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How Travel Purpose Interacts with Predictors of Individual Driving Behavior in Greater Montreal

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Abstract

Rising transport emissions represent a significant challenge for policy makers. Two principal options exist to reduce emissions: make driving less polluting or reduce driving overall. Though cities have a role to play in both approaches, the levers that may influence the latter more squarely align with municipal competences concerning the urban form. This paper aims to refine our understanding of the relationship between urban form, public transport systems, and driving behavior by exploring whether accessibility—the ease of reaching desired destinations—exerts a different influence on people's decision to drive on weekdays and total distance driven depending on travel purpose. We relied on disaggregate data from the 2013 Montreal Origin–Destination Survey and employed a two-step "hurdle" approach with multilevel logistic and linear models. We found both local and regional accessibility displayed statistically significant negative correlations with driving mode choice and vehicle distance driven by drivers. Concerning the decision to drive, regional accessibility, defined by transit-accessible jobs, appeared to possess a stronger relationship than local, as measured by Walk Score across all purposes. When considering total kilometers driven, however, the relative impact of both types of accessibility varied. Overall, and for work and school driving, regional accessibility correlated with the greatest declines in distance driven. For healthcare and discretionary travel, local accessibility correlated with a larger decline in total driving distance. Our findings also highlight the potentially profound impact of other explanatory factors, particularly car ownership, suggesting additional policy approaches for municipal decision makers to reduce vehicle kilometers traveled.

Human-induced climate change represents one of the most significant threats to cities and their residents over the short-, medium-, and long-term (*1*). In the United States, transport-related greenhouse gas emissions (GHGs) constituted 29% of total GHGs in 2017 (*2*). In Canada, transport GHGs have steadily increased since 1990 (*3*). Indeed, transport was responsible for nearly 25% of Canada's global warming emissions in 2017, ranking as the second-largest source by economic sector (*3*). Although heavy vehicles and light-duty trucks accounted for much of the increase, personal automobile travel continues to produce a significant portion of the transportation-related total (*3*). Reducing emissions from personal vehicle travel therefore represents a key challenge for combating climate change at the local and national levels.

Cities throughout Canada and across the world have begun considering options to reduce transport-related emissions. There are two principal approaches to reducing road-travel emissions. One is to reduce emissions per kilometer traveled by switching to electrical vehicles or other lower-carbon fuel sources; the other is to reduce total vehicle kilometers traveled (VKT), which yields numerous additional environmental and health-related benefits (*4*,*5*). Cities and other local policymakers possess a range of tools within their traditional municipal competencies concerning land use and transport systems to reduce the number of people who choose to drive at all (mode shifting) and the distance they travel when they do (*6*–*8*).

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Through regulations such as zoning, taxing, and spending, cities can directly and indirectly shape many of the elements of the urban form, dubbed the 5Ds: density, diversity, design, distance to transit, and destination accessibility (*9*). Accessibility sits at the intersection of these factors and remains an area of sustained interest for researchers. (*10*,*11*). In its simplest form, accessibility measures the ease of reaching opportunities (*12*). But this unassuming definition belies the conceptual power it boasts as a composite measure that unifies two important, but frequently siloed, considerations in transport planning: mobility and proximity (*13*). It also represents the cumulative interaction of four discrete factors: land use, transport, individual characteristics, and time (*10*). In effect, the modern concept of accessibility directly connects land-use patterns and transport-system characteristics. For city decision makers, then, accessibility is an especially valuable metric because it offers a wholistic and simultaneous assessment of these characteristics.

Using disaggregate travel data from Montreal, Quebec's 2013 Origin–Destination (O-D) Survey, this paper explores accessibility's relationship with driving behavior at two spatial scales: (a) local accessibility—the availability of walking-distance amenities as represented by neighborhood-level Walk Score assessments and (b) regional transit accessibility, defined here as the number of jobs that can be reached by public transit in a given time from the respondent's home census tract. Travel choices and behavior are highly idiosyncratic and influenced by a constellation of factors, including personal characteristics and the purposes for which trips are made (*14*). To address some of this variety and to support more nuanced policy recommendations, this research took the additional step of considering how local and regional accessibility may influence travel for different purposes: (a) overall travel, (b) work, (c) education, (d) healthcare, and (e) "discretionary" travel, consisting of leisure, socialization, shopping, or errands. Conceptually the travel purposes considered represent varying degrees of individual discretion concerning time and mode and were thus expected to respond differently to planning interventions aimed at promoting different types of accessibility.

Literature Review

The impact of the built form on travel behavior is among the most researched and, at times, contentious topics among planners and transport researchers. Overall, it is safe to state that the preponderance of published articles suggests that varying combinations of the 5Ds display statistically significant relationships with reductions in different measures of vehicle distance traveled (*8*,*15*,*16*). Yet, despite sustained scholarly interest, the exact nature of the relationship between the urban form and travel preferences and behavior, its causal direction, and the intensity of its impact, remains opaque and, in some cases, disputed (*5*,*8*,*17*,*18*).

As a subcomponent of the 5Ds, destination accessibility represents a major line of inquiry, in part because it serves as a valuable composite indicator, linking elements of land use and transport systems (*19*). For planners and city policy makers, it is a particularly useful concept because, depending on its application, it can help achieve broader environmental and socioeconomic outcomes (*20*). Location-based accessibility measures, which calculate opportunity tallies for specific zones, are by far the most commonly applied. Within these, two more frequently applied measures exist: cumulative opportunities and gravity (*10*,*21*). Cumulative-opportunities measures are those that tally the number of opportunities that can be reached from a given origin without exceeding a specified travel-cost threshold, commonly time, distance, or cost.

Of the researchers whose studies have examined the impact of accessibility, most have identified a statistically significant, though sometimes moderate, relationship (*5*,*22*,*23*). In the study that most directly influenced our approach for this analysis, Ewing et al. found that both car and transit accessibility measured by jobs reachable within different times are associated with decreases in household VMT (*23*). In an earlier study, Cervero and Duncan found that the relative impact of accessibility on vehicle distance traveled, as measured by elasticities, can even outweigh that of individual and household characteristics (*24*). Indeed, they found that accessibility—as measured by jobs and housing balance—reduces total travel distance more than retail balance (*24*).

Two key issues arise when looking across these studies, and these issues have implications for the direction of this and future research. First, considerable variance in household or individual vehicle distance traveled often remains unexplained in even the most robust models (*5*,*18*,*23*), as reflected by the *r*-scores obtained. Second, there is considerable variation in vehicle distance traveled outcomes across urban and individual contexts, making further research into different environments and under different conditions particularly important, as demonstrated by the broad range of explanatory variables, results, and elasticities obtained by different studies (*8*,*25*).

Data and Statistical Analysis

Trip-level mode and destination data were obtained from the 2013 edition of Montreal's O-D survey, the most recent publicly available version (*26*). Conducted every 5 years since 1970, this survey collects information from

a random sample of tens of thousands of Montreal-area households concerning travel habits over the preceding 24-h weekday period. Our analysis draws on a subset of these data representing people who made trips fully within the local and regional public transit-service areas. The use of disaggregate, person-level data allowed us to model individual choices and behavior, potentially allowing policy makers to develop more precisely targeted interventions than might be possible with models based on aggregate mode choice at the census tract or other level.

To streamline calculations, we restricted our analysis to people whose trips consisted of O-D pairs located within 100 km of the Montreal Island center as measured by road-network travel distance. Because we sought to identify the influence of individual, household, and neighborhood characteristics on driving behavior for different reasons, we discarded records with missing data concerning destinations, trip purpose, mode, or household characteristics. Finally, we focused exclusively on those people who could be reasonably classified as "potential drivers." For the purposes of this analysis, a potential driver means a licensed driver from a household with at least one car (*26*).

For each of the trip segments recorded in the survey, we classified the mode as primary driver or other. Because our primary research question focused on built-environment and transport-system determinants of (a) the decision to drive for travel at any point throughout the day and (b) the distance driven once that decision is made; a distinction between alternative modes was not considered important. To calculate driving distance, we relied on the ArcGIS Network Analyst toolbox applied to a road network downloaded using OSMnx (*27*). (This road network was downloaded in April 2019 and may therefore reflect changes not present when the 2013 O-D Survey was completed. Although historical road-network data were unavailable, the study-area network was already well-established at the time of the O-D Survey, suggesting that differences in on-network road distances are not especially significant.)

Before assigning purposes to travel, we grouped individual trip segments into home-based loops, a common definition for a trip chain. We then assigned a primary purpose to each loop from one of four categories (*28*). Trip-purpose categories included work, school, healthcare, and "discretionary," which encompasses leisure, recreation, social calls, and shopping. Based on the assumption that work, school, and, to a certain extent, healthcare have schedules and locations that are not defined wholly by the traveler, they were considered to be primary purposes in descending order of priority for any loop for which they were present (see Figure 1).

All loops lacking segments for these "mandatory" activities were classified as "discretionary." Creating loops beforehand ensured that all reported vehicle travel, including returns home, could be classified according to the trip purposes of interest. We then aggregated loop-level trip distance calculations for each individual person in the retained data set.

For our measures of local accessibility, we relied on Walk Scores for home neighborhoods (*29*). For regional accessibility, we employed a transit-based cumulative-opportunities measurement with a 45-min threshold. For the transit network, we assembled general transit feed specification (GTFS) data for all transit agencies providing service in the study area. To more closely align with conditions at the time of the O-D Survey, we used archived GTFS data from November 2013, the earliest date for which data were consistently available from all the agencies. We then calculated travel times between all census tract centroids using the ArcGIS Network Analyst extension for Transportation Analysis developed by Melinda Morang (Principal Product Engineer, Esri Network Analyst). We derived census tract jobs figures from census work flows (*30*). When calculating jobs accessibility, we established the 45-min threshold because it most closely aligns with the average transit commuting time in Montreal (*31*). To enable direct comparison of the impacts of local and regional accessibility, we normalized both using *z*-scores.

Modeling

Modeling individual VKT from our data set presented two interrelated challenges: the data are generally not

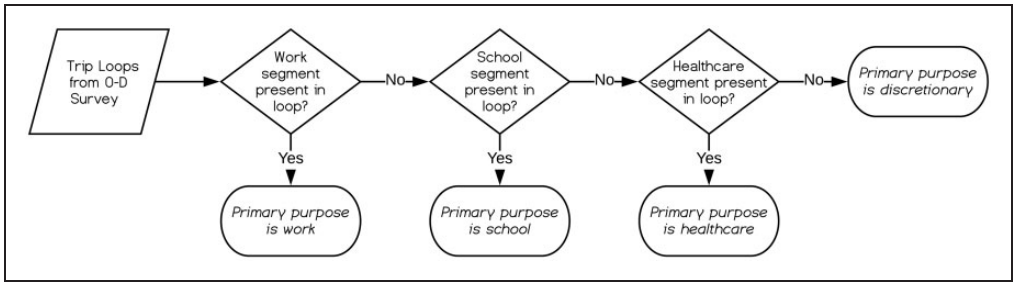

Figure 1. Assignment of primary travel loop purposes.

normally distributed, requiring a log transformation, but also contain many zero values, which cannot be directly log transformed. To address this, we employed a two-step "hurdle process" as described by Ewing et al. (*23*). In the first step, we constructed multilevel logistic regressions to explain the binary decision to drive or not using our complete data set, including all travelers whether they drove or not. Under this approach, the decision to drive for any of the studied purposes is the initial "hurdle," or criterion, for inclusion in the subsequent analysis of the determinants of driving distance. For this second step, we constructed a series of multilevel linear regression models to explain total weekday driving distance for each of the studied travel purposes together and separately. By using only the subset of observations with non-zero driving distances in this second step, we were able to directly log transform our distance-driven dependent variable. This two-step approach also mapped well with the sequential policy objectives we aimed to support through the identification of correlations between land use and transport systems and driving behavior that policy makers may potentially leverage to reduce VKT: first keep people out of cars and, when that is unlikely or impossible, figure out how to get them to drive less.

For both the logistic and linear models we first used a nested, multilevel mixed-effects approach using R statistical programming language. We nested individuals within households and households within census tracts to account for home- and neighborhood-related similarities not otherwise addressed within the model (*23*,*32*). The household level did not prove statistically significant for the binary logistic regressions and was removed in the final modeling.

We included the following independent variables for individual characteristics: age, gender, employment and student status, and possession of a driver's license. For the purposes of modeling, we organized employment status into three bins reflecting the assumed differences in the associated need to travel routinely outside the home (1: full-time employees; 2: part-time employees and students; 3: homemakers, retirees or otherwise not employed). For household characteristics, we included household income, the number of preschoolers, the number of school-age children, the number of adults, and the number of vehicles in a household.

For our neighborhood and regional characteristics, we included two measures of accessibility, which reflect different geographic scales and types of destinations. For local accessibility, we relied on a 2010 database of neighborhood-level walkability scores from Walk Score, a private company that prepares a publicly available gravity-based assessment of amenities within 1 mi of locations. For regional accessibility, we used transit-based jobs accessibility, defined as the number of jobs reachable within 45 min from the centroid of each home census tract. Initially, we sought to include vehicle-based jobs accessibility and a transit-to-car accessibility ratio, but the variables were found to be too closely correlated with transit accessibility.

When evaluating mode and distance by segmented by trip-purpose, we also included travel for other purposes as independent variables to account for possible time competition and fatigue from other travel. For example, when analyzing work-related driving travel and VKT as dependent variables, we included VKT for school, healthcare, and discretionary travel as explanatory variables.

Our modeling did not directly consider the effects of self-selection, a key component of the causal relationship between built-form and other related determinants of VKT. The use of multilevel modeling and the inclusion of socioeconomic control variables, however, can help account for some of this phenomenon's impact. Furthermore, we assumed consistent accessibility throughout the day, which has been demonstrated to serve as a reliable measure (*33*,*34*). Many trips, however, took place at different times, introducing unexplained variance into the model.

Results

Descriptive Statistics

The total number of potential drivers who traveled outside the home during the survey period numbered 59,761 for any purpose. Of these potential drivers, more than 75% reported driving at least once during the survey period (see Table 1). Among the 37,104 people who reported work travel and the 22,341 who reported discretionary travel, similar percentages reported driving for these purposes. Of the 2,453 people who traveled for healthcare, 71% drove. At the other end of the spectrum, only 38% of 4,695 school travelers drove.

Table 1. Summary of Potential and Actual Drivers Segmented by Trip Purpose

Travel type	All travelers	Drivers	Percent drivers
All types (combined)	59,761	45,011	75
Work	37,104	28,580	77
School/education	4,695	1,783	38
Healthcare	2,453	1,737	71
Discretionary (recreation, shopping, socialization, pick-ups)	22,341	16,759	75

Within the sample subset, households on average contained 2.9 people: 2.3 adults and 0.7 children (see Table 2). On average 61% of adults in each household in the retained data set reported being a full-time employee. Households averaged a car-to-driver's license ratio of nearly 1 to 1.

The average distance driven for respondents in the survey for all purposes combined was 19.6 km, including return trips. Among the disaggregated travel purposes, people who traveled for work had the highest average daily VKT at 13.8 km. School and healthcare travel had significant lower average distances driven of less than a kilometer, while automobile travel for discretionary purposes averaged 4.3 km. Differences in driving distances by work status and sex also appeared (see Figure 2). For all purposes combined, women who worked full- or part-time, or were homemakers or retirees had lower median driving distances than men for all purposes combined. Women who were students or unemployed recorded higher overall median distances driven. Generally speaking, individual driving distances were more flatly dispersed for full-time workers and students. Homemakers and retirees showed less variation in distance driven, clustering more tightly at the lower end of the spectrum.

Study Area Description

This study analyzed travel occurring within 100 km of the center of the Island of Montreal, which is located at the heart of the Montreal Census Metropolitan Area in southern Quebec. The region, home to more than 4 million (*35*), is characterized by a largely monocentric development pattern with the highest concentration of jobs located in the Ville Marie Borough, Montreal's central business core adjacent to the St. Lawrence River (see Figure 3). The area's regional and metro rail service is principally designed to funnel travelers into this central core from surrounding Montreal boroughs and independent municipalities. These surrounding jurisdictions display widely varying urban forms and land-use patterns, ranging from the densely populated areas of

Table 2. Summary Statistics for Travel, Individual, Household, Neighborhood, and Regional Variables (Based on Subset of People Having a Driver's License Coming from a Household with at Least One Car [$N = 59{,}761$])

Statistic	Mean	SD	Min.	Max.	Source
Individual travel (km)					
All VKT	19.6	20.2	0.0	81.2	Calculated
Work VKT	13.8	19.5	0.0	81.2	Calculated
School VKT	0.822	5.6	0.0	80.8	Calculated
Healthcare VKT	0.6	4.5	0.0	81.0	Calculated
Discretionary VKT	4.3	10.7	0.0	81.2	Calculated
Individual characteristics					
Age	47.4	15.8	16.0	98.0	2013 O-D Survey
Age (squared)	2,498.0	1,534.8	256.0	9,604.0	2013 O-D Survey
Female	0.50	0.5	0.0	1.0	2013 O-D Survey
Student	0.09	0.28	0.0	1.0	2013 O-D Survey
Full-time	0.61	0.49	0.0	1.0	2013 O-D Survey
Part-time	0.06	0.24	0.0	1.0	2013 O-D Survey
Homemaker	0.02	0.14	0.0	1.0	2013 O-D Survey
Retired	0.19	0.39	0.0	1.0	2013 O-D Survey
Not employed	0.03	0.17	0.0	1.0	2013 O-D Survey
Household characteristics					
Cars per household	1.81	0.89	1.0	14.0	2013 O-D Survey
Adults per household	2.26	0.85	0.0	13.0	2013 O-D Survey
School-age children per household	0.49	0.84	0.0	6.0	2013 O-D Survey
Preschoolers per household	0.17	0.47	0.0	5.0	2013 O-D Survey
Neighborhood and regional characteristics					
Neighborhood Walk Score (local accessibility)	56.9	22.0	0.0	100.0	Walk Score
Local accessibility (z-score)	0.0	1.0	–2.37	1.86	Walk Score
Transit-accessible jobs by census tract (regional accessibility)	228,001.20	273,827.0	0.0	1,584,390.0	STM, RTL, EXO, STL GTFS, Statistics Canada
Regional accessibility (z-score)	0.0	1.0	–0.83	4.95	STM, RTL, EXO, STL GTFS, Statistics Canada
Percent of car jobs accessible by transit in 45 min	27.3	28.5	0.0	117.6	STM, RTL, EXO, STL GTFS, Statistics Canada

Note: O-D = origin–destination; VKT = vehicle kilometers traveled; STM = société de transport de Montréal; RTL = Réseau de transport de Longueuil; STL = Société de transport de Laval; GTFS = General Transit Feed Specification.

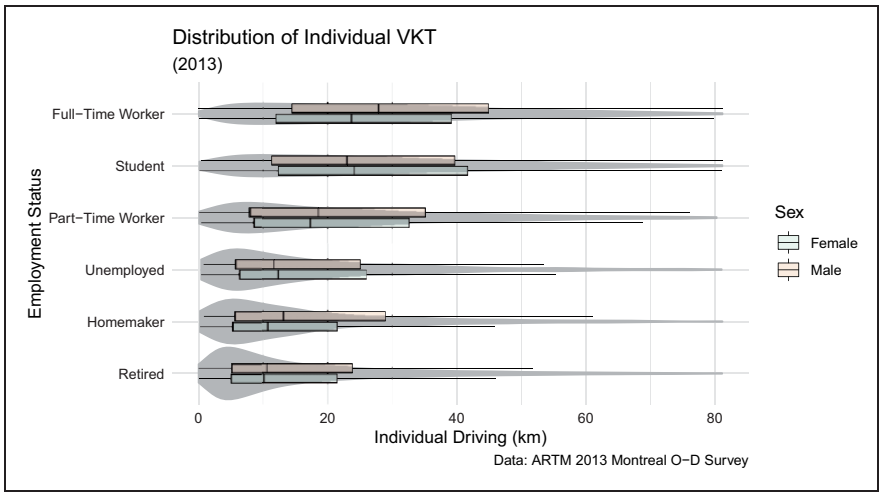

Figure 2. Distribution of individual vehicle kilometers traveled (VKT) by employment status and sex.
Note: ARTM = Autorité Régionale de Transport Métropolitain; O-D = origin-destination.

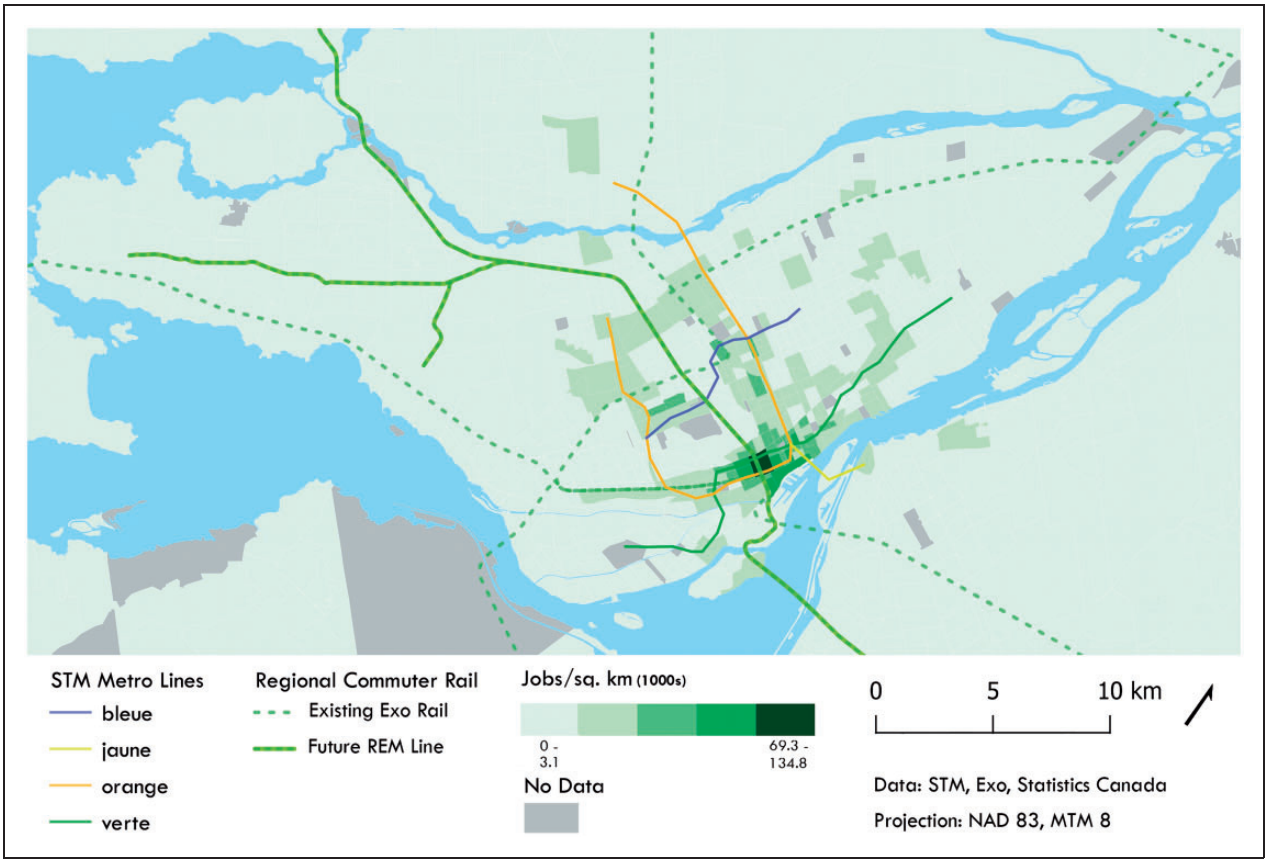

Figure 3. Montreal's major rail transit network in relation to job density.
Note: STM = Société de transport de Montréal; REM = Réseau express métropolitain; NAD = North American Datum; MTM = Modified Transverse Mercator.

mixed residential and commercial properties in boroughs such as the Plateau Mont-Royal to predominantly single-family residential areas, such as Hempstead, Westmount, and the West Island suburbs.

Spatial Patterns in Average Individual VKT

As seen in Figure 4, our driving-behavior data presents clear spatial patterns that largely conformed to our

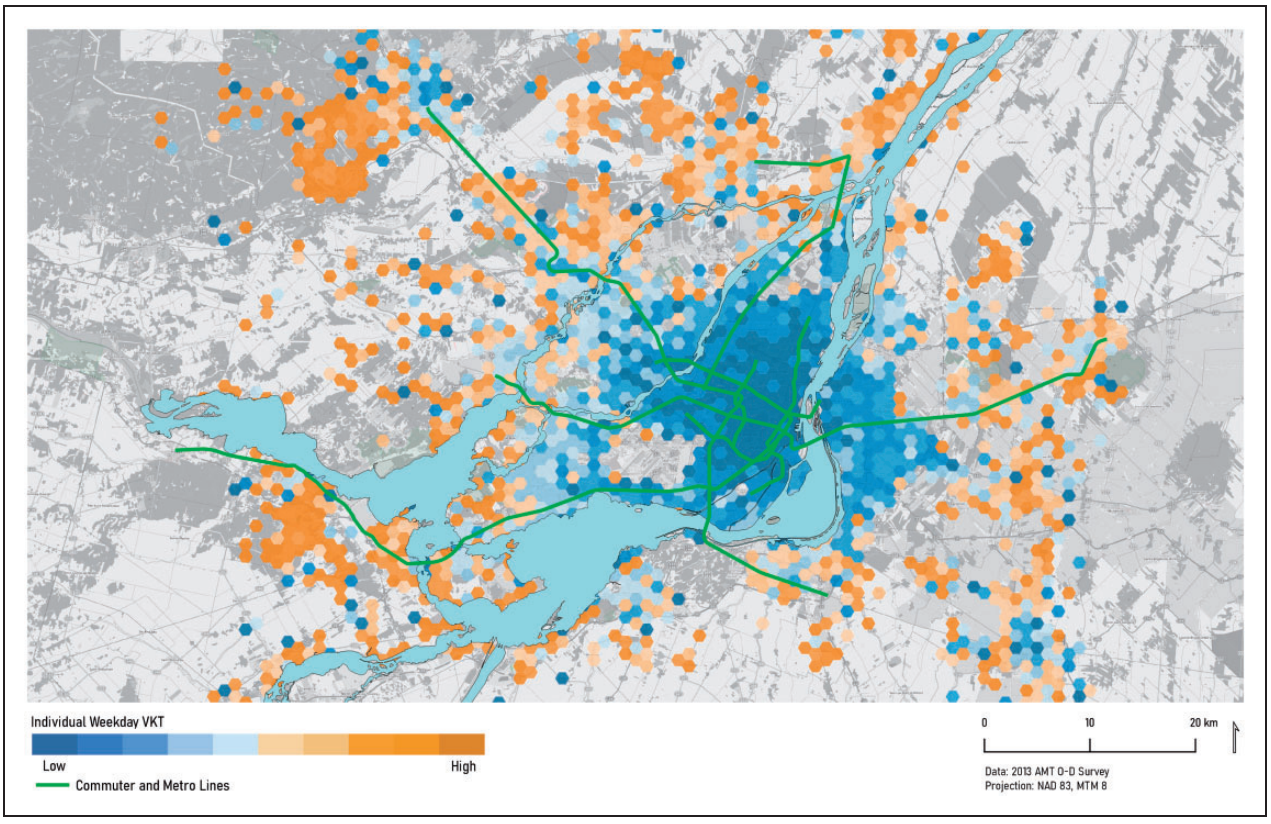

Figure 4. Average individual vehicle kilometers traveled (VKT) by deciles for all trip purposes combined.

expectations at the study's outset: as one moves further from Montreal's downtown, VKT increases. The greatest average individual driving distances for all purposes are concentrated in suburban and exurban areas forming a ring around the Island of Montreal. By contrast, the denser inner-city areas tend to generate lower VKTs. The distribution also highlights several outlying areas that defy this general pattern, potentially underscoring the value of commuter transit infrastructure and polycentric development as possible means to reduce individual VKT.

To Drive or Not to Drive: That Is the Regression

As a first step in our analysis, we sought to determine when potential drivers—those who have a driver's license and come from a household with at least one car—become actual drivers. To that end, we explored two principal questions: (a) which of the selected factors has an influence on the binary decision to drive or not to drive at some point during the survey day and (b) whether that influence is consistent across travel purposes. For this analysis, we relied on a multilevel mixed-effects logistic regression for all people within our data subset who reported any travel for the categories we considered. The findings from the statistical models are reported in Table 3. For all travel purposes combined, car ownership in the household appeared to exert the strongest positive influence on the likelihood of driving. For each additional car, the odds of driving increased 2.6 times, all things being equal. By contrast, the presence of additional adults in the household appeared to have a moderating influence, perhaps owing to increased competition for cars. To a point, increasing age was significantly correlated with a higher likelihood of driving for all purposes combined, and for disaggregated travel purposes. Both regional accessibility to jobs by public transport and local accessibility (Walk Score) were statistically significant with a negative impact on the likelihood of driving for all trip purposes combined and, to varying degrees, for the disaggregated travel purposes, when holding all other variables constant. Interestingly, incremental improvements in regional accessibility by transit (as measured by *z*-scores) appeared to be correlated with more significant declines in the propensity to drive than local accessibility across all purposes, with all other variables held constant. Overall, women were statistically far less likely to drive than men, all things being equal. This held true across all travel purposes.

Relative to people from high-income households, people from lower-income households were more likely to travel by car for all purposes combined and for work and school travel, with all other variables held constant. Had we not controlled for regional and local accessibility in the models, we might have hypothesized that these somewhat surprising results derived from different residential patterns, perhaps with lower-income households occupying less accessible areas. Here, however, the models controlled for both public-transit and walking accessibility from a traveler's home census tract, indicating that this counterintuitive finding cannot be explained by uniformly applied measures of accessibility at the point of departure. One possible explanation that merits additional investigation is that lower-income people may travel to destination areas that are less directly served by alternative transport. That is to say, transit may currently be structured to provide access to job and education destinations that are more desirable or relevant to wealthier people than to people from lower-income households. Though beyond the scope of this paper, one way to test this hypothesis would be to determine whether there is a statistically significant difference in the travel-time penalty (difference between car and transit times) incurred by individuals within the survey.

Having preschoolers, as opposed to school-age children, was correlated with a much higher likelihood of driving for all reasons combined, possibly owing to the perceived need to carry accoutrements such as strollers or supplies.

Multilevel Linear Regressions for VKT

In the second step of this analysis, we modeled the relationship between the same set of explanatory variables and log transformed individual vehicle distance traveled by the subset of respondents who drove. Similar patterns of statistical significance emerged as with the logistic regression for positive VKT, though the direction of the relationship was not always the same. Table 4 shows the findings from the multilevel regression models.

Total VKT. All variables–except (a) the presence of preschoolers in the home and (b) being a part- rather than full-time employee–showed statistical significance in the model, all things being equal. The number of cars per household had a positive and statistically significant impact on VKT. When holding other variables constant, each additional car in the household was associated with an increase in total individual VKT of nearly 5%, perhaps as a result of reduced competition for vehicles within a household. However, the number of adults represented a drag on individual VKT, while keeping all other variables constant, potentially as a result of increased competition.

Being from a lower- rather than a higher-income household was associated with driving 16.3% less total distance; being from a middle-income household was associated with driving 4% less than a high-income household, while keeping all other variables equal at their means. These relationships could be explained by the financial limitations imposed by lower incomes; a broader geographic dispersion of lower-income jobs, placing them in closer proximity to more people than higher-income jobs, which tend to be concentrated in central business districts; or a combination of the two.

For all categories except healthcare, the model indicated that as people grow older, they drive more. This trend reversed at a certain point as illustrated by the statistical significance of the age-squared variable.

Both local and regional accessibility presented a statistically significant negative correlation with individual VKT for all purposes of travel combined, all things being equal. Local accessibility was associated with slightly greater declines in overall VKT than regional accessibility for all driving travel. Each point increase in the z-score of the home census tract Walk Score was associated with a decrease in VKT of approximately 10%, all other variables held constant. Each increment in the z-score for transit-accessible jobs corresponded to a decline of about 9.5%, all things being equal.

Work-Related VKT. Work-related VKT displayed a similar pattern of statistical significance to overall VKT with two notable exceptions: part- versus full-time employment and the number of preschoolers in the household both proved statistically significant; they did not in the overall model. Part- versus full-time employment was associated with 19.3% fewer kilometers driven for work purposes, suggesting that part-time employment opportunities may be more geographically dispersed and therefore closer to residences.

Additional household cars tended to be associated with increases in driving distance (+2.5%), while each additional adult in the household was correlated with a decline of 5% in personal VKT to work, keeping all other variables constant at their mean.

Being a woman was associated with driving about 17.8% less, as was being from a lower- rather than higher-income household, all things being equal. The age of children in the household influenced work-related travel. Work-travel distance increased 2.6% for each preschooler in the household but declined by 1.2% for each school-age child in the household, all things being equal.

Local and regional accessibility were strongly correlated with decreases in work-related driving. As expected, regional transit accessibility as measured by reachable jobs corresponded to greater reductions in

Table 3. Results Table for Multilevel Logistic Regressions for Odds of Driving for Various Travel Purposes.

	Drove for...				
Predictors	Any purpose Odds ratios	Work Odds ratios	School Odds ratios	Healthcare Odds ratios	Discretionary purposes Odds ratios
Age (years)	1.055***	1.037***	1.278***	1.039***	1.035***
Age (squared)	1.000***	1.000***	0.997***	1.000***	1.000***
Female (y)	0.559***	0.618***	0.783***	0.618***	0.457***
Part-time worker (versus full-time employed)	0.281***	0.475***	0.935	0.62	0.546***
Unemployed, student or home-maker (versus full-time employed)	0.812***	1.281	2.314*	0.86	0.963
Additional cars in household	2.597***	3.286***	2.703***	1.445***	1.465***
Adults in household	0.605***	0.570***	0.649***	0.591***	0.716***
Preschoolers in the household	1.213***	1.169***	1.204	1.054	1.245***
School-age children in the household	1.019	1.041*	0.778***	1.119	1.141***
Lower-income household (<60 K CAD/year) (versus higher-income)	1.339***	1.648***	1.524***	1.076	0.974
Medium-income household (60–120 K CAD/year) (versus higher-income)	1.044	1.109**	1.083	0.929	0.926
Transit-accessible jobs within 45 min (10s of thousands of jobs) (z-score)	0.731***	0.708***	0.670***	0.798***	0.745***
Home neighborhood Walk Score (z-score)	0.885***	0.852***	0.810***	0.831*	0.884***
Drove for work (y)	na	na	3.043***	1.746*	1.202***
Drove for school (y)	na	4.843***	na	6.048*	3.087***
Drove for health purposes (y)	na	1.649*	6.538**	na	1.746***
Drove for discretionary purposes (y)	na	1.258***	1.997***	2.283***	na
(Intercept)	0.658***	0.626**	0.003***	2.32	1.809***
Random effects					
Intraclass correlation coefficient	0.01	0.02	0.05	na	0.02
N census tracts (ct)	811	748	559	510	716
Observations	59,761	37,104	4,695	2,453	22,341
Marginal R^2/conditional R^2	0.268/0.275	0.299/0.311	0.372/0.402	0.143/na	0.136/0.156

Note: CAD = Canadian dollars; na = not applicable.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

work-related VKT. For each increase in the *z*-score for regional accessibility, work-related driving distance was expected to drop about 12%, all things being equal. Meanwhile, each increase in the *z*-score for Walk Score for a home neighborhood was associated with a decline in work VKT of approximately 7.5%.

The impact of travel for other purposes appeared to be small but generally in the same direction. Each additional kilometer traveled for school, healthcare, or discretionary purposes corresponded with increases of between 1% and 1.7% in work-travel distance, while keeping all other variables constant at their means.

School VKT. An increase in the number of cars in the household by one was found to drive up distance traveled by 6.5%. However, unlike work travel, additional adults in the household did not represent a moderating influence on school-related VKT, keeping all other variables constant at their means. For each additional year in age, expected VKT increased by 4%, but then began to decline, all things being equal. Rather surprisingly, household income was not statistically significant for school-related VKT.

Again, both local and regional accessibility demonstrated a negative correlation with VKT. Regional

Table 4. Results Table for Multilevel Linear Regressions for Individual Vehicle Kilometers Traveled (VKT) for Various Travel Purposes

Predictors	log (total VKT) estimates	log (work VKT) estimates	log (school) estimates	log (health VKT) estimates	log (discretionary VKT) estimates
Age (years)	0.0141***	0.0287***	0.0390***	0.0081	0.0080*
Age (squared)	–0.0002***	–0.0003***	–0.0006***	–0.0001	–0.0001***
Female (y)	–0.1540***	–0.1955***	0.0716*	–0.0809	–0.0385*
Part-time worker (versus full-time employed)	–0.0351	–0.2145***	0.141	–0.2744	0.0991
Unemployed or homemaker (versus full-time employed)	–0.5182***	–0.1002*	–0.041	–0.0461	0.0037
Additional cars in household	0.0490***	0.0249***	0.0650**	–0.0388	0.0406***
Adults in household	–0.0655***	–0.0494***	0.0003	–0.0204	–0.0799***
Preschoolers in the household	0.0049	0.0257*	–0.1142*	0.0158	–0.0089
School-age children in the household	–0.0115*	–0.0123*	–0.0454*	–0.0694*	–0.0370**
Lower-income household (<60 K CAD/year)	–0.1744***	–0.1871***	–0.0261	–0.0927	–0.1316***
Medium-income household (60–120 K CAD/year)	–0.0422***	–0.0585***	–0.0585	0.0079	–0.0058
Transit-accessible jobs within 45 min (tens of thousands of jobs) (z-score)	–0.0951***	–0.1228***	–0.2382***	–0.1335***	0.0025
Home neighborhood Walk Score (z-score)	–0.1024***	–0.0752***	–0.0669*	–0.1700***	–0.1678***
Work VKT	na	na	–0.0105**	–0.0163***	–0.0108***
School VKT	na	–0.0179***	na	–0.0027	–0.0126***
Healthcare VKT	na	–0.0119***	–0.0148	na	–0.0099***
Discretionary VKT	na	–0.0098***	–0.0095***	–0.0022	na
(Intercept)	2.9569***	2.6977***	2.1362***	2.8243***	2.4266***
Random effects					
Intraclass correlation coefficient	0.11	0.16	0.23	0.21	0.17
N	$32{,}281_{h\_id}$ 798_{ct}	$21{,}657_{h\_id}$ 733_{ct}	$1{,}678_{h\_id}$ 399_{ct}	$1{,}700_{h\_id}$ 462_{ct}	$15{,}101_{h\_id}$ 703_{ct}
Observations	45,011	28,580	1,783	1,737	16,759
Marginal R^2/conditional R^2	0.140/0.233	0.080/0.226	0.166/0.359	0.093/0.284	0.046/0.205

Note: CAD = Canadian dollars; ct = census tract; h_id = household id numbers; na = not applicable.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

accessibility displayed a stronger influence than local accessibility. For each additional increase in the *z*-score for transit-accessible jobs, school driving distance fell by about 24%, all things being equal; each increase in Walk Score *z*-score related to a 7% decline in school driving distance.

The presence of preschoolers and school-age children in the household had a statistically significant negative relationship with individual school-related VKT, with a decline of 11% for each preschooler in the household and a decline of 4.5% for each additional school-age child in the household, all things being equal. For each added kilometer of work-related or discretionary driving, there was an approximate 1% decline in school driving distance.

Healthcare VKT. Few variables in the model showed statistical significance with respect to healthcare distance driven, suggesting other factors more strongly influence driving distance for healthcare purposes. Indeed, local and regional accessibility, work driving, and the presence of school-age children in the household appeared to be significant at least the 95% confidence level. Here, local accessibility was associated with greater decreases in individual healthcare VKT than regional accessibility. Each point increase in the *z*-score for the home neighborhood Walk Score corresponded to a decrease of 17% in healthcare VKT, all other variables held constant. Meanwhile, each additional increment in the *z*-score for regional accessibility related to a 13% decline in health driving distance.

Work driving distances were negatively correlated with healthcare distance traveled with each additional kilometer associated with a decline of 1.6% in healthcare driving, while keeping other variables constant at their means.

Discretionary VKT. The number of cars within a household had a significantly significant positive impact on distance traveled by car for discretionary purposes, each additional car corresponding to a 4% increase in VKT for discretionary purpose. As the number of adults increased,

distance driven declined by 8%. Each year of age corresponded to a 0.8% increase in discretionary distance traveled, up to a point, all things being equal.

Being a woman was associated with driving 4% less discretionary distance compared with men. Hailing from a lower-income household was associated with 12.3% less discretionary driving distance; keeping all other variables constant at their mean.

Here, only local, rather than regional, accessibility had a statistically significant correlation with declines in driving distance for discretionary purposes. Each additional increment in the *z*-score for the home neighborhood Walk Score point corresponded to 17% fewer discretionary VKT. This result is perhaps unsurprising, but it does underscore the notion central to this research that travel decisions made for different purposes are subject to different considerations. It is conceivable—even likely—that people are obliged to travel further from home for less discretionary purposes, such as work. But for discretionary purposes, they may have both the ability and desire to opt for destinations closer at hand, meaning that the capability to travel regionally by transit is of less importance in this context.

School, healthcare, and work distance driven were all significant, highlighting the notion that discretionary travel is, in fact, discretionary and therefore subject to the constraints imposed by other travel demands. Each additional kilometer driven for each of those categories was associated with a decline in discretionary driving distance of approximately 1%, all things being equal.

Discussion

These results suggest a range of policy options for reducing individual VKT. The varying patterns of significance across travel purposes also suggest that policy responses must be conceived and targeted in different ways. Given the statistical significance of many of the socioeconomic variables, it is also clear that not all these policies will relate directly to the built environment and transport system, although changes to both may serve as essential prerequisites or supports.

First and foremost, our findings suggest that addressing car ownership must be a much greater portion of the policy puzzle when it comes to reducing transport-related VKT. Among all the variables studied, the presence of additional cars in the household represents one of only two variables that showed consistently statistically significant relationships across all categories of travel for both the binary decision to drive and the distance driven once that decision was made. (The other was local accessibility.) Policies in this regard might include incentives for eschewing a car altogether, such as free or discounted transit passes. These polices might also include using pricing mechanisms, such as sales and property taxes, congestion charging, and registration and parking fees, to dissuade travelers from having or using a car when possible (*36*). In many places, however, car ownership remains essential for basic day-to-day activities such as work and shopping. To avoid unduly burdening car-dependent residents, policy makers may wish to consider progressive approaches to pricing that make each additional car incrementally more expensive. Currently, among all households retained in our analysis, the ratio of cars to adults in each household was approximately 0.8; among drivers the ratio was higher at 0.88.

Second, local and regional accessibility showed consistent impacts on driving and driving distance across most travel purposes considered. In the aggregate—and in combination with other initiatives—accessibility-focused planning efforts may therefore prove influential both directly and as support for other initiatives (*16*). For example, enhancing accessibility by transit and other modes may reduce the perceived need to purchase additional cars.

Third, patterns in the role played by demographic and socioeconomic characteristics render equity a vital consideration. The data showed, for example, that people from lower-income households were far more likely to drive than people from wealthier households. But in many cases, these same people were likely to drive shorter total distances for both work and discretionary purposes than people from higher-income households. This finding suggests different spatial patterns of employment in the Montreal region as lower-income jobs may be more broadly dispersed. Policy makers could potentially take advantage of the differential in driving distances by income group to soften the financial impact of future road pricing mechanisms (*37*). They could, for example, apply charges over a certain annual or monthly threshold of driving. These particular results may also indicate that people from wealthier households are better served by transport alternatives, affording them greater opportunity to select their mode of transport to their preferred destinations, especially for work purposes, which is consistent with the findings of other studies exploring inequity in transport systems that found the wealthy generally travel faster and further than lower-income groups (*38*).

Conclusion

Understanding the conditions policy makers can adjust to reduce the impact of rising individual car travel represents a fundamental and enduring challenge.

The stakes are high as communities across the world confront an unfolding climate crisis. Transport emissions represent a large and growing fraction of total emissions in both Canada and the United States. Reducing them will require a wide range of options and tools, one of which may be to further refine approaches for urban planning with an eye toward at least allowing people to comfortably, conveniently, and safely make the choice not to travel by car (*39*).

Much remains to be explored when considering the highly idiosyncratic and context-specific nature of travel behavior and driving decisions. Yet the research to date and this study clearly indicate that many factors with a demonstrable influence fall squarely within planners' and city officials' control. As other researchers have noted, "residents do tend to drive less and use other modes more often when they live in compact areas, all else being equal" (*39,* p. 26). When combined, the 5Ds—of which the destination accessibility studied here is an essential element—may yield large reductions in total vehicle distance traveled. Though important from the standpoint of cutting GHG emissions, reductions in mobile travel will certainly provide other additional benefits, including decreases in other air- and water-borne pollution, less costly travel, fewer roadway deaths and injuries, and more lively streetscapes.

In many respects, accessibility and the other Ds merely enable more responsible and sustainable transport choices. The rest remains up to people and their individual and collective choices. This strongly suggests the need to pursue these policies in conjunction with a broader range of supportive tools, such as road pricing. In the meantime, promising areas of additional research remain to eventually put Montreal drivers and others on the "short" road instead of the long one.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: JDW, AE-G; data collection: JDW, AE-G; analysis and interpretation of results: JDW, AE-G; draft manuscript preparation: JDW, AE-G. All authors reviewed the results and approved the final version of the manuscript.

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