

1 **MODELING THE EFFECT OF LAND USE ON ACTIVITY SPACES**

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1 **ABSTRACT**

2 Historically, when analyzing the effect of land-use on transportation demand, research has
3 concentrated on a few key indicators, notably mode choice, VMT and number of trips. At the
4 same time, this literature has primarily focused on the effects of individual land-use variables:
5 e.g. what is the effect of land-use mixity or population density on mode choice. It is becoming
6 increasingly clear however that the isolated impact of particular measures of land-use on
7 individual and household transportation behavior is small, but that when dealt with using a
8 clustered approach, their combined influence becomes both less ambiguous in direction and
9 greater in magnitude. This paper contributes to the transportation and land-use literature by
10 examining the effect of clusters of land-use indicators on activity spaces, an emerging but
11 traditionally ignored, transportation behavior indicator. Regression analysis results point to a
12 significant relationship between large and dispersed activity spaces, low levels of population and
13 employment density, and low levels of public transit accessibility and land use mix.
14

1 INTRODUCTION

2 Research on the effects of land-use on transportation has historically concentrated on a few key
3 indicators, notably mode choice, VMT and number of trips. The focus of such research has also
4 overwhelming been concerned with the effects of individual land-use variables: e.g. what is the
5 effect of public transit accessibility or residential density on distances travelled. Recent literature
6 has however brought to light that when modeled using a clustered approach, which typifies areas
7 based on combinations of certain land-use variables as opposed to dealing with them
8 individually, their combined influence on individual and household transportation behavior is
9 less ambiguous in direction and greater in magnitude. The importance of the relationship
10 between particular measures and the cumulative nature of their impact has led to this new wave
11 of research.

12 In line with such findings and using the Metropolitan region of Montreal as an application
13 environment, this paper examines the effect of clusters of land-use indicators on activity spaces,
14 an emerging but traditionally ignored, transportation behavior indicator.

15 The paper begins with a review of the literature on the relationship between land use
16 variables and travel behavior, followed by a summary of the work on clustering, and finally that
17 which pertains to activity spaces. The data used for this paper is described, as well as the ways in
18 which it was employed to quantify the impact of land use variables on activity spaces.
19 Regression model results and data analysis follow, and the paper concludes with a summary of
20 key findings and suggestions for future research.

21 LITERATURE REVIEW

22 The following literature review outlines the different approaches taken to measuring the effect of
23 land use variables on transportation behavior, both individually and as clusters, and will end with
24 the material related to activity spaces.

26 Traditional Land-use and Travel Behavior Literature

27 The traditional approach to linking land use variables to transportation behavior looks to the
28 levels of either mixity or density and links these to common measures of travel activity such as
29 vehicle kilometers travelled (VKT), vehicle hours travelled (VHT), number of trips and mode
30 choice. Ewing and Cervero's (1) (2) seminal works looked at this body of literature in both 2001
31 and 2010, highlighting the links found between different indicators and travel behavior. They
32 point out those with the strongest correlation, but also highlight areas where links have proven
33 either difficult to quantify or demonstrate as significant.

34 Travel behavior variables are usually broken up into categories for individual, household
35 and built form characteristics. Commonly used individual variables include gender, age, income
36 (3) and education (4), whereas household variables, or indicators, commonly used are number of
37 persons or children per household (the latter acting as a proxy for stage in the life-cycle) (5),
38 income and number of vehicles owned (6). Built form characteristics can be broken into a few
39 categories; Krizek, for instance, uses density and land use mix (7).

40 There is a widespread agreement within the literature that the three Ds proposed by
41 Cervero and Kockelman act as the basic categories of urban form (UF) indicators, notably
42 density, diversity and design (7) (6). One can find residential and employment densities
43 quantified as simple measures of individuals per unit area (8) or retail employment per area (4),
44 but more elaborate methods also been employed. Many sources outline the different ways to

1 address the issue of public transit accessibility, dealing with it as proximity to stations or bus
2 stops (6), rail and bus line coverage (3), headway (9), etc.

3

4 **Literature on clustering of urban form and public transit variables**

5 Newer literature in the field deals with the effect of multiple land-use variables on transportation
6 behavior through clusters, or neighborhood typologies.

7 In the literature which links specific urban form characteristics to travel behavior, three
8 distinct problems are encountered, namely that of biased elasticities (3) (4), results which are not
9 conclusive or statistically significant (10) (6) and finally issues of causation, or the impact of
10 self-selection (11) (9). Neighborhood typologies, combined with household-level control
11 variables, enable researchers to deal with urban form attributes while avoiding issues related to
12 biased coefficients, statistical significance and causation (9) (5) (6) (8) (12).

13 Measuring levels of the three Ds is a common approach to linking travel behavior to land-
14 uses, however, authors such as Krizek have argued that interpreting such measures individually
15 disregards the inherent relationship which exists among them (7). By combining indicators, one
16 can better describe activity density (13) and more clearly understand the effect that changing
17 levels of urban form and public transit can have (3). Techniques such as k-means clustering (14)
18 can be employed to define these typologies and, when combined with control variables such as
19 income or life-cycle characteristics, aid in building more accurate models for predicting travel
20 demand.

21 These clusters and neighborhood typologies can be built in different ways, with or without
22 the use of weights, and can include any indicator one finds pertinent, be it population or
23 employment density, street grid connectivity, sidewalk provision, transit availability, etc. See
24 Gershoff, Pederson, & Aber (2009), Lin & Long (2008), Manaugh, Miranda-Moreno, & El-
25 Geneidy (2010) or Shay & Khattak (2007) for an overview of different techniques and indicators
26 used.

27

28 **Activity Space Literature**

29 Activity spaces can be used to measure and display the areas individuals or households come to
30 interact with as they go about their activities and travel from one location to another (15). They
31 can be seen as tools both to describe the amount of space covered by an individual, but also the
32 activities to which they have easiest access.

33 These techniques have been used in the fields of criminology (16), transit planning (13),
34 nutrition exposure or foodscapes (15) and healthcare (17), among others, to measure either
35 access to certain resources or the spread of activities. Activity spaces bring a new dimension to
36 travel behavior, whether it be measured using standard deviational ellipses (SDE), minimum
37 bounding geometry or other means (18) (19).

38 Many techniques exist to measure activity space, some accounting only for routine
39 activities based on interviews (17), others using travel diaries (13), but the concept remains to
40 map out the areas people interact with. Fan and Khattak used the indicators of building density,
41 retail accessibility and street connectivity to quantify the impact of land use variables on
42 individual spatial footprints and found downtown residents generated smaller spaces than their
43 suburban counterparts (20) (21). Smaller activity spaces are commonly viewed as beneficial
44 from an energy and environmental perspective (22) (23); this is also true from a health (24) (25)

1 and economic perspective (26). Activity spaces can therefore aid in developing policy to guide
2 cities towards more sustainable mobility futures.

3 The idea of moving away from traditional transportation demand measures to activity
4 spaces is fueled by a growing recognition of the importance of non-commuting trips to the total
5 travel of households (18). The link between land use characteristics and distances travelled has
6 already been investigated by many scholars, but a strong body of literature on the relationship
7 between urban form, transit accessibility and activity spaces is not yet available. This research
8 will begin to fill that void by demonstrating the effect clustered indicators can have on activity
9 spaces.

10

11 **STUDY AREA & DATA USED**

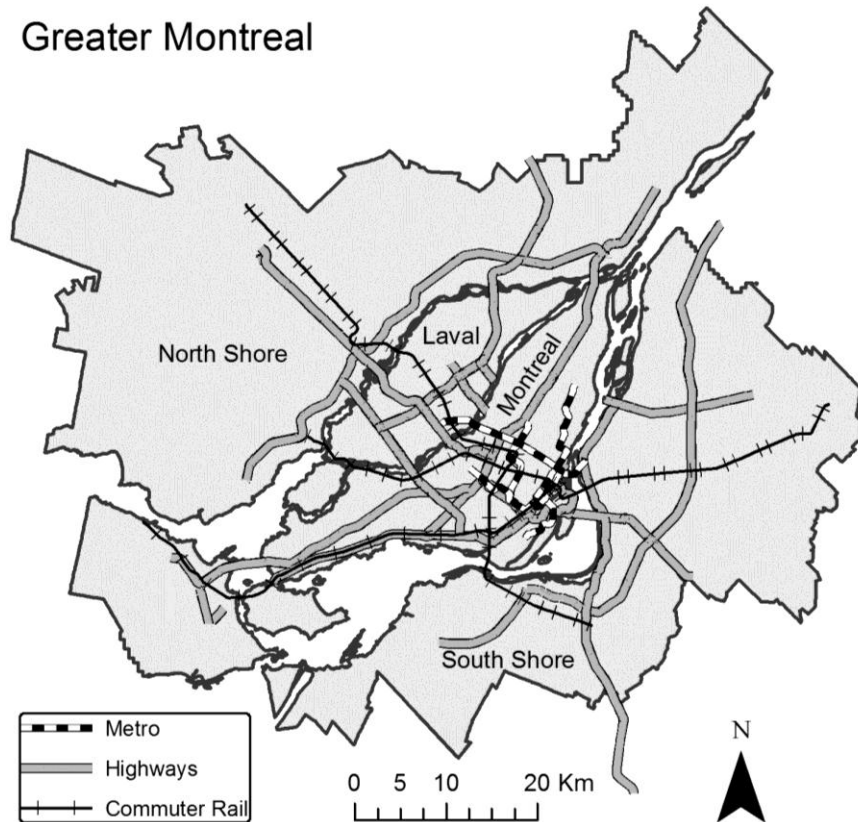
12 The methods proposed in this paper are applied to the greater Montreal region of Quebec,
13 Canada. Montreal is the second largest Census Metropolitan Area (CMA) in Canada with a
14 population of more than 3.6 million inhabitants in the latest (2006) census. It is an old city by
15 North-American standards, one which is characterized by an urban form which has been built up
16 over many phases. It also has a varied housing stock and a heterogeneous mix of transportation
17 options, offering both heavy and commuter rail, and extensive bus service in addition to a well-
18 developed highway network (see figure 1). This heterogeneity in urban form and transit
19 accessibility creates a landscape which makes Montreal a perfect case study for the effects of
20 urban form and public transit on travel demand.

21 Six different sources of data were required for this analysis, which builds upon the
22 methodological approach of Miranda-Moreno et al. (9) : population counts and census tract
23 demographic characteristics, census tract employment counts, land use data, public transit data,
24 personal and household mobility data, and finally census tract shapefiles.

25 Land use shapefiles were obtained from Desktop Mapping Technologies Inc. (DMTI), a
26 recognized GIS content provider. DMTI categorizes land use into seven categories, including
27 water, open areas, residential, commercial, governmental and institutional, industrial and parks
28 and recreation. Census tract shapefiles were then obtained from Statistics Canada's Census Tract
29 Digital Boundary Files (27). These boundaries, as well as those for land use data, were used to
30 delimit the study area.

31

Greater Montreal



1

2 **FIGURE 1 Study area.**

3 With respect to public transit accessibility, geocoded transit lines and stops tagged with
 4 unique identifiers linking them to weekday AM-peak headways were used. The transit network
 5 used as the source of this information is a hybrid network. The base network comes from an
 6 existing TransCAD network of the Island of Montreal from 2003. Transit lines from off the
 7 island were added to the existing network in the summer of 2011. Both parts of the network were
 8 geocoded by hand since network information (property of five main transit operators) is not
 9 generally available outside of those institutions. That said, while the networks have changed over
 10 time, the main characteristics of the network have remained similar. The main difference
 11 between the 2003 and updated network was the addition of three metro stations on the Island of
 12 Laval.

13 For household mobility data, the Montreal 2003 and 2008 Origin Destination surveys
 14 (OD), which are comprehensive travel demand surveys carried out every 5 years by the Agence
 15 Métropolitaine de Transport (AMT) – Montreal’s public transport planning agency- were used.
 16 Montreal’s OD surveys, which cover 5% of the households in the study area, collect time, mode
 17 and motive specific travel descriptions, as well as origin and destination XY coordinates for all
 18 the trips carried out by persons aged over 4 years. They also collect household and personal
 19 characteristics for the individuals in each surveyed household. It should be noted that in 2003,
 20 household domicile coordinates were coded as the XY coordinates of the actual home, whereas
 21 in 2008, the domicile coordinates were instead entered as the XY coordinates of the
 22 dissemination area (census subdivision smaller than a census tract) within which the household
 23 was found. This required a transformation of 2003 trip origins and destinations for all home-

1 based trips, to ensure compatibility with the 2008 dataset. Data concerning 56,965 HHs in 2003
2 and 66,124 in 2008 were used in this analysis (28).

3 A grid consisting of cells 500 meters by 500 meters as well as a nine-cell grid
4 encompassing the host and references to the eight surrounding cells was also used. The latter is
5 used to average indicator values over a larger area.

6 Census level data was acquired via StatsCan's E-Stat website, which provides information
7 at the census tract level regarding both the socio-demographics of the populations– including
8 incomes, employment sectors, education, etc.-, as well as built form – including building type,
9 age, condition and other variables (29) (30). Employment data was obtained through the 2001
10 and 2006 “Enquête sur le travail et le milieu de travail et les employés,” produced by Statistics
11 Canada (31) (32). This was provided by Statistics Canada as a ‘special order’ from a consortium
12 of provincial government ministries and agencies. Statistics Canada uses census information to
13 infer employment information (number of jobs by NAICS sector by census tract).

14 For all calculations involving residential density, only residential land use area was used,
15 likewise for employment density, only commercial, government and institutional and industrial
16 land use areas were used. That is ‘net’ and not ‘gross’ density was used.

17

18 **METHODOLOGY**

19 This section provides a description of the generation of clusters from the four selected indicators,
20 the calculation of activity spaces and statistical methods employed to estimate the effect of land-
21 use on activity space size.

22 Whereas much of the research previously published has made use of aggregated data for
23 their analyses, either at the transportation analysis zone or census tract level, this paper uses very
24 disaggregate data for cluster analysis. For example, data such as population and employment
25 may be obtained at the census tract level, but by isolating land uses which could contain them
26 and calculating their density after an adjustment to area, much more accurate data on the
27 locations and densities of indicators is obtained.

28 Previous work on clusters has looked at population density, land use entropy, public transit
29 accessibility (9), urban design (7) (5) and other variables, and research by Leck (2006), Bento
30 (2005) and Ewing and Cervero (2010) has demonstrated that employment density is an important
31 predictor of travel demand. As such, clusters were designed to incorporate the following four
32 indicators: population density, land use mix, PT accessibility and finally employment density.

33

34 **Densities**

35 All indicators were measured at the cell level using the grid previously described. This quantified
36 population and employment densities by intersecting clipped population or employment-density
37 tagged land uses with cells.

38

39 **Land use mix**

40 A similar process was used in the calculation for land use mix, also at the cell level, where an
41 entropy index was devised based on that of Miranda-Moreno et al. (see equation 1). The more
42 land uses there are in a cell and the more evenly their areas are distributed, the higher the value;
43 its range is 0 (no mix) to 1 (perfectly heterogeneous).

1

$$E_j = - \sum_{i=1}^n \frac{\left[\left(\frac{A_{ij}}{D_j} \right) \ln \left(\frac{A_{ij}}{D_j} \right) \right]}{\ln(n)} \quad \text{Eqn. (1)}$$

2 Where:

3 A_{ij} : area of land use4 D_j : area of cell (excluding water and open area)5 n : total number of different land uses

6

7 **Public transit accessibility**

8 The grid approach was used to calculate the accessibility of cells to transit by finding the nearest
 9 bus, metro and rail line stops to each cell and summing each line's closest stop's contribution to
 10 a transit accessibility index; a stop closer to a cell centroid or with a smaller headway (calculated
 11 using AM peak) would mean a larger contribution to transit accessibility (see equation 2).

12

$$PT_{access_j} = \sum_{i=1}^n \frac{1}{(d_{ij} * h_i)} \quad \text{Eqn. (2)}$$

13 Where:

14 PT_{access_j} : accessibility to public transit as cell j 15 d_{ij} : distance, in km, from cell centroid j to nearest bus stop of line i (minimum value of 0.1 km)16 h_i : average headway, in hours, of line i in AM peak (maximum value of 1 hour)

17

18 All four indicator values were then averaged with those contained in the eight surrounding
 19 cells. There are particular ways in which incomplete cells near bodies of water or the boundaries
 20 of the study were dealt with, in addition to the weighing of cells that intersected partial land use
 21 tracts, but it is beyond the scope of this paper to describe these.

22

23 **Neighborhood typologies, or clusters**

24 After compiling indicator values, k-means cluster analysis in STATA was employed to create the
 25 typologies. The means by which the clusters were defined was similar to the procedure outlined
 26 in Lin and Long, whereby clusters were generated attempting to find a balance not only between
 27 predictive power and number of cases (households in this case), but also using visual
 28 representations as a 'sanity' check (5). Such a verification of face validity was also used later on
 29 in the regression stage, combined with a review of the correlation matrix, so as not to include
 30 variables which too closely paralleled others. The four cell values, for population density,
 31 employment density, PT accessibility and land use mix were input in STATA, but to increase the
 32 relevance of clusters, only cells which contained OD survey households and at least one non-null
 33 value were kept. Excluding cells which contained only null values removed 6,125 of 17,601
 34 cells, or 35%, from the clustering exercise, but only 1% of the valid OD households. Of these,
 35 3,007 cells contained the dissemination area centroids of valid OD HHs for 2003 and 3,168 for

1 2008. Since the goal was to predict activity spaces, assigning clusters to areas which were
2 uninhabited was deemed unnecessary.

3 Although the densest cluster contains very few cells (having only 1.2% of the total
4 number of HHs in a 7 cluster approach), the large size of the original dataset still makes this a
5 significant segment of the population. See Table 1 for the mean of UF and PT characteristics, as
6 well as counts and percentages for every cluster.

7 **TABLE 1 Summary statistics for clusters (valid HHs only)**

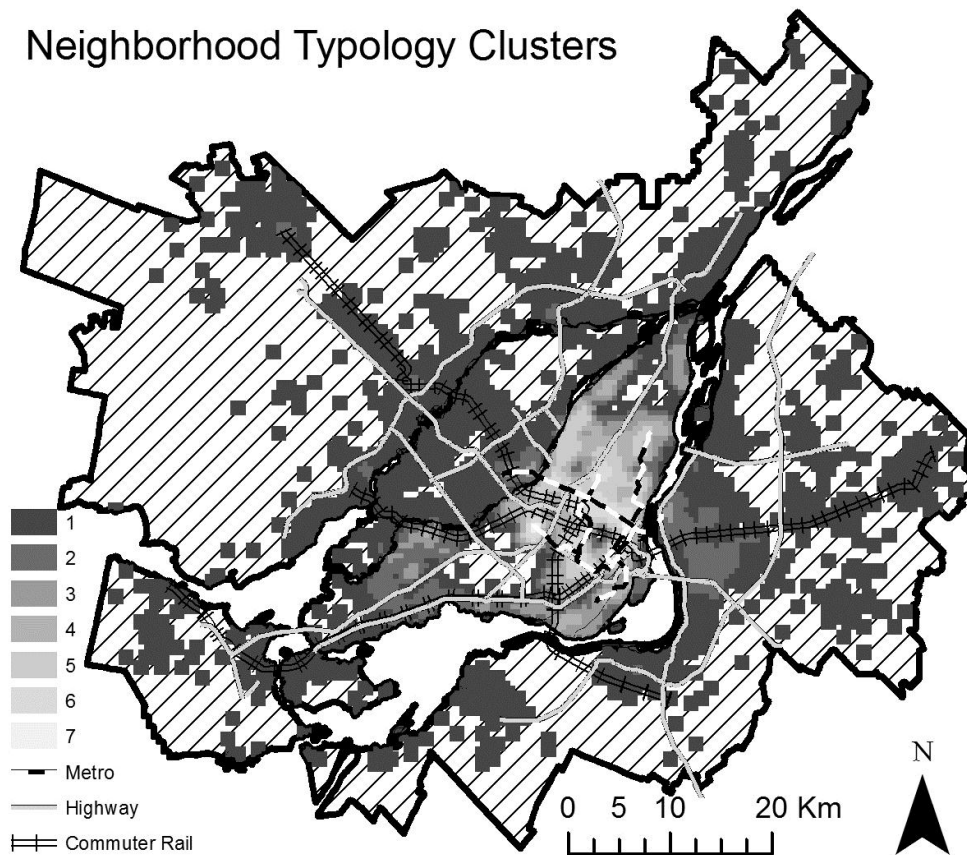
2003 & 2008 Clusters	Observations	Persons / Hectare	Employment / Hectare	Land Use Mixity	PT Accessibility	Activity Space (km ²)	HH Trips	Montreal (Dummy)
1, Rural no Transit	44% / 18,210	19.66	4.70	21%	6.98	68.79	8.60	24%
2, Rural	11% / 4,685	29.78	8.90	30%	46.42	40.57	8.54	68%
3, Rural / Suburban	11% / 4,493	44.90	12.18	37%	109.54	33.31	8.20	100%
4, Outer Suburb	12% / 4,771	66.46	21.66	44%	171.75	22.86	7.82	99%
5, Inner Suburb	13% / 5,165	86.72	29.82	50%	247.95	18.27	7.53	100%
6, Urban Core	8% / 3,294	96.22	67.79	56%	362.37	14.87	7.16	100%
7, Downtown Core	1% / 499	86.38	250.55	59%	554.52	11.41	6.55	100%
Mean	41,117 Total	61.44	56.52	42%	214.22	30.01	7.77	84%

8
9 Clusters were reclassified to represent increasing levels of transit accessibility, land use
10 mix and density. From cluster 1 to 2 and so on, the densities (measured in persons or jobs per
11 hectare) increase rather significantly; cluster 7 has four times the mean population density and
12 over 50 times the mean employment density as its suburban/rural counterpart, cluster 1 (see table
13 1). Land use mix also increases significantly when one passes from the low value clusters (20%
14 entropy value) to the higher ones (60%), and transit increases almost exponentially, from 7 to
15 550 units. The transit indicator's values are unbounded, but in the Montreal case range from a
16 low of 0, which indicates that no public transit stops are within a host cell's search radius, to a
17 high of 775.

18 To be useful to planners, the clusters formed must not only be significant in modeling
19 travel demand, they must also provide clear and legible descriptions of the neighborhoods they
20 represent. Based on the literature, limiting the generation to less than 10 clusters, was expected to
21 produce legible typologies. The results and discussion sections describe two variations attempted
22 and the problems encountered.

1 With mean population densities ranging from 19 to 29 persons per hectare, clusters 1 and 2
 2 (see table 1) could be considered, as Newman and Kenworthy would call them, automobile-
 3 oriented outer suburbs (33). Clusters 3 through 5, with mean densities of 45 to 86 persons per
 4 hectare would be transit-oriented inner and middle suburbs, and clusters 6 and 7, with mean
 5 densities ranging from 86 to 96 persons per hectare, and much higher employment densities,
 6 would be walking-oriented core suburbs (33) (see figure 2 for a visual representation of their
 7 distribution). Land use mix, transit supply and employment density also reflect the typical
 8 definitions of such neighborhoods.

Neighborhood Typology Clusters



9
 10 **Figure 2 Neighborhood typology clusters and the city's main transportation infrastructure.**

11 12 Activity spaces

13 With respect to activity spaces, there are many different tools that one can use to describe the
 14 travel behavior of HHs (see Sherman et al. for an overview of SDE, road network buffer and
 15 standard and relative travel time polygons (17)). Given the type of data available (daily travel
 16 surveys), the convex hull minimum bounded geometry (CVH) was however the best fit;
 17 regressions were also run on models using the standard deviational ellipse (SDE), but R^2 values
 18 were found to be higher using the CVH. Because of the joint constraints of the OD survey being
 19 a one-day travel diary, and that of activity spaces requiring 3 unique points, household activity
 20 spaces were chosen over individual activity spaces. Previous research supports such an approach,
 21 household characteristics having been demonstrated to effect travel behavior in previous models
 22 (18).

1 The CVH polygons were generated using ArcMap 10. The first step was to isolate
2 individuals whose trips were all performed within the study area, then to map the origins and
3 destinations of these. Using the Minimum Bounding Geometry tool, convex hull polygons were
4 generated around each household's origin and destination coordinates. Households whose trips
5 only included one valid origin and destination pair were excluded from the statistical analysis
6 step later on as, having formed lines with no area as opposed to polygons. These were isolated by
7 looking to the CVH properties and selecting the polygons with zero width (16,727 of 52,386
8 valid households in 2008 and 13,400 of 47,053 in 2003). It should be noted that the prevalence of
9 households with thin polygons was slightly higher in the dense urban clusters, where they
10 account for roughly 35% of CVH polygons against 28% in the more sprawling suburban clusters
11 (2008 numbers), but thin polygons also occur most often in smaller households (46% in
12 households of 1 person and 41% in households with 2 persons, 2008 also). These small
13 households are more prevalent in dense urban clusters, where the mean household size is 2.27 as
14 opposed to 3.22 in less dense, more rural clusters. Since the major influence is households, and
15 not cluster,-based, it was determined results would be more accurate if the model were built
16 without taking zero width polygons into account.

17 Out of an awareness of the importance of household and life-cycle characteristics, over 25
18 different variables were run alongside clusters in the regression model; only the final set will be
19 reported here. Since census tracts define areas which are "designed to be homogeneous with
20 respect to population characteristics, economic status, and living conditions" (5 p. 741) (8), CT-
21 level information was included by matching households to the census tracts in which they reside.
22 This made due for the absence of socio-demographic information such as income and
23 employment fields, as well as lifestyle indicators in the OD survey.

24 Distance to central business district (CBD) was considered, but as had been demonstrated
25 in Shearmur 2006 (34), Montreal has many employment centers, and although the downtown
26 core attracts high numbers of commuters working in specific fields, the concentrations of
27 employment present in these other centers, combined with the changing demographics of society
28 (the increasing number of dual-income households for instance), would have required a much
29 more elaborate model be devised.

30

31 **RESULTS**

32 From table 2, one can be seen that all signs for the reported coefficients carry face validity and
33 only variables with significance levels above 95% were kept. The results of models predicting
34 activity space took into account the CVH formed by households that had more than one unique
35 OD XY coordinate pair and performed both mandatory as well as non-mandatory trips; such an
36 approach was also taken in Manaugh and El-Geneidy (22). This left us with 20,704 valid
37 polygons for analysis in 2008 and 20,413 in 2003.

38

39

1 **TABLE 2 Regression results, the logarithm of the CVH area is the dependent variable**

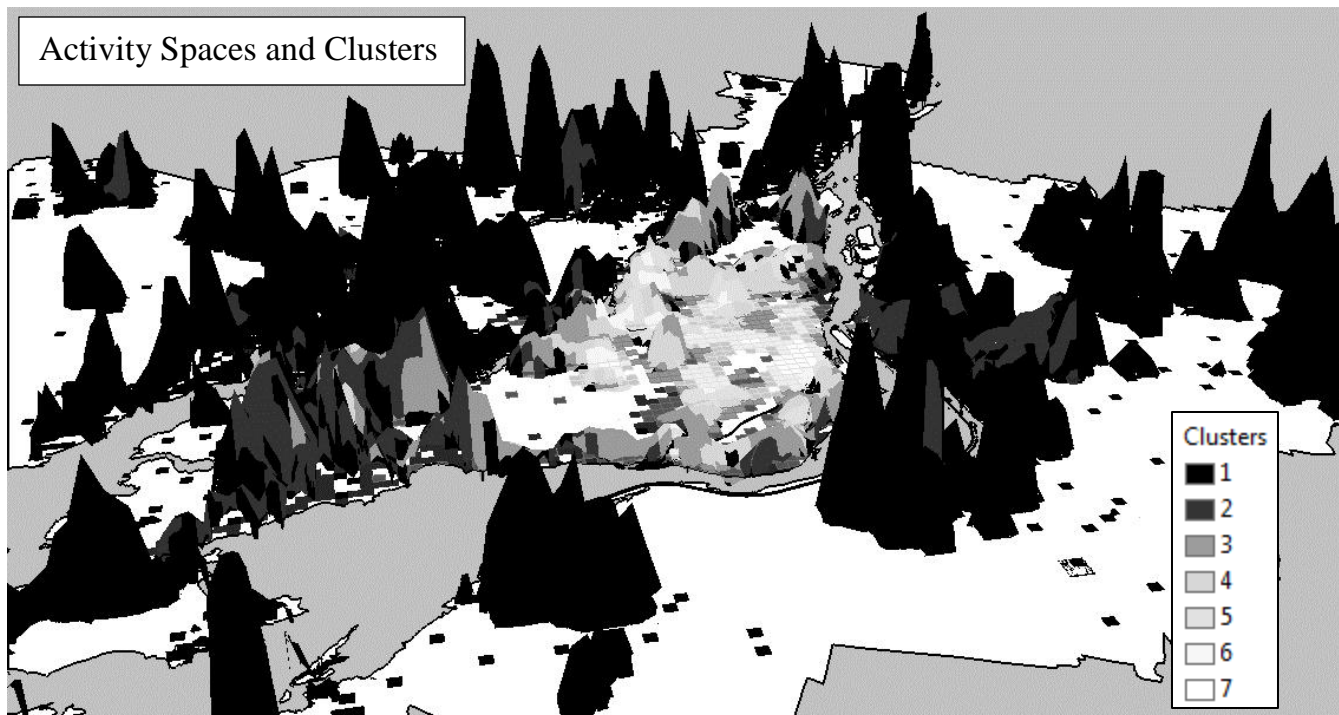
	Number of observations		41,117
	R-squared		0.28
Variable	Coefficient	t-stat	95% Confidence Interval
Cluster 2, Rural	-0.25	-8.91	-0.31 to -0.2
Cluster 3, Rural/Suburban	-0.44	-15.17	-0.5 to -0.39
Cluster 4, Outer Suburb	-0.64	-21.54	-0.7 to -0.58
Cluster 5, Inner Suburb	-0.77	-25.55	-0.82 to -0.71
Cluster 6, Urban Core	-0.97	-26.57	-1.04 to -0.9
Cluster 7, Downtown Core	-1.52	-19.37	-1.67 to -1.36
FG workers per CT (%)	-1.07	-11.42	-1.25 to -0.88
# of Children	-0.32	-24.65	-0.35 to -0.3
# of Seniors	-0.27	-5.58	-0.37 to -0.18
# of Full-time Students	0.15	11.67	0.12 to 0.17
# of Full-time Workers	0.40	31.78	0.38 to 0.42
Licences per HH	0.32	25.94	0.3 to 0.34
# of Trips	0.10	34.79	0.09 to 0.1
Resident of Laval	0.15	5.47	0.09 to 0.2
Homemakers per CT (%)	2.95	18.29	2.63 to 3.27
OD 08 HH	-0.05	-3.03	-0.08 to -0.02
Constant	14.79	208.88	14.65 to 14.93

*Reference cluster is cluster 1, the most rural cluster

2 As the model demonstrates, dense clusters lead to consistently smaller activity spaces; this
3 can be seen in the negative coefficients for cluster dummy variables becoming larger in
4 magnitude as cluster values increase (see table 2).

5 A constant of 14.79, with a coefficient of -0.25 for cluster 2 and -1.52 for cluster 7 would
6 mean that all else being equal, a household with mean values for all the variables included in the
7 model would be predicted to produce an activity space of 11.10 km² in the base case (cluster 1,
8 or low density suburban/rural), 8.63 km² in cluster 2 (suburban) and 2.44 km² in cluster 7 (dense,
9 downtown core). As a note, the number of trips was included in the model despite higher trip
10 generation in suburban clusters, because their numbers were found to be more closely tied to
11 household size than to urban form and transit indicators.

12 Model results show a significant relationship between clusters and activity space. The
13 magnitude and direction of coefficients mean that increases in cluster values consistently lead to
14 decreases in the size of the activity space produced by households. See figure 3 for a 3D
15 representation of the link between clusters and activity space. Darker colors represent low cluster
16 values, heights represent activity space magnitude and the cells which appear flat on the map
17 represent values for activity space below a certain threshold (the heights are multiples of the
18 square root of activity space area, for display purposes). Notice how many flat cells appear in the
19 central portion of the island of Montreal and how many low-height peaks are in white and light-
20 grey (high-value clusters, or dense, highly mixed and well-served by transit areas).



1
2 **Figure 3 Clusters and activity spaces, 2008 data displayed – heights represent activity space**

3 The inclusion of F and G categories of employment (percentage of persons per CT
4 working in occupations in art, culture, recreation and sport, and sales and service occupations) as
5 a CT-level variable was based upon trial and error, but also previous work which found that
6 these sectors were consistently overrepresented outside of employment centers (34); i.e. more
7 dispersed leading to smaller distances traveled to access work locations. There being a lower
8 level of specialization within these sectors, local workforces are more likely to fill these
9 positions.

10 An indicator whose predictive power and significance proved very high was
11 “homemakers”. This CT-level variable indicated the percentage of women aged 15 and over in a
12 CT who spent more than 15 hours a week performing unpaid child care. When tracts with high
13 homemaker values were displayed in ArcMap, a pattern emerged where most were rural CTs, a
14 few being high average-income tracts as well. Both rural location and high incomes can explain
15 large activity space; rural populations would logically have to travel long distances to reach
16 activities, while high incomes would justify one partner’s ability to stay home tending to
17 children, while the other partner (most likely working in a specialized field or occupying a
18 management position, would need to travel long distances to commute to his or her high income
19 position).

20 Household sizes in the more suburban clusters are on average larger, and as such it would
21 be normal that their activity spaces be larger. However, these households also contain more
22 children, who, as Shay and Khattak have found, lead to increases in household size without
23 adding drivers (6). As such they are unlikely to travel large distances for work or school, and by
24 their influence on the time budget of adults, actually decrease average activity space (14).

25 “From an economic perspective, distance to work is conceptualized as a cost, and greater
26 travel distances are associated with higher earnings (and/or lower residential costs)” (34 p. 332),
27 as such it was odd to find that the average income variable attempted in the model resulted in

1 very small coefficients. This may be due to the aggregated nature of data, it having come from
2 the CT as opposed to the household, but the fact that many high income tracts are found near the
3 CBD is likely the determinant factor.

4 High percentage of detached housing led to larger activity spaces and high rental-housing
5 proportions led to smaller activity spaces, but these and many other CT-level variables were
6 excluded from the model because they were not found to be statistically significant, possibly due
7 to high collinearity between variables. These housing indicators merely stand as poor proxies of
8 urban form and transit characteristics, but without taking into account the subtle variations that
9 make the clusters more accurate.

10 11 **DISCUSSION**

12 Data analysis had the objectives of quantifying the relationship between clusters and travel
13 behavior and in particular activity spaces.

14 The number of clusters to include in the final model was not only based on face validity
15 when looking at the maps produced by assigning clusters to cells, nor was it determined purely
16 on the basis of regression results. It is important in any study of the effect of urban form and
17 transit on travel behavior to bear in mind that the goal is to provide planners with easy to
18 interpret and apply templates for neighborhoods and not merely to increasing statistical
19 significance.

20 7 clusters were generated in the end, but a look at the Montreal (dummy) column of table
21 1 reveals the greatest weakness of this study; over 98% of the households represented by clusters
22 3 through 7 are on the island of Montreal (as can also be seen in figure 2). When only 6 clusters
23 were chosen, this was even worse, with 92% of households represented by clusters 2 through 6
24 being Montreal households. In essence, the difference that exists between the landscapes of
25 Montreal and its surrounding areas is so large that bringing their urban form and transit
26 characteristics together to generate clusters leads to an almost complete disappearance of the
27 subtleties present off-island. The clustering approach still leads to intuitively consistent
28 predictions, but it does not leave much room for off-island tracts to learn from on-island ones;
29 the differences in urban form and transit accessibility being so stark between the two that off-
30 island municipalities aiming to emulate characteristics of denser Montreal clusters to reduce
31 travel demand would face landscape redesign challenges worthy of Haussman's transformation
32 of Paris. This also demonstrates the chasm which exists between their geographically proximate,
33 but vastly dissimilar neighborhood typologies.

34 An interesting notion to keep in mind when interpreting results is that there can be a point
35 beyond which the concept of diminishing returns begins to take hold. As Krizek has stated, once
36 a certain level of service provision or accessibility is exceeded, an increase in the number of
37 businesses or transit stops may have negligible impact on travel behavior (7). This is reflected in
38 the regression results, whereby the decrease in mean value for activity space is only 23.5%
39 between clusters 6 and 7, compared to 41% between clusters 1 and 2 (see table 1).

40 Another point to mention is that it may be better to use another measure for transit. As
41 can be seen when mapping activity spaces alongside infrequent bus lines (with headways of 60
42 minutes or more) and commuter rail stops, areas which are proximate to such stops find
43 themselves host to very large activity spaces. Future research should thus try and separate local
44 transit from regional and express transit, which by their very nature carry people over large
45 distances, but all the while create an upward bias to cluster cells near them.

1 Looking to the regression results in table 2, one can see that the influence of clusters was
2 high and all the included coefficients were intuitive and right-sided: household licences, high
3 homemaker CTs, more trips, full time students and workers, and coming from Laval (an island
4 just North of Montreal island, separated from it by bridges) increasing activity space, while high
5 cluster values (which are associated with dense, mixed use and transit rich environments),
6 service sector employment and children and teens associated with smaller activity spaces. The
7 OD 08 dummy variable produced a significant but very small negative coefficient, which would
8 indicate that activity spaces decreased slightly from 2003 to 2008. The magnitude of the
9 coefficient however (-0.05), would indicate that this difference is negligible and not the sign of a
10 trend.

11 12 **CONCLUSION**

13 To conclude, this paper has demonstrated the pertinence of using a clustered approach to relate
14 urban form and transit to activity spaces. Results point to a significant link between land use
15 clusters and activity spaces, and imply that efforts to increase density, mixity and transit
16 accessibility are valid investments for cities seeking to reduce travel demand they deem
17 excessive, environmentally detrimental or unproductive. Since household and CT characteristics
18 were used as control variables, the regression results make a strong case for promoting
19 densification, increased land use mixity and better transit provision.

20 An approach which could bear fruit to improve model accuracy in the future may be to use
21 latent-class linear regression, which would combine the land use clustering approach with a form
22 of household clustering. Instead of using continuous household or even CT variables like
23 income, number of cars, persons and children to predict activity spaces, they could instead be
24 treated as subpopulations. Another improvement could be to endogenize household location
25 (cluster) choice to account for residential selection bias.

26 Future research aimed at developing land use and transportation policy could definitely
27 make use of the clustered approach combined with activity spaces, but what this case study has
28 demonstrated is that the scale and heterogeneity of the region studied must be carefully
29 considered before undertaking such an endeavor. Smaller scales or an altered methodology
30 would be needed for clear policy to be written from these analyses, especially if it concerns
31 altering the off-island urban form and transit landscape. Cluster analysis provides an effective
32 means by which the potential impacts of urban form and transit interventions can be assessed,
33 and thus their costs and benefits properly evaluated.

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