Energy and Urban Form: Special Feature

Urban Form and Vehicular Travel: Some Empirical Findings

Eric J. Miller and Amal Ibrahim

This paper presents some empirical findings concerning the relationship between urban form and work trip commuting efficiency, drawn from the analysis of 1986 work trip commuting patterns in the Greater Toronto Area. "Work trip commuting efficiency" is measured in terms of the average number of vehicle kilometers traveled (VKT) per worker in a given zone. Preliminary findings include: VKT per worker increases as one moves away from both the central core of the city and from other high density employment centers within the region; "job-housing" balance, per se, shows little impact on commuting VKT; and population density, in and of itself, does not explain variations on commuting VKT once other urban structure variables have been accounted for.

Eric Miller is Professor of Civil Engineering and Director of the Joint Program in Transportation at the University of Toronto. Amal Ibrahim is a graduate student in the Department of Civil Engineering at the University of Toronto.

1. INTRODUCTION

This paper presents an empirical investigation into the relationship between auto usage and (implicitly) energy use and the spatial form of the Greater Toronto Area (GTA).

The second section of the paper provides a brief discussion of the relationship between urban form and vehicular travel. Section 3 describes the development of the database used for the work. Section 4 presents the empirical results which have been obtained to date. Finally, the fifth section discusses future research activities.

2. DISCUSSION

The relationship between urban form and transportation energy efficiency is a matter of considerable concern among planners and policy-makers dealing with issues of sustainable urban development. A recent comprehensive review of this issue is provided in [Anderson, *et al.*, 1996], and no attempt will be made here to cover this ground again in any detail. Rather, the starting point for this paper derives from the following very simple observations.

To begin, note that the energy consumed by the transportation sector depends directly on the level and spatial distribution of activities within the urban area and the "behavioral interconnections" between these activities as manifested in the spatial-temporal patterns of activity in which residents within the urban area engage. Let us loosely define this combination of the physical distribution of activities and the activity patterns of people over time and space as defining **urban form**. Note that activity patterns are essential to considerations of energy use: the same distribution of population, employment, etc. can give rise to quite different levels of energy use, depending on the nature of the home-work, home-shop and other linkages which actually exist at any point in time.

The physical distribution of activities is, in principle at least, susceptable to some measure of control through mechanisms such as official plans, zoning, and the provision of physical infrastructure such as roads, sewers, etc. Much of the literature dealing with urban form has focused on this component of the problem, generally reducing to the consideration of a relatively few key "dimensions":

(a) **density**;
(b) **sprawl** or **degree of decentralization**; and
(c) **structure**.

These three dimensions tend to be interrelated but they are not identical. Density measures the intensity of a given activity at a point in space. Decentralization provides a measure of where this point is in space, taking the Central Business District (CBD) or city center as the point of reference. Structure here is meant to cover a combination of factors relating to the mix of activities at a point (or within a relatively small area) -- the extent to which workers have ready access to jobs, the amount of mixed-use development which occurs in a given location, and, in general, the overall distributions of people and activities over the two-dimensional urban space.

In this paper we attempt to use simple measures of density, decentralization and structure in order to represent the physical component of urban form.

Activity (and, eventually, travel) behavior is generally more indirectly affected by public policy. Provision of transportation infrastructure and services can directly affect behavior, as can various "transportation demand management" policies. A wide variety of other policies (taxation, monetary policy affecting interest rates and macroeconomic performance, etc.) can have a variety of effects. Ultimately, however, the final outcome is the result of the complex location and activity/travel choices which people make over time in response to these various stimuli. Any projection of the future impacts of a given policy ultimately requires a dynamic model of transportation - land use interactions. This is the subject of other research of the primary author [Miller and Salvini, 1998], but is not the focus of this paper.

In the cross-section (i.e., at a single point in time), observed travel patterns can be used to represent the outcome of this dynamic land use - transportation process. In this paper we use the Greater Toronto Area (GTA) as our case study and examine the spatial distribution of travel behavior for the GTA as captured in a major travel survey conducted in 1986.

Given a particular travel pattern, energy use depends upon the modes of travel used, the energy efficiency of the various vehicles being operated, travel speeds, congestion levels, etc. [Miller and Hassounah, 1993]. Ultimately, however, transportation energy consumption is dominated by the energy used by private automobiles and trucks. In this study we focus on private auto usage. Automobile energy use, in turn, is highly correlated with the total number of vehicle kilometers traveled (VKT). In this study, VKT is taken as the primary variable summarizing both travel demand and energy use. VKT is a convenient summary measure which reduces the highly dimensional nature of travel demand (number of trips, the spatial distribution of these trips, the modes and routes used on these trips) to a single variable, as well as a useful surrogate for the amount of energy consumed in executing these complex travel patterns.[1]

[1]VKT is not a perfect surrogate for automotive energy use, however. Vehicle stock, driving cycle and even weather can influence energy use per VKT.

Many empirical studies involve analysis of data from many different cities in an attempt to identify variations in energy efficiency as a function of urban form defined at the very aggregate level of the entire urbanized area. While undoubtedly useful, such analyses have at least two potential problems.

First, it is not an easy task to characterize an entire urban area's "urban form" in a few simple variables which are susceptible to statistical analysis. The result is often the use of overly aggregate and simplistic variables which may or may not be "representative" of a given urban area and which may or may not be consistently computed among the urban areas in the sample. As a simple example, "average population density" for a city such as "Toronto" is a variable which often enters these analyses. But what is meant by "Toronto" is often unclear: is it the City of Toronto, Metro Toronto, the Toronto Census Metropolitan Area (CMA), the GTA, or some other variation on this theme? Further, for any given spatial definition of "Toronto", given the considerable variation in densities which occur, how meaningful is average density as an explanatory variable?

Second, the policy guidance provided by such aggregate, cross-city analyses is not always clear. Taking density again as the example, if such an analysis indicates that, on average, an urban area's energy efficiency improves with increased density, what does this imply for urban design and planning within a given urban area. Should higher densities be encouraged everywhere? Are certain areas or combination of factors more conducive to achieving energy efficiency improvements through density increases than others? Questions such as these presumably require more detailed, intraurban area analysis.

In response to the arguments presented above, the focus of this paper is to explore empirically the cross-sectional relationship between the physical dimensions of urban form (density, degree of decentralization, structure) and auto travel (as a surrogate for energy use) within a large urban area (the Greater Toronto Area), with particular emphasis on identifying within-area variations in VKT as a function of within-area variations in the urban form attributes.

3. DATA

The study area is the Greater Toronto Area (GTA), defined as the six regional municipalities of Toronto, Durham, York, Peel, Halton and Hamilton-Wentworth. This is a broad functional definition of the urban region surrounding the City of Toronto which encompasses three Canadian Census Metropolitan Areas. This study area is divided into 1404 zones, defined by the 1991 GTA Traffic Zone System.

All travel-related data used in this study are obtained from the 1986 Transportation Tomorrow Survey (TTS) database [Data Management Group, 1987]. While the larger study from which this paper is drawn dealt with all trip purposes [Ibrahim, 1997], this paper focuses on 24-hour on **Home-Based-Work (HBW) trips**. A trip which begins or ends at home, with the other end of the trip being work is classed as a HBW trip. The home end of the trip, regardless of whether home is the origin or destination of the trip is referred to as the **production** end of the trip. The work end of the trip, again regardless of trip direction, is the **attraction** end of the trip. These traditional transportation modeling definitions relating to HBW trips are useful in this application since they allow us to aggregate work-trip making by home zone (and hence relate it to the residential population and employed labor force) and by work zone (and hence relate it to employment).

Vehicle kilometers traveled (VKT) for a given zonal origin-destination (O-D) pair were calculated using the EMME/2 road network assignment procedure.[2] Observed 1986 peak-period vehicle trips were assigned to the 1986 network using the EMME/2 deterministic user equilibrium assignment procedure [INRO Consultants, 1994]. As part of this assignment, equilibrium O-D travel distances over the road network were computed. Multiplying these distances by O-D flows for a given trip purpose yields VKT for this trip purpose on an O-D basis.

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[2]This procedure assigns traffic to the fastest available routes from origin to destination while taking account of the congestion implied by the entire pattern of zone-to-zone flows.

These O-D VKTs were then summed by origin or destination, as appropriate to generate zone-based VKT totals.

The O-D network travel distances computed within the EMME/2 network model are based on morning peak-period congestion levels. These distances, however, have been applied to 24-hour flows under the assumption that non-peak trip distances do not deviate significantly from peak-period distances. Zone-based network models such as EMME/2 do not directly provide an estimate of intrazonal travel times or distances, since these trips by definition travel zero distance within these models (i.e., the trips never leave their zone centroids). In order to estimate these distances, average straightline distances for intrazonal trips observed in the 1986 TTS were computed for each zone using the trip geocodes.

Note that all densities used in this study are based on gross land area. In addition, all distances are straightline, centroid-to-centroid distances. This distance metric is deliberately chosen over the road network distance measure discussed above in order to use as "abstract" (transportation network independent) a measure as possible. One difficulty with straightline distance which has not yet been corrected in the analysis is that centroid-to-centroid straightlines between Hamilton and locations on the north shore of Lake Ontario cut across the lake -- probably implying that even in this "abstract" spatial dimension we are underestimating the spatial separation between Hamilton and the rest of the GTA.

4. ANALYSIS

The empirical analysis is divided into two sections: 1.descriptive analysis of the GTA's urban spatial structure; and 2.descriptive analysis of the spatial distribution of HBW vehicular travel across the GTA, and its correlation with spatial structure.

4.1 GTA Urban Structure

Figure 1 plots the 1986 population density distribution for the GTA. This distribution can be characterized as follows:

1. a relatively high density central city, largely contained within the City of Toronto;
2. medium to high densities throughout most of the remainder of Metropolitan Toronto;
3. medium density development running east and west from Metro Toronto along the lakeshore (this lakeshore corridor is served by both expressways and commuter rail lines and is historically the main travel corridor through southern Ontario);
4. medium to high densities in traditional smaller cities within the GTA of Hamilton (west end of the lake), Oshawa (east of Metro Toronto) and Brampton (north-west of Metro Toronto); and
5. very low density development scattered throughout the remainder of the GTA.

Figure 2 similarly plots the 1986 employment density distribution across the GTA. Points to note concerning this distribution include:

1. the very high concentration of jobs in the Toronto Central Area, stretching from the lake up the Yonge Street corridor is very evident;
2. in addition to the lakeshore corridor, a second corridor exists along Highway 401, a major expressway running east-west through the region, passing through the northern third of Metro Toronto and the City of Mississauga (immediately west of Metro Toronto); in particular, with the exception of the traditional employment nodes of the central areas of Toronto, Hamilton and Oshawa, virtually all high density employment zones (5000 or more employees/km^2) are located within the Highway 401 corridor; and
3. although difficult to discern in Figure 2, much of the employment within Metro Toronto has traditionally been located in an "industrial U" running from the northwest corner of Metro diagonally down to the Central Area and the diagonally back up to the north-east, following railway main lines through the city.

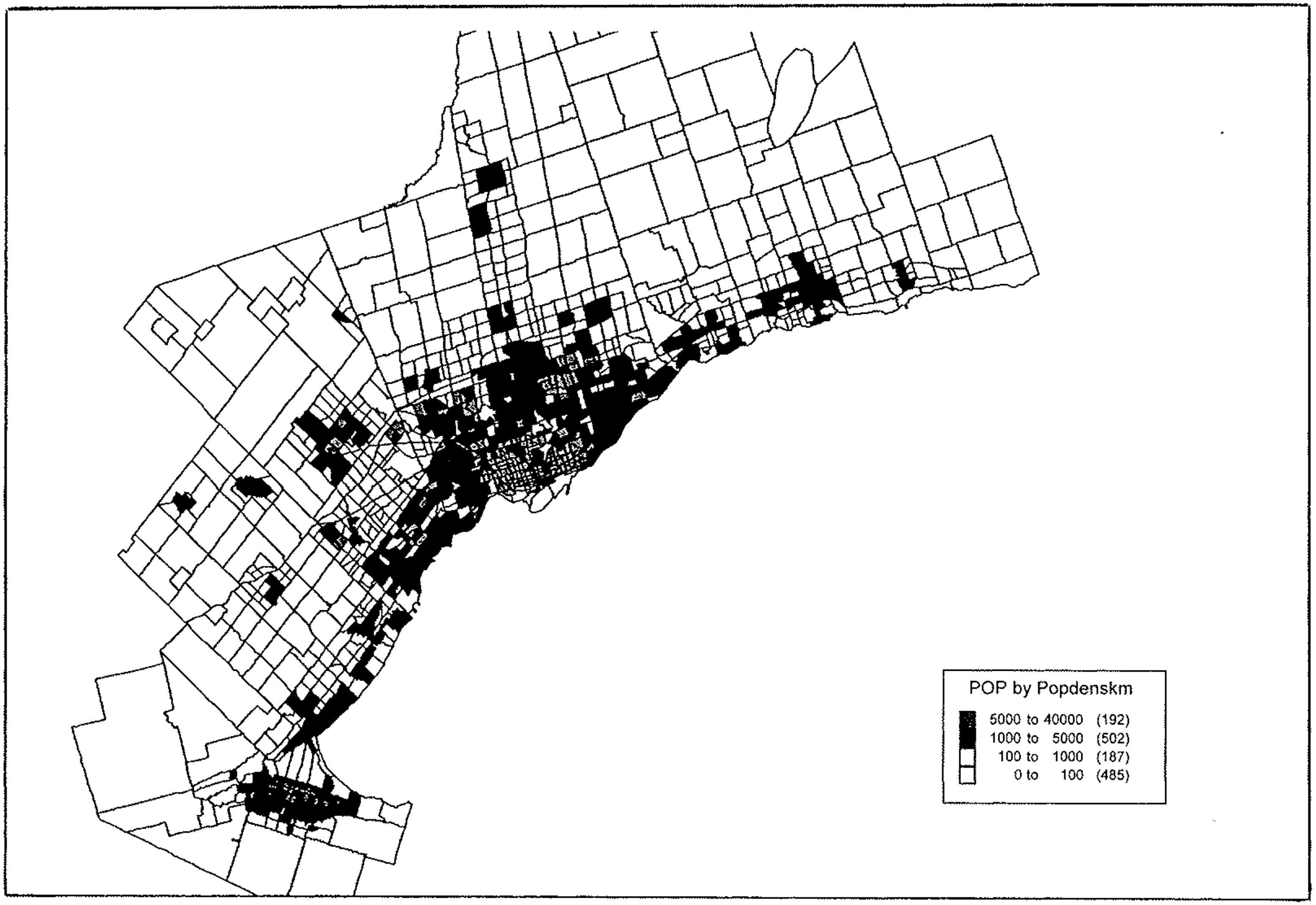

Figure 1
Spatial Distribution of GTA Population Density

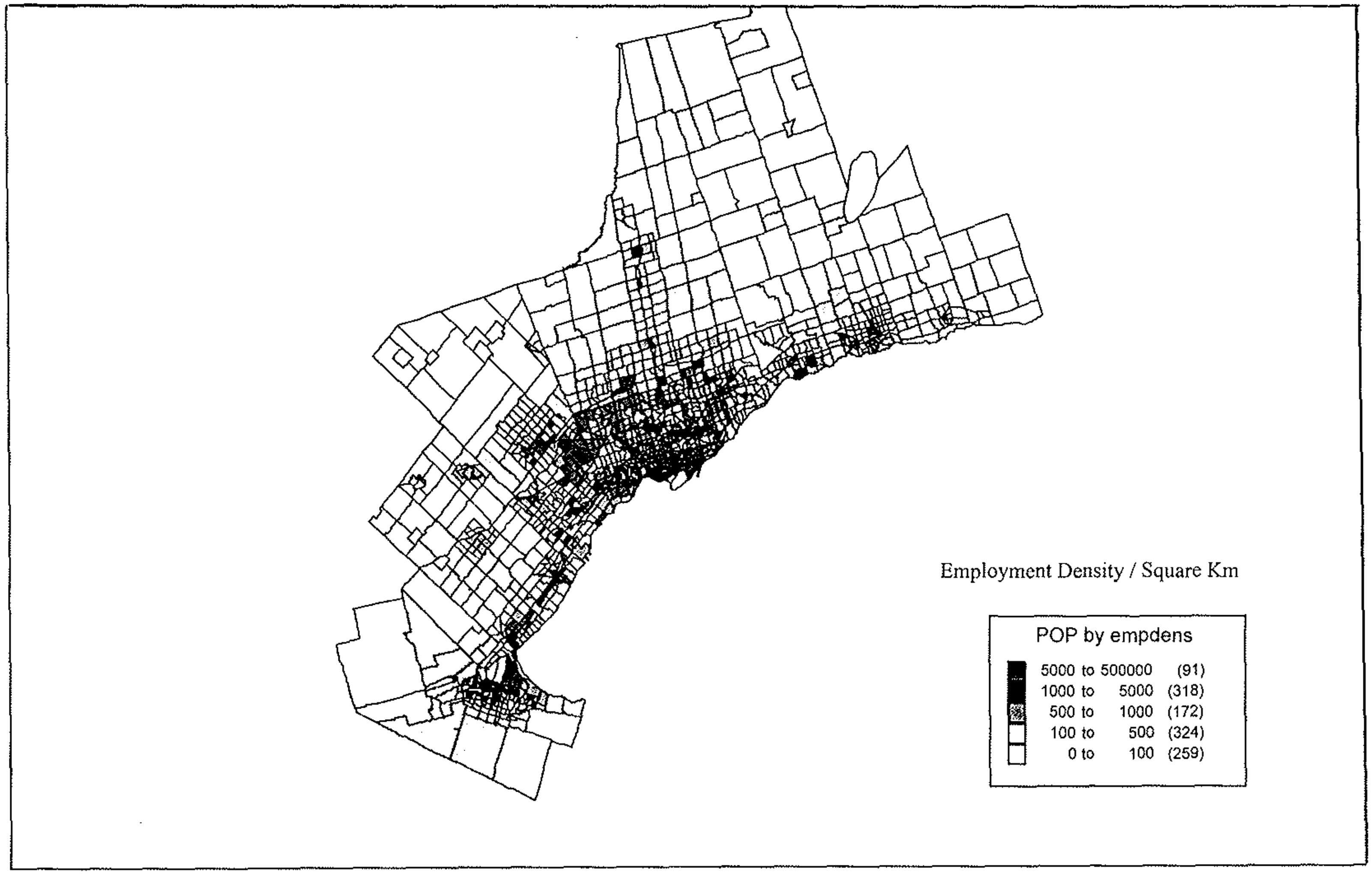

Figure 2
Spatial Distribution of GTA Employment Density

What cannot be seen in Figures 1 and 2 are the trends in these distributions over time, both before and since 1986. Very simplistically, these include:

1. continued growth in both population and employment within the Central Area of the City of Toronto;
2. modest employment growth and very little population growth in the remainder of Metro Toronto, with the overall modest employment growth being generated by a combination of lost manufacturing jobs (typically from the "industrial U" area) and new service-based jobs in suburban office locations; and
3. considerable growth in both population and employment, generally in a relatively low density, dispersed manner, outside the Metro Toronto boundary.

Figure 3 provides one measure of accessibility to employment. This figure plots the number of jobs within 5 km (straightline distance) of each residential zone's centroid. The figure shows a very smooth, radially decreasing pattern of employment accessibility as one moves away from the Toronto Central Area, although accessibility remains high throughout most of Metro and into eastern Mississauga. The influence of Hamilton in the west and Oshawa in the east as local employment centers is also very evident.

Figure 4 provides one measure of the spatial distribution of household auto availability in terms of the percentage of zonal households having access to two or more vehicles. Most of the zones outside Metro and the City of Hamilton have very high levels of auto availability, generally showing a high correlation with distance from the Toronto Central Area.

Finally, Figure 5 displays the proportion of zonal 24-hour produced trips (i.e., home-based work trip productions plus non-work trip origins) which use some form of public transit. Transit service exists throughout most of the developed portion of the GTA. Significant levels of transit usage only exist, however, within Metro Toronto (particularly within central areas), the City of Hamilton, and portions of central Mississauga, which also has a reasonably evolved local transit service. The negative correlation of this pattern of transit usage and the household vehicle availability distribution shown in Figure 4 is self-evident.

From the foregoing analysis it can be argued that the Greater Toronto Area consists of several "urban structures" superimposed on and interacting with one another. In addition to the reasonably self-contained cities of Hamilton and Oshawa at the western and eastern ends of the GTA, at least three distinct regions exist within the GTA:

1. **The central region**, consisting of much of the City of Toronto and adjacent inner-Metro areas. In this region population and employment densities are high, transit usage is quite high by North American standards, and auto ownership is relatively low.
2. **The remainder of Metro Toronto.** This "inner suburban" ring is, in many respects, the most interesting of the three in that it is probably the most unique in North American terms. Although largely "suburban" rather than "urban" in form, densities in this area are on average higher than normally experienced, transit usage and auto ownership are still relatively high and low, respectively, and, as is discussed in more detail in the next section, the "energy efficiency" of trip-making in this region is not dissimilar from that associated with the central, more highly urbanized region.
3. **The remainder of the GTA.** Outside Metro lie the newer suburban regions where most population and employment growth is occurring. These areas are similar in design and as auto-dominated as any other late Twentieth Century North American suburban area.

4.2 Spatial Distribution of Vehicular Travel Across the GTA

Figure 6 plots 1986 average 24-hour HBW VKT "produced" per resident adult for each zone in the GTA. As shown in this figure, the average HBW VKT generated by Metro residents is quite low (generally less than 10 km/adult), reflecting a

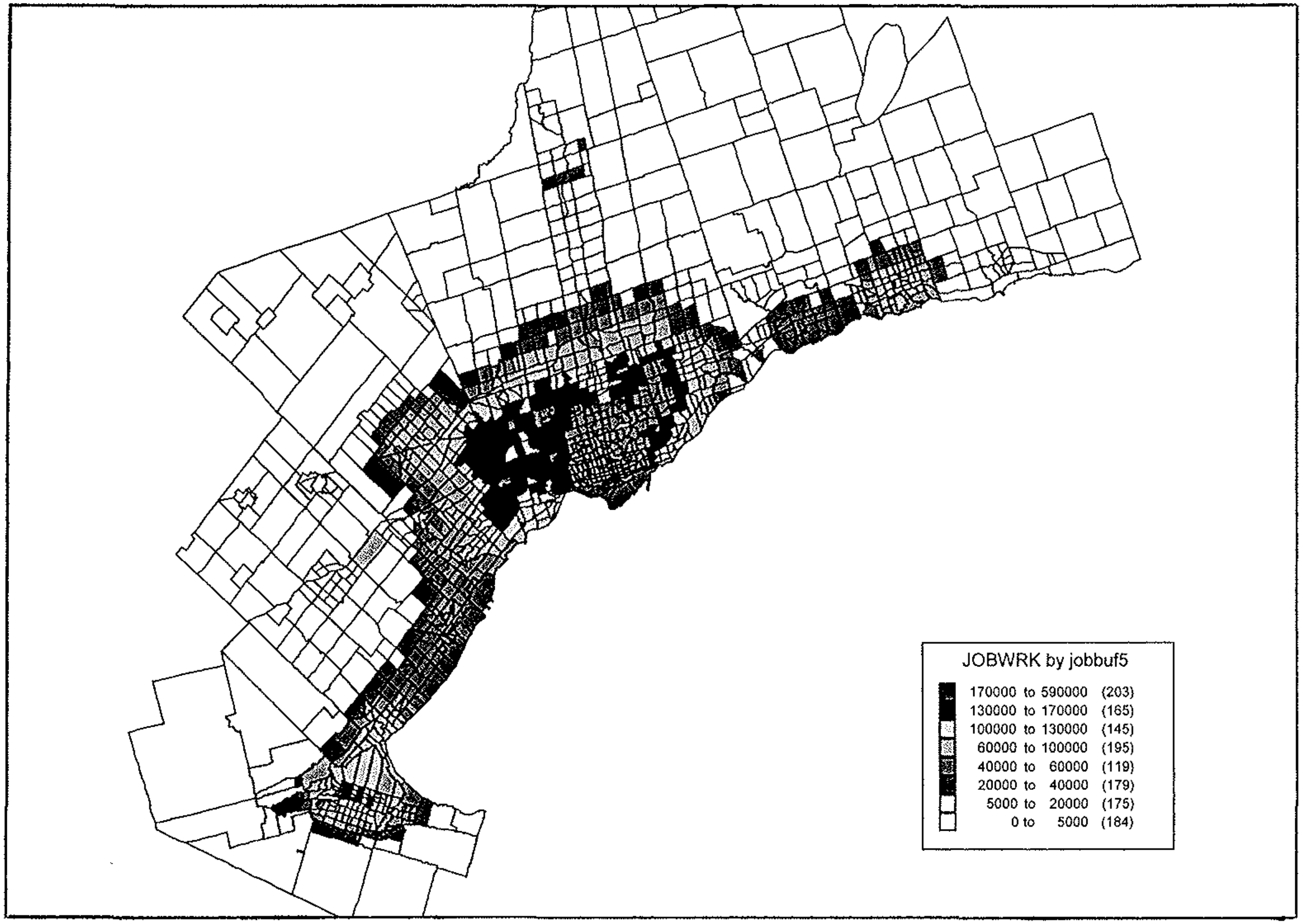

Figure 3
Spatial Distribution of GTA Jobs within 5 Km of Each Residential Zone

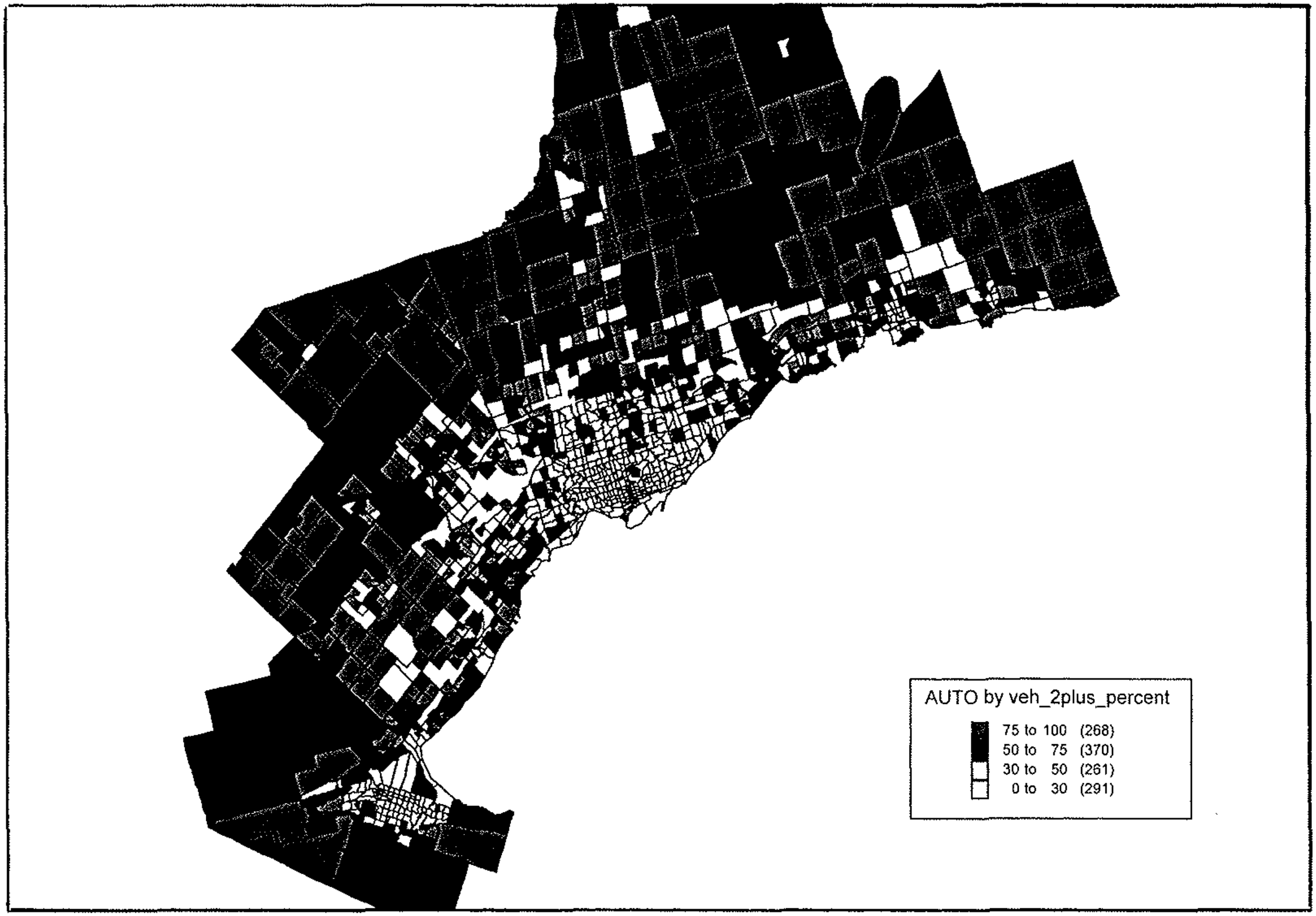

Figure 4
Spatial Distribution of GTA Households with 2 or More Vehicles

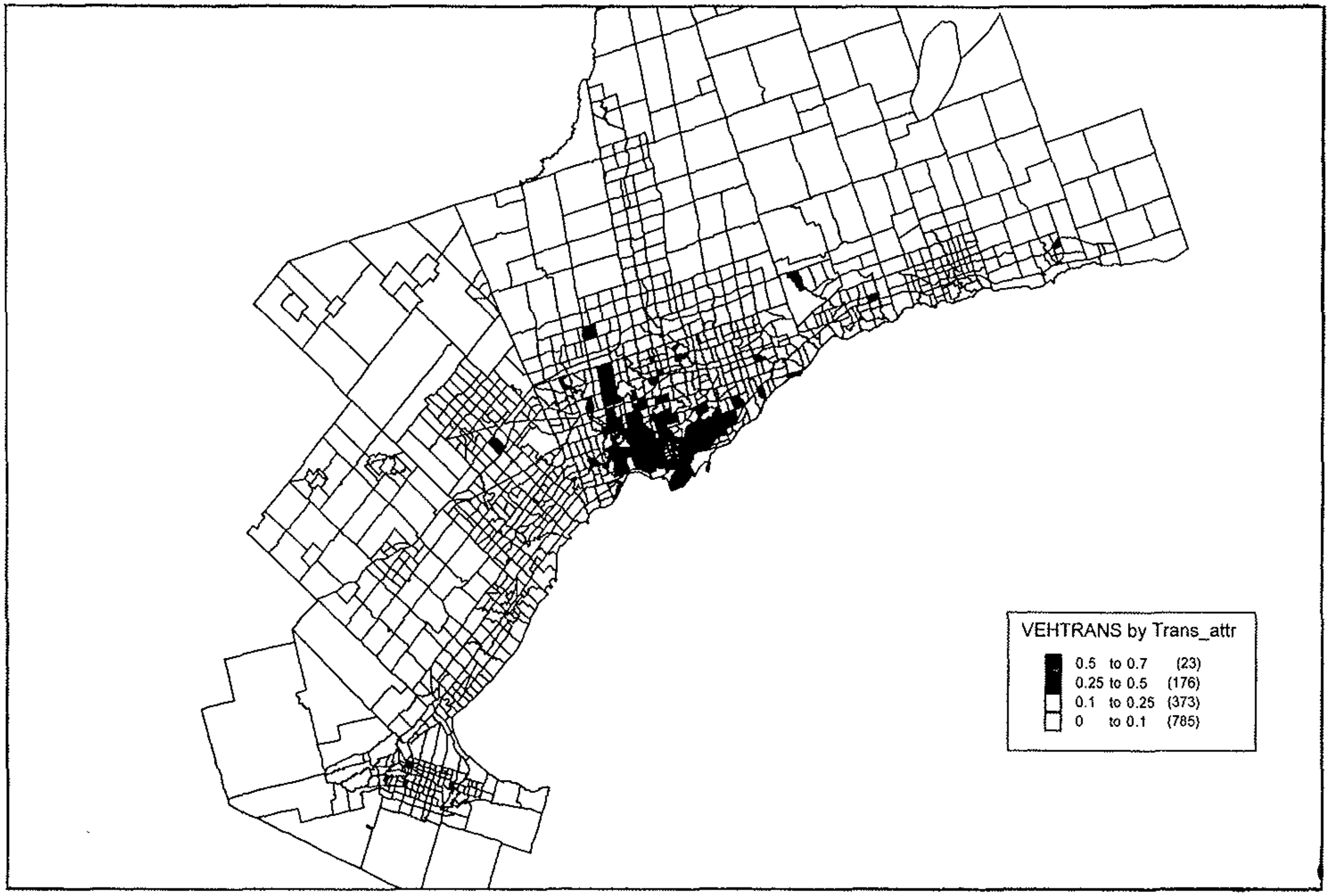

Figure 5
Spatial Distribution of GTA Produced 24-Hour Public Transit Trips

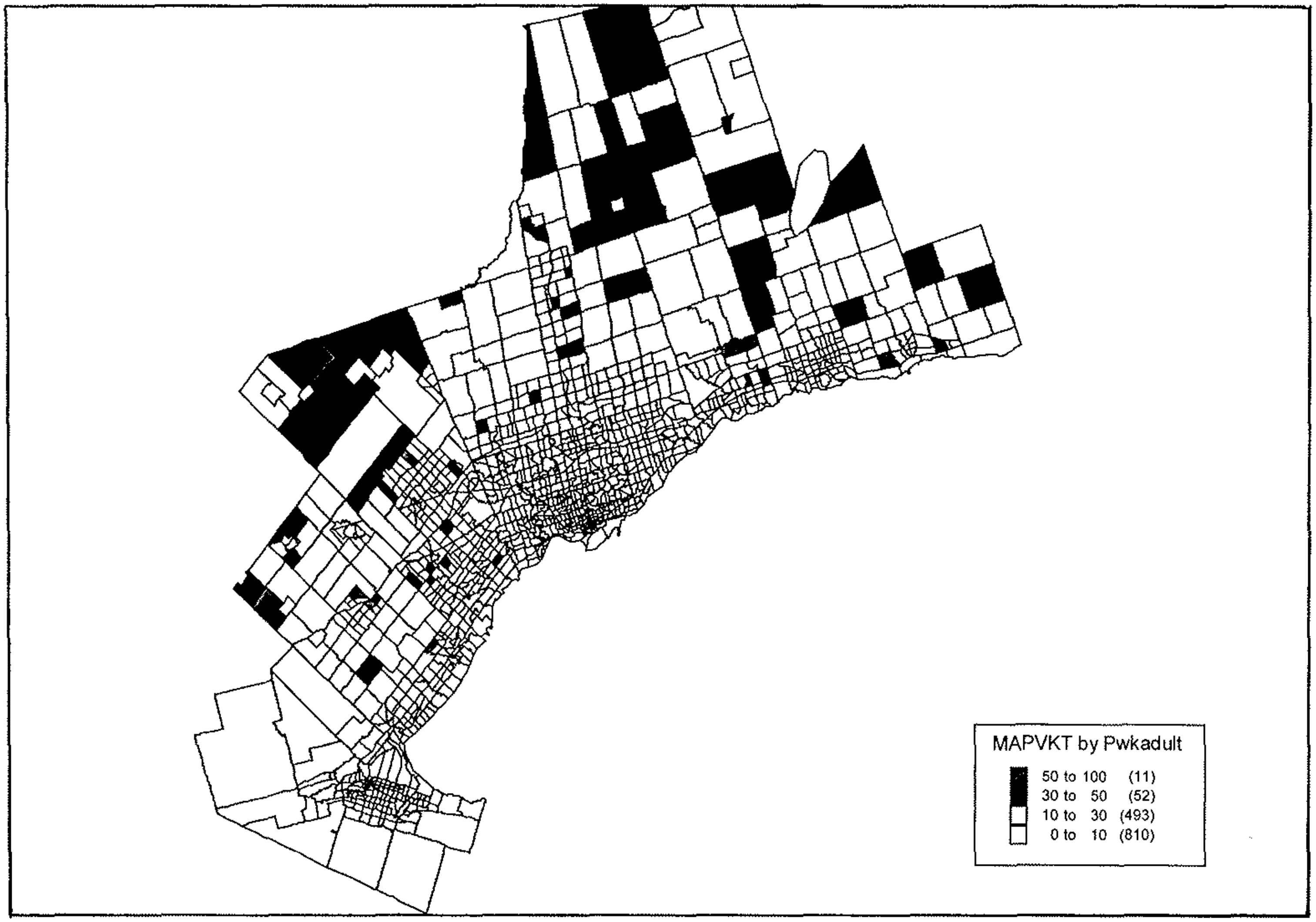

Figure 6
Spatial Distribution of GTA Produced Work VKT per Adult

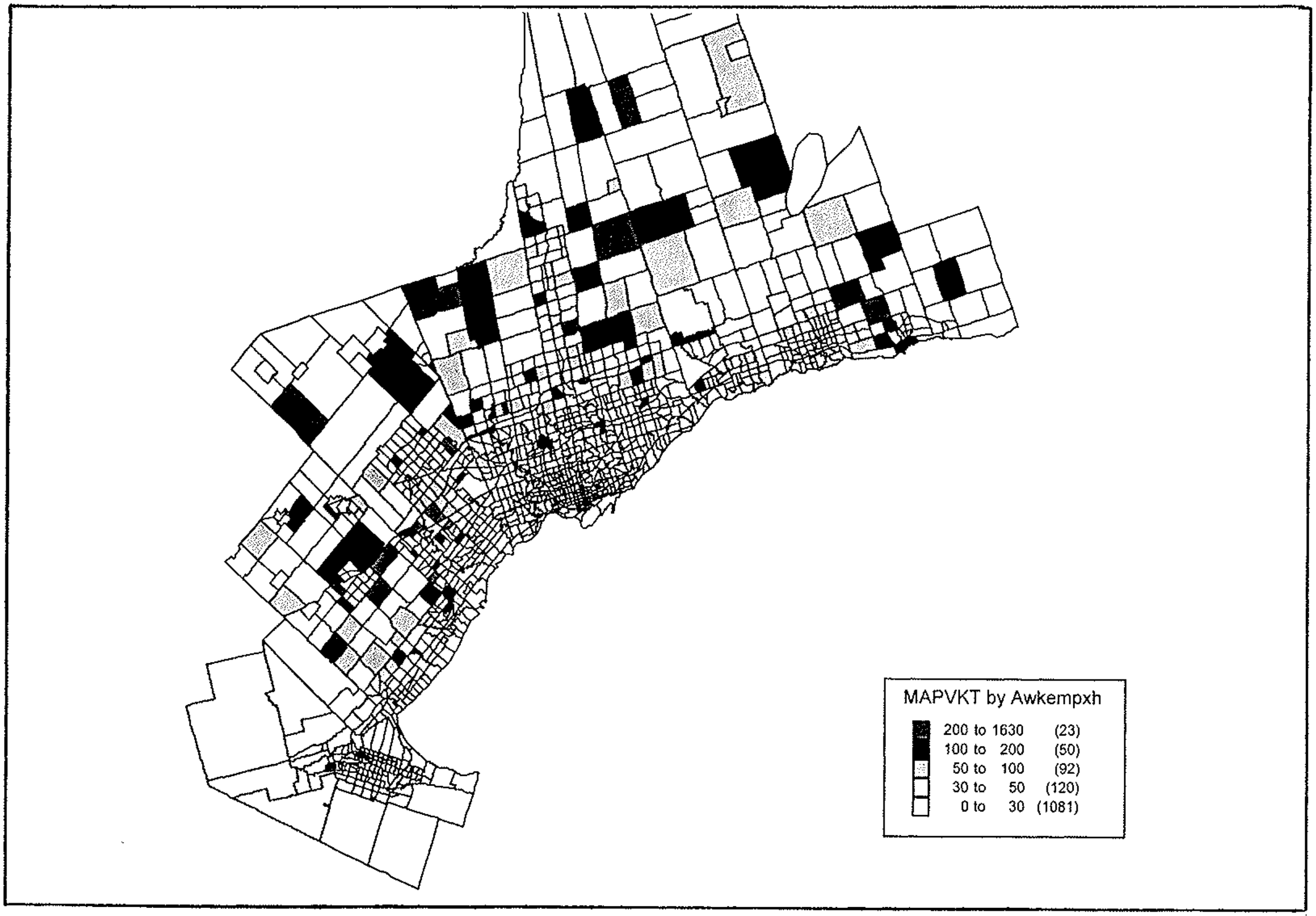

Figure 7
The Spatial Distribution of GTA Attracted Work VKT per Employee

combination of relatively short trip lengths and high levels of transit usage (and/or walk trips in the central area). Also note, at the level of precision presented in Figure 6, that there is no discernable difference between the VKT generated by residents of the higher density central region and the relatively lower density suburban portions of Metro.

Outside Metro, HBW VKT per adult rises significantly, typically averaging 10 to 30 km/adult, with values tending to rise as one moves further from the Metro boundary.

Figure 7 similarly plots average HBW VKT "attracted" per job for each zone. Comparing this figure with the employment distribution shown in Figure 2, it is seen that the high employment zones throughout much of the GTA have relatively similar levels of attracted VKT per worker, of under 30 km/worker. Though showing considerable scatter, this value tends to rise as one moves into the GTA hinterland, although in many cases the values shown are based on relatively few observed trips.

Although clearly very qualitative, Figures 6 and 7 provide little support for the hypothesis that the combined decentralization of employment and population results in a more efficient commuting pattern (due to shorter trip lengths, etc.) relative to a more monocentric structure in which a dominant employment center exists. While it is true that average trip lengths to the Toronto Central Area are longer than to other GTA locations, these longer trip lengths are more than compensated for by the significantly higher transit modal shares which are achievable in the high density radial travel corridors into the central city.

Figures 8 and 9 plot HBW VKT produced per worker resident in each zone versus distance from the Toronto CBD, categorized by zone population density. These figures only contain zones up to 40 km away from the Toronto CBD, since beyond this range the impact of the City of Hamilton on VKT levels confounds the analysis. Despite the considerable scatter in the data, a clear increase in VKT per worker with increased distance from the CBD is evident.

Table 1 summarizes various simple linear regressions which were run on these data. Points to note from Figures 8 and 9 and Table 1 include the following.

1. Clear differences exist between the "behavior" of very low density zones (less than 250 persons/km^2) and higher density zones. Average HBW VKT per worker for the low density zones exhibits a huge amount of scatter and low correlation with distance from the CBD. This is probably due to the small sample sizes typically obtained for these zones. In addition, many of these zones lie in the fringe areas of the GTA and hence are relatively undeveloped and/or may have significant interactions with areas external to the GTA, which are not captured in this analysis. Given these observations, these very low density zones are excluded from subsequent analyses presented in this paper.
2. As shown in Table 1, little differences exist in the relationship between HBW VKT per worker and distance from the CBD as density varies above the 250 persons/km^2 level, implying that density *per se* has little effect on HBW VKT. This is confirmed by a regression of VKT/worker versus density (not shown here), in which density is found to have relatively low explanatory power (R^2 of 0.143), although a statistically significant negative relationship does exist.
3. Given the statistically insignificant differences among the population density categories above the 250 persons/km^2 level shown on Table 1, subsequent analysis pools these categories together.

Table 2 presents a set of additional regressions, in which variables other than distance to the CBD are introduced. In all cases, the zones included in the analysis lie within 40 km of the Toronto CBD, and have population densities greater than 250 persons/km^2. Points to note from these regression results include the following.

1. Distance from the CBD is by far the single most important explanatory variable, explaining 41% of the observed variance in VKT per worker.
2. In regressions not shown here, the percentage of 2+ vehicle households also

Figure 8
HBW VKT Produced Per Worker Versus Distance from the CBD,
Population Density < 250 Persons/Km

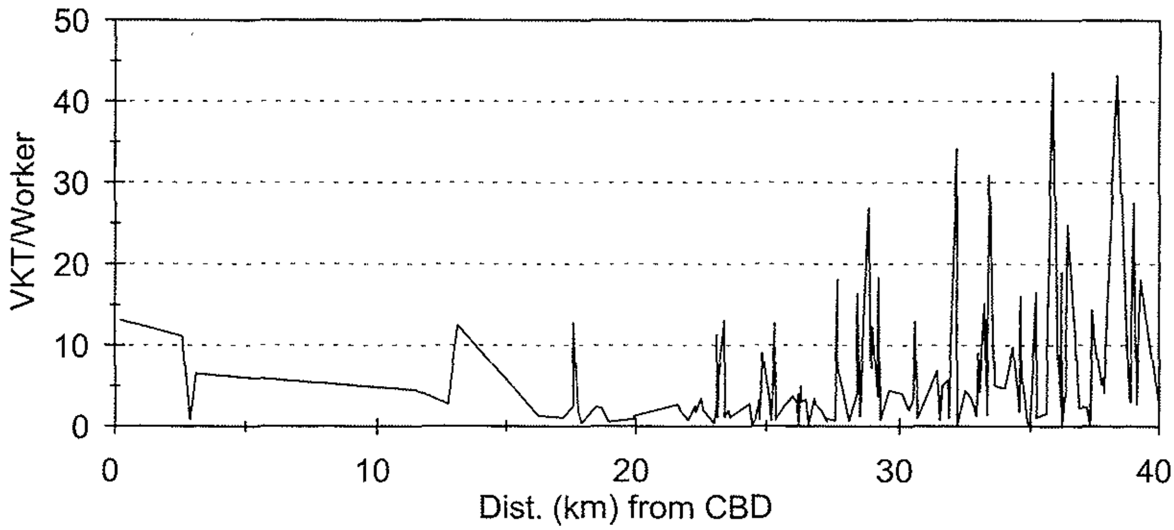

Figure 9
HBW VKT Produced Per Worker Versus Distance from the CBD,
Population Density > 250 Persons/Km^2

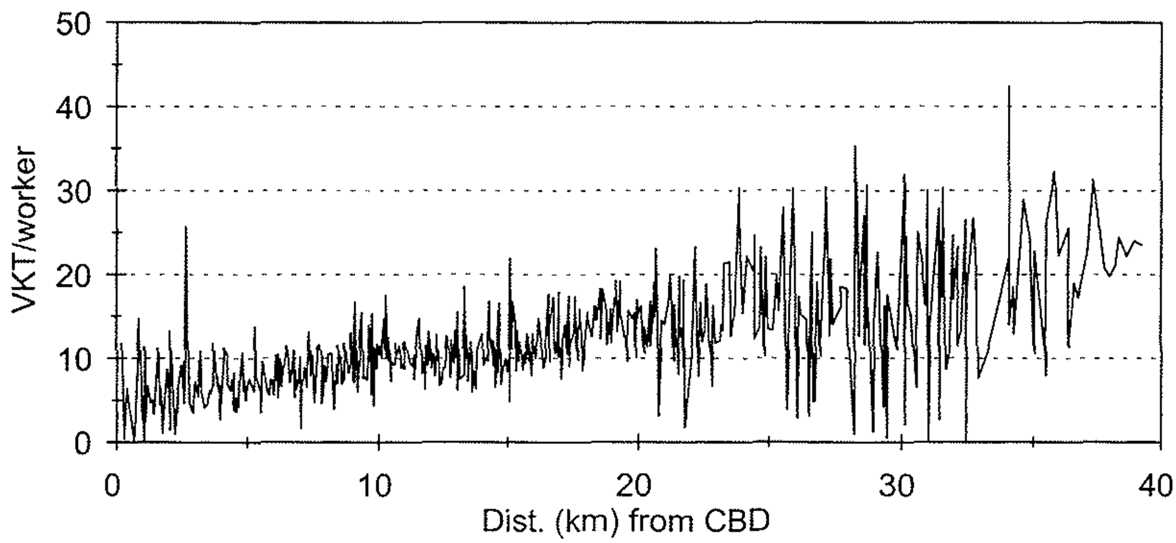

Table 1

Variation in Produced HBW VKT with Density and Distance from the CBD

All regressions are of the form: VKT = a + b*DCBD

where: VKT = Average daily HBW VKT per worker produced by the residential zone

DCBD= Straightline distance (km) from the zone to the Toronto CBD (taken as the centroid of GTA traffic zone 408)

(A) REGRESSION RESULTS

	Pop. Density Range (persons/km^2)	a	b	R^2	No. of Obs.
1	0 - 250	-1.67	0.189	0.048	246
2	250-500	0.31	0.501	0.175	28
3	500-1000	2.87	0.383	0.270	41
4	1000-2000	7.15	0.379	0.320	79
5	2000-4000	5.49	0.415	0.412	203
6	4000-10000	4.29	0.382	0.503	199
7	> 10000	2.92	0.514	0.532	38

(B) PAIRWISE T-TESTS FOR DIFFERENCES IN VALUES OF "b" BETWEEN POP. DENSITY CATEGORIES

	1	2	3	4	5	6
2	1.42					
3	1.70	0.50				
4	2.30	0.55	0.03			
5	3.53	0.40	0.31	0.50		
6	3.22	0.55	0.00	0.05	0.75	
7	3.37	0.06	1.02	1.33	1.13	1.56

Table 2
Selected Regression Results, HBW VKT Per Worker Produced Per Zone As A Function of Urban Structure Variables
(T-statistics in brackets)

Model No.:	**1**	**2**	**3**	**4**	**5**	**6**
Constant	5.60	5.60	6.49	7.28	7.38	7.42
DCBD	0.401	0.316	0.282	0.267	0.250	0.250
	(20.04)	(12.57)	(10.65)	(9.36)	(7.28)	(7.25)
DHEMP		0.357	0.380	0.381	0.383	0.382
		(5.41)	(5.80)	(5.81)	(5.84)	(5.81)
WRAIL1			-1.632	-1.556	-1.472	-1.468
			(-3.59)	(-3.41)	(-3.15)	(-3.14)
EMP/POP				-0.945		
				(-1.45)		
EMP5N					-1.554	-1.465
					(-1.46)	(-1.28)
POPDEN						-0.014
						(-0.22)
R^2	0.411	0.440	0.452	0.454	0.454	0.454

Variable Definitions:

Dependent Variable: Average HBW VKT per worker produced per zone, zones within 40 km of the Toronto CBD and with a population density greater than 250 persons/km^2

DCBD Straightline distance from zone to Toronto CBD (zone 408), km

DHEMP Straightline distance from zone to the closest high density employment zone (>5000 jobs/km^2) outside the Toronto Central Area, km

WRAIL1 = 1 if the zone is within 1 km straightline distance of a subway or commuter rail station; = 0 otherwise

EMP/POP Number of jobs within a 5 km radius of the zone centroid divided by the population within this same 5 km radius

EMP5N Number of jobs within a 5 km radius of the zone centroid, normalized on the range 0 to 1 by dividing by the largest observed value for jobs within a 5 km radius

POPDEN Zone population density (10^3 persons/km^2)

has considerable explanatory power. Given its high correlation with distance to the CBD, as well as the expectation that a behavioral relationship underlies this correlation (i.e., people who live in increasingly remote locations will be increasingly auto dependent and hence need to have access to many vehicles), in the absence of a structural equations analysis of this system (something which was beyond the resources of the current study), only one of these two variables should probably be included in the analysis. Since distance from the CBD is a "physical structure" variable while auto ownership is a "behavioral response" variable, it is assumed that distance from the CBD is the more "fundamental" of the two, and it is retained in subsequent regressions.

3. Distance to the nearest high density employment center (outside the Central Area) and being within walking distance of a rail station (1 km or less) make statistically significant contributions to the model, with expected signs (positive and negative, respectively).
4. Two "self-containment" measures were experimented with. EMP/POP is the ratio of employment to population located within 5 km of each residential zone's centroid. EMP5N is simply the employment located within 5 km of each zone's centroid, normalized by the largest such value. Both variables are marginally significant (93% confidence level, one-tailed test) and do not improve the overall goodness-of-fit of the model. Somewhat arbitrarily, EMP5N is kept in the model rather than EMP/POP.
5. Population density does **not** make a statistically significant contribution to the model, once the variables discussed above have been included.

While this analysis is admittedly simple (if not also simplistic) it provides at least partial tests of several hypotheses concerning the relationship between urban form and work trip commuting efficiency. First, and foremost, to the extent that the distance from the CBD variable can be interpreted as a measure of the effect of "sprawl" or "decentralization", it is seen that VKT per worker clearly increases as workers live farther from the city center. In this case, average VKT per worker increases on average by about 0.25 km for every km the worker moves away from the CBD. This finding provides support for those who argue in favor of dense, compact urban forms.

The argument that "edge cities", in which large suburban employment "centers" bring jobs closer to the suburban resident labor force, may, in fact, be "efficient" is also supported by the results, given the significance of the "distance to nearest high density employment center" variable. On average, reducing this distance 1 km (either by the worker moving closer to the center or by moving the center closer to the worker) reduces average VKT per worker by about 0.38 km. Some care, however, should be taken in extrapolating these results to suburban employment centers in other cities, given that in the Toronto case many of these suburban centers are relatively well served by transit (e.g., Mississauga), and/or may, in fact, be traditional, smaller urban centers which have been subsumed within the GTA urbanized area (e.g., Brampton, Oshawa) and which historically have had a well defined localized labor market.

In addition note that the **net** effect of employment suburbanization on work trip commuting efficiency will depend on the relative location of this employment growth relative to the population distribution, as well as on its long-run impact on this population distribution. Given a fixed population distribution, locating high density employment centers outside the central area will generate a net reduction in VKT. If, however, these centers encourage a redistribution of population (in particular, increased decentralization of this population), then the net effects are less clear.

To the extent that the EMP/POP and EMP5N variables capture some notion of "self-containment", the results shown in Table 2 provide little evidence that self-containment is being achieved to any great extent within the GTA and hence that "jobs-housing balance" leads to any significant VKT savings. The result is not inconsistent with the findings of Giuliano and Small [1993]. Also, combined with the strong performance of the DHEMP variable, these results would argue in favor of concentrated regional employment centers to capture suburbanizing employment, rather than permitting this employment to disperse in a more haphazard fashion.

Population density fares surprisingly poorly in this analysis, especially given the prominence it usually receives in the literature. One possible interpretation of this result is that it is not density *per se* which determines VKT, but rather **compactness**. As compactness increases, densities must necessarily rise in order to accommodate a given number of people within a smaller area. Of course, operationally, increasing residential densities is how greater numbers of people are housed within a more compact urban form. Further, it is higher densities (especially within well defined travel corridors) which make high quality transit services possible, which, in turn, provide much of the efficiency achieved by compact urban forms. The key point emerging from this analysis is that **where** the high density is achieved is important: it should be concentrated near high density employment centers, whether these be the traditional city core or newly emerging regional sub-centers.

5. SUMMARY AND FUTURE WORK

Trends and intercity differences in commuting patterns are key to understanding trends in transportation energy use. Although a very preliminary and sketchy analysis, the findings presented in this paper provide some clues to the interrelationship between urban form and work trip commuting efficiency, at least as these relationships manifest themselves within the Greater Toronto Area. These include:

1. Centralization or compactness matters: VKT per worker clearly increases as one moves away from the city center, and/or other major employment zones within the urban area.
2. Assuming that a suburbanized population is a fact of life, a multi-regional system of high density employment/activity centers appears to reduce VKT per worker relative to what would likely occur in the absence of these sub-regional centers (especially if the employment in these centers were to stay in the suburban areas in a more dispersed fashion).
3. No strong evidence is found that "self-containment" or "jobs-housing balance" is an effective policy for reducing VKT per worker, over and above the impacts of the suburban employment centers discussed in point 2.
4. Population density appears to more of an "intermediate" variable than a strong "causal" variable in the explanation of variations in VKT per worker across the urban area.

Many possibilities exist for extending this work. These include:

1. Using data from addition surveys undertaken in 1964 and 1996 to explore time-series trends in these relationships.
2. Moving beyond simple one-equation regressions to a structured equations approach, in order to address the interconnectedness of many of these variables (e.g., the relationships between urban structure, auto ownership and travel behavior).
3. Exploring the impact which spatial autocorrelation may have on the results.
4. Extending the analysis to other North American urban areas.

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