
Toronto GO Train	Heavy railway	191,376	450 km (280 mi)	63 (0.14)	3,037
Vancouver West Coast Express	Heavy railway	11,309	69 km (43 mi)	8 (0.12)	1,414

NOTE: LRT = light rail transit; AMT = Agence Métropolitaine de Transport; GO = Government of Ontario.

Since the station catchment areas do not align with census tract boundaries, the number of persons, for example, is assigned proportionally depending on how much residentially zoned land of a given tract falls within the catchment area. In other words, it is assumed that population and employment are dispersed evenly in the appropriately zoned land and are then assigned proportionally to each catchment area. Although this assignment requires some estimation and inherently introduces error into the measurement, it is the best method given the scale of the census data available and the fact that it accounts for the varying land uses found within the tracts rather than assuming that population and employment are spread evenly throughout the whole tract.

TABLE 2 Variable Statistics

Variable	Mean	SD
Dependent		
log (boardings)	8.225	1.362
Socioeconomics		
Unemployed (%)	7.8	2.7
Median household income ($)	58,545	21,128
Renter households (%)	46	23
Age (years)		
20 to 30 (%)	17.3	7.6
30 to 40 (%)	15.7	5.1
40 to 50 (%)	14.4	3.1
50 to 60 (%)	13.2	3.1
60 to 70 (%)	9.0	2.5
Station attributes		
Bus connections	1.72	0.79
Park-and-ride spaces	342	597
Terminal station (1 = yes)	10.5 of stations	
Transfer station (1 = yes)	5.3 of stations	
Distance to terminus	16,006	16,095
Relative distance to terminus	0.39	0.24
Spacing	2,211	3,109
Bike parking dummy (1 = yes)	76.0% of stations	
Car share dummy (1 = yes)	20.5% of stations	
Neighborhood, street network, and land use		
Population density (/km^2)	5,260	4,374
Jobs + population density (/km^2)	23,025	43,795
Nodes	75.1	38.9
Link–node ratio	1.3	0.4
Total links	96.56	54.14
Total road length (m)	11,542	5,208
Street density (/km^2)	3,903	5.458
Average block length (m)	138	71
Intersection density (/km^2)	83.2	36.9
Open area (%)	9.0	14.2
Park area (%)	8.0	9.9
Residential area (%)	51.3	21.2
Job density (/km^2)	17,765	42,814
Dwelling density (/km^2)	2,815	2,760
Resource–industrial area (%)	18.5	18.6
Government–institutional area (%)	6.0	11.4
Commercial area (%)	3.03	6.14
Residential–nonresidential	6.8	67.2
University dummy	7.3% of stations	
CBD dummy	15.8% of stations	
Land use mix	2,009	5,277
Land use entropy	0.64	0.16
Walkability index	–0.008	2.464
Commercial site density	540	853
Service attributes		
Peak only ($)	13.5% of stations	
Pass cost ($)	129	65
Regular fare ($)	4.22	2.22

NOTE: SD = standard deviation. Can$1 = US$1.01 in December 2012.

Data Description

All the variables considered for this study can be found in Table 2. The dependent variable, average daily boardings at stations, represents unlinked trips. This variable was observed to be heavily left-skewed so it was logarithmically transformed in order to satisfy the linearity assumption of OLS regression. Two measures of residential population density (total residents/total land area and total dwellings/total land area) were used to represent the intensity of residential use of land within each station area. Similarly, one measure of employment density (total jobs/total land area) is used. In order to understand the effect the presence of different age groups in a station catchment area may have on ridership, the proportion of ages 20 to 30, 30 to 40, 40 to 50, 50 to 60, and 60 to 70 was tested. It was assumed that certain age groups were more likely to take transit and therefore a larger presence of these groups was likely to influence station demand. A number of socioeconomic variables were considered, including the percentage of renters, the median household income, and the unemployment rate within a station area.

Total nodes (or three- and four-way intersections), link-to-node ratio (total links/total nodes), total number of links (or blocks), street density (total street length/catchment area size), average block length, and intersection density were included as measures of the local street network. Land use data obtained from DMTI Spatial's RouteLogistics package include seven types of land use: open area, parkland, water, industrial and resource, government and institutional, residential, and commercial. These designations were tested as proportions of the total station catchment area and also in composite land use mix or entropy measures. The first measure, taken from work by Cervero et al. (*12*), is a mixed-use entropy index:

$$\text{entropy} = -1 \times \left(\frac{\sum_{i=1}^{k} p_i \times \ln(p_i)}{\ln(k)} \right) \tag{1}$$

where p_i is the proportion of land in use i of total of all land and k is the number of land use types considered.

The second is a land use mix variable adapted from work by Chan and Miranda-Moreno (*13*):

$$\text{mix} = \frac{\text{household density} \times \text{job density} \times \text{commercial density}}{\text{household density} + \text{job density} + \text{commercial density}} \tag{2}$$

And finally, a walkability index adapted from work by Ryan and Frank (*15*):

$$\text{walkability} = 2 \times \begin{bmatrix} Z[\text{land use mix}] \times Z[\text{residential density}] \\ \times Z[\text{commercial sites}] \\ \times Z[\text{intersection density}] \end{bmatrix} \tag{3}$$

where land use mix is the entropy measure in Equation 1 and Z is the Z-scores of the inputs.

It is assumed that more mixed-use areas are more amenable to transit ridership. This assumption is partially supported by literature on transport and land use that at least in part indicates that elements such as jobs–housing balance and mixed uses can reduce car travel and increase walking and transit trips (*7, 22, 38*).

The total number of commercial locations was chosen as a variable under the assumption that an increase in the number of potential activities in a station area may increase ridership. Data for this variable were collected from the DMTI Spatial Enhanced Points of Interest shapefile for Canada, which contains the locations of more than 1 million commercial and recreational points of interest. The total number of locations was narrowed down to retail trade, services, and public administration categories by Standard Industrial Classification code divisions.

A CBD dummy variable was tested in the models to account for the fact that downtown stations may attract more ridership by virtue of their location and the surrounding attractions and services. No clear definition of CBDs exists, so the procedure developed by Lane et al. was used (*25*). The procedure involves computing the job density of census tracts, logarithmically transforming the figure, and delimiting the CBD as contiguous tracts with job densities at least two standard deviations above the mean for the city. Stations falling within these tracts are considered to be CBD stations and are coded 1 while all outside are coded 0. A number of variables related to the transit network and the station's placement within it were also considered. Dummy variables for terminal and transfer stations were tested since these types of stations were observed to attract more ridership. A transfer station refers to a station that either serves more than one line on the same system or connects to other rapid transit systems. Other system variables tested were pass cost and basic single fare. Distance to the downtown terminus was included as was a measure of centrality similar to the one proposed by Kuby et al., where the total distance of the station to the downtown terminus is divided by the longest distance on the network to enable comparisons between systems (*14*). Station spacing was also considered and is included as a measurement of the next-closest station to account for a station's catchment outside the buffer and the fact that some catchment areas are relatively small owing to their proximity to other stations. It is expected that stations that are closer together may draw less ridership owing to competition between them.

The effect of service supply on ridership is difficult to assess since ridership and service supply are likely to be decided in conjunction with one another. The studies by Estupiñán and Rodriguez (*18*) and Taylor et al. (*24*) both attempt to control for this effect through the use of two-stage simultaneous models with instrumental variables for supply; both found that supply does indeed influence ridership even when their reciprocal relationship is considered. Ignoring this fact has the potential to bias regression estimates; therefore service supply variables were chosen with caution. One service-level variable, a peak-service-only dummy variable, was included to differentiate the small number of low-ridership stations that only have service during peak periods. Stations are accessed by three primary modes: active (walking and biking), transit, and car (driver, drop-off, or carpool), so station access variables were created to account for these ridership generators. First, the total number of buses serving the station was counted from transit agency websites, and, second, the total number of parking spaces provided by the transit agency (in park-and-ride areas) was counted. And finally, a bike parking dummy and carshare reserved space variables were included to see if they have the potential to increase ridership; these variables were collected through transit agency websites and Google Streetview.

RESULTS AND DISCUSSION

One linear model was developed for all 342 stations that showed signs of heteroscedasticity (Brausch–Pagan test score < 0.262) or nonconstant error variance, a violation of one of the main assumptions of OLS regression, which can lead to biased estimates of the explanatory strength of variables. As a result a heteroscedasticity-corrected covariance matrix (also known as the White–Huber covariance matrix) found in the "car" package for the *R* statistical analysis software was used to obtain corrected *p*- and *t*-values (*39, 40*). The model also demonstrated signs of kurtosis and skewness indicating nonnormal error distribution, another violation of an OLS assumption. In order to correct for this effect bootstrapped regression estimates were generated. Bootstrapping is a nonparametric approach that involves the random resampling of cases with replacement and does not require any distributional assumptions (*41, 42*). In other words, the bootstrapping method treats the sample as a population and samples randomly from within it a large number of times (in this case 4,000) to simulate large sample sizes (*43*). All models were also checked for multicollinearity by using the variance inflation factor and any variables with high variance inflation factor were removed from the models.

Table 3 presents the results of the complete model for all Canadian rail rapid transit stations. Bootstrapped coefficient estimates and standard errors are reported alongside an elasticity calculation and 2.5% and 97.5% confidence intervals for the result. The model fits well with an R_a^2 of 0.8033, which indicates significant positive relationships between boardings and population density, commercial site density, intersection density, bus connections, parking spaces, transfer dummy variable, and three land use variables (commercial ratio, government–institutional ratio, and residential ratio). As expected, population density is positively associated with ridership at the station level with an elasticity of 32.6%; this result means that an increase in population density of 10% would increase station boardings by 3.3%. Intersection density is positively associated with ridership, but street density has a negative effect.

Negative relationships were found between boarding and street density and the peak-only dummy. Although the negative association of street density appears counterintuitive, this result is likely a product of the use of network-based buffers. Street density in this context reflects the size and shape of station catchment areas, which are based on road network distances. In most cases this approach limits the extent of catchment areas to corridors along relatively few roadways, particularly in suburban locations where ridership is typically lower. In these cases roadways will make up a significant proportion of the catchment area. Bus connections and parking supply are, as expected, significant ridership generators with elasticities of 40.8% and 16.2%. These findings indicate that both play a significant role in delivering riders to a station but that the supply of bus service has a greater potential to increase ridership. This result may in part be mitigated by the fact that urban rapid transit stations in this sample tend to have more bus connections and higher ridership, whereas regional rail stations have more parking and lower overall boardings. In separate regressions not reported here, both variables are significant for both forms of transit, whereas their relative strength varies with parking availability, showing stronger associations with suburban train ridership and buses with urban system ridership.

The transfer dummy variable's positive association with ridership indicates that stations that offered more options for travel tended to attract more riders. The negative relationship with stations that only have peak service reflects the fact that these stations are used mainly

TABLE 3 Model Results

Model Component	Estimate	Elasticity (%)	SE	*p*-Value	Confidence Interval 2.50%	97.50%
(Intercept)	6.62728		0.15698	.00000	6.32216	6.94129
Population density	0.00006	32.61	0.00001	.00000	0.00004	0.00008
Intersection density	0.00428	35.59	0.00114	.00050	0.00211	0.00657
Street density	–0.00014	–55.43	–0.00014	.00000	–0.00016	–0.00013
Log (bus connections)	0.40885	40.88	0.05502	.00000	0.29960	0.51836
Parking spaces	0.00047	16.19	0.00007	.00000	0.00045	0.00062
Transfer dummy	0.98174	62.53	0.21333	.00001	0.57964	1.41498
Peak only	–0.48966	–63.18	0.12498	.00040	–0.76003	–0.23354
Commercial site density	0.00024	12.75	0.00005	.00000	0.00014	0.00034
Residential ratio	0.60671	32.71	0.20115	.00380	0.20826	0.99682
Commercial ratio	1.90771	5.79	0.70690	.01919	0.56382	3.31842
Government–institutional ratio	1.53726	11.00	0.50400	.01933	0.60369	2.48835

NOTE: $R^2 = .8097$; and $R_a^2 = .8033$. SE = standard deviation.

for commuting. The significance of the station spacing variable indicates that stations closer together may compete for ridership, although the magnitude of the effect is relatively small. The density of commercial sites contributes to ridership again in a small but significant way. Finally, the proportions of residential, commercial, and government and institutional land uses are all positively related to ridership. The strength of this relationship varies depending on the land use in question but reflects the theory that a mixture of land uses contributes to the use of transit.

No socioeconomic variable was found to be associated with ridership at the station level, in contrast to most of the DRM studies reviewed. The results indicate that there is the potential for transit and city planners to exert a degree of influence on transit ridership. This finding may be explained in part by differing attitudes toward transit in Canada as well as a lesser degree of racial segregation when compared with the United States. Of particular interest is the relative strength of the parking and bus connection variables, which indicate that facilitating station access can be an effective means of generating ridership. For both new and existing stations increasing transit connections and adding parking spaces are relatively straightforward means of augmenting rail transit usage. However, these options should be carefully weighed against overall objectives; although parking provision may increase boardings, it can be a costly strategy that does not generate tax revenue as transit-oriented development and also lessens the benefits associated with transit infrastructure. Park-and-ride lots are typically situated adjacent to stations occupying prime developable land. There is also evidence to suggest that reductions in vehicle kilometers traveled owing to park-and-ride facilities are overstated and a proportion of users may have been diverted from transit or active modes (*44, 45*).

The importance of built environment variables such as population and commercial site density and proportions of various land uses also indicates that gains in ridership can be achieved through promoting mixed-use developments around existing stations and ensuring density and diversity when new infrastructure is planned. The relative strength of the ratio of residential land and population density variables in conjunction with the intersection density and negative street density variables clearly indicates that both having a local user base and facilitating pedestrian access to stations are critical elements to the success of transit. The results of this analysis suggest that a number of interrelated factors contribute to the use of transit in Canada. Policies aiming to increase transit usage must then take a diverse approach that ensures density, diversity, and access.

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