

**Investigation of the Relationship between Urban
Spatial Structure and Travel Demand in the GTA**

by

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A thesis submitted in conformity with the requirements for the degree of
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ABSTRACT

This thesis includes analyses to explore empirically the cross-sectional relationship between the physical dimensions of urban form and auto travel as a surrogate for energy use within the Greater Toronto Area, with particular emphasis on identifying variations in VKT as a function of variations in urban form attributes.

A number of variables in the 1986 Transportation Tomorrow Survey (TTS) database were extracted to represent spatial structure and travel demand in the GTA. Attempts were made to define combination of physical distribution of activities over space such as density, degree of sprawl, accessibility to employment, self containment ratio, demographic characteristics, and transit use, to reflect the urban form of the GTA.

Analyses were performed to test several hypotheses related to urban form and travel demand. Both population and employment density were found to be influential factors in determining travel demand. Also, both degree of sprawl and accessibility to the nearest employment node, explained to a great extent variation in vehicular travel demand. Also, both ratios of spatial match between employment opportunities and labour force, and self containment were found to be significantly influencing travel demand in the GTA.

Stepwise regression technique was used to test the explanatory power of combinations of spatial structure variables to variation in travel demand. Combination and ranking of these variables which explained variation in travel demand, differed from one location to another.

Results for produced work VKT per adult are as follows: in Metro, more than 30% of the variation was explained by degree of sprawl, level of car ownership, employment participation rate, percentage of children, percentage of people who work at home, and accessibility to employment nodes. In Hamilton, 60% of the variation was explained by level of car ownership, employment participation rate, employment density and percentage people who work part time, percentage of children and percentage of adults with driving license. In suburban area 1 (Halton and Peel), 30% of the variation was explained by employment density, self containment ratio, level of car ownership, employment participation rate, percentage of children and accessibility to employment nodes. In suburban area 2 (York and Durham), around 40% of variation was explained by accessibility to employment nodes, employment participation rate, transit use, self containment ratio, and percentage of part time workers.

Employment density was a key variable which explained one third of variation in attracted work VKT per employee at all locations except in Metro. The use of transit system was the most influential variable in Metro followed by employment density, where both variables explained around 20% of variation in attracted VKT per employee.

Population and employment density were the most powerful explanatory to variation in both produced and attracted non-work demand at all locations.

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Chapter One

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

It is believed that travel patterns vary depending upon the city's special mix of geographical, environmental, social, political and economic circumstances. Recently, the relationship between urban form and transportation energy efficiency has become a matter of considerable concern among planners and policy-makers who are concerned with issues of sustainable urban development.

Learning about the attributes that define how cities are spatially organised is the key to answering many questions about the interaction between the structure of a city and associated travel patterns. As widely acknowledged in the literature, changes in urban form have important impacts on urban transportation demand, energy consumption and environmental quality.

Recently, attention has been focused on reduction of travel demand in cities by encouraging more efficient land-use patterns and better transportation system design and management. This realisation highlights the importance of exploring to what extent the spatial structure of the GTA affects travel demand. This thesis attempts to find out which combination of spatial structure attributes influence travel demand in the GTA the most. Also, this empirical investigation will help to improve the quantitative capabilities for assessing the likely impacts of spatial structure on travel demand in the GTA.

This thesis includes identification of a set of characteristics that possibly reflect the spatial structure of the GTA and an investigation of the impact of the spatial structure attributes on travel demand in the GTA.

The thesis document is organised in 6 chapters. The first chapter includes a literature review that discusses a number of previous works that attempt to identify a set of characteristics and measures of urban form and spatial structure of cities, studies the trends in urban form of Canadian cities, and explores the link between urban form, travel pattern and energy consumption. The direction for the current study and a brief list of the issues that will be discussed in this thesis are included at this chapter.

Chapter two includes a detailed description of the extracted data and estimated measurements used in the current study. These variables were extracted from the 1986 Transportation Tomorrow Survey (TTS) database to reflect spatial structure in the GTA and travel demand data. The third chapter involves an investigation of the spatial distribution of the explanatory variables of urban form of the GTA, and travel demand.

The following two chapters, four and five, represent the core of the study which involves exploratory analyses and tests of several hypotheses that were mentioned in the literature related to the relationship between urban form and travel demand. Following is a statistical analysis of the nature of the relationship between the spatial structure of the GTA and the associated travel demand. The final section of the statistical analysis includes an attempt to rank the possible influential factors on travel demand in the GTA. Finally, chapter six includes a summary of the findings and a conclusion of the conceptualisation of the underlying relationship and issues that can be explored in future work.

1.2 Literature Review

This literature review discusses a number of previous works that attempt to identify a set of characteristics and measures of urban form and spatial structure of cities, study the trends in urban form of Canadian cities, and explore the link between urban form, travel pattern and energy consumption. Following this review is a section showing the direction for the current study.

This review is organised in five sections: the first involves basic definitions of urban form and urban spatial structure. The second includes a discussion of the elements of urban form and urban spatial structure. The third section shows the trends in urban form for Canadian cities. The fourth provides a general discussion of the link between urban form, travel pattern and energy consumption. Finally, the fifth section covers the suggested approach for the current study.

1.2.1 Definition of Urban Form and Urban Spatial Structure

Learning how cities work and why they are spatially organised as they are, is the key to answering many questions about the interaction between the structure of cities and travel patterns. A number of research works involve attempts to obtain a good understanding of what is meant by both terms urban form and spatial structure.

The three key terms mentioned in the literature to define urban structure are:

1. Urban form, or Form
2. Urban interaction, or Function
3. Urban spatial structure, or Structure.

Urban form is the spatial pattern or arrangement of individual elements such as buildings and uses, as well as a social groups of economic activities and public institutions within urban area. Alternatively, **Form** is the physical pattern of land use activities, population distribution and the networks linking them (Bourne, 1982, Russwurm,1980, and Wurster, 1963).

Urban interaction is the underlying set of interrelationships, linkages and flows that act to integrate the pattern and behaviour of individual land uses, groups, and activities into functioning entities. Alternatively, **Function** is the activity undertaken and the movement of flow necessary to partake of that activity.

The term **Urban spatial structure** was discussed in early attempts made by Post (1964) and Von Boventer (1962). Post referred to spatial structure as changes in, and arrangement and extension of urban form. While Von Boventer defined spatial structure as spatial distribution of producers of various goods, and services and consumers in cities and town of various sizes. Alternatively, **Structure** is the combination of form and function. In system terms, form refers to interdependent parts, road network, houses, stores, parks, etc., and function refers to the interrelationships, why and how people, goods, and messages move or flow between parts.

However, these concepts are limited and static in nature. **Spatial structure** was thought of broadly later by Bourne (1982) as a combination of both urban form and the overlay of patterns of behaviour and interaction with subsystems with a set of organisational rules that link these subsystems together into a city system.

1.2.2 Elements of Urban Form and Urban Spatial Structure

Researchers looked broadly at urban spatial structure from different perspectives such as economics, politics, social psychology, political economy, human ecology, physics and engineering. For the sake of our study, discussion will be limited to the combination of both urban form and the overlay of patterns of travel behaviour and interaction into the city system. Each of the following works involves different levels of complexity and involves different scope of definitions to serve a certain purpose of investigation depending upon which level of aggregation or detail of the study, and generality of the results.

1.2.2.1 Main Characteristics of Urban Form

Urban form was defined on different levels of complexity in Berry's work (1974). First, microscopically in terms of detailed location of jobs, residences, commercial areas, recreation areas, and vacant non-urban land, with particular attention to location of heavy polluting facilities (power stations). Second, at a higher level of generalisation, urban form

can be specified in terms of density of activities and elements, separate of uses, type and structure of transportation network, and time dimension of the utilisation of its space. Third, at the most generalised level urban form may be approached in terms of spatial configurations: compact versus dispersed, single nuclei versus multi-nuclei, and form that adapt to growth or those which have predetermined size.

The three traditional models of urban structure described in the literature were based on the spatial configuration of the city as follows: concentric, radial, and multiple nuclei models specifications of urban form. Description of these models was included in work done by Rice (1978) as follows:

Concentric city: The CBD is location with maximum employment density, maximum number of trip ends, and maximum rent. Land uses are segregated in the form of concentric zones around the CBD.

Radial City: Transportation network consists of a small number of major routes that extend out from the CBD. Also, land uses extend out from the CBD along major lines of transportation. A special case of this form is the linear city, in which there is only one transport line with the CBD located at its centre.

Multinucleated city or polycentric city: The CBD is the dominant focal point of the city but there are also other local focal points of high employment density, trip ends and rent. The transportation system is more complex and not all routes are oriented toward the CBD. This form is characterised with a higher overall level of connectivity in the city.

Any of these basic forms can occur at different population densities. Anderson, Kanaroglou and Miller (1996) emphasise that it is important to recognise that no real urban form is determined by the circumstances that exist at one particular point of time, but rather it reflects events, technologies, policies, and preferences that have occurred over the entire history of the city and that is why researchers face the complexity of investigating the spatial structure of cities and people travelling behaviour.

In other work done by Russwurm (1980), demand and competition are considered major factors which generate the general form of urban structure. Also, other factors were considered such as cultural and economic environment, property rights, developers' activities, planning controls and concepts, and technological aspects as important factors influencing the spatial structure of city.

1.2.2.2 Characteristics of Urban Spatial Structure

The term urban spatial structure was extended to represent various attributes as follows (Bourne, Mackinnon and Simmons, 1973):

1. Land use distribution and arrangement.
2. Organisation, concentration and intensity of activities and human occupancies.
3. Formal networks of interaction, flows and communication linking human behaviour and physical artefacts.
4. Decision-making powers.
5. Values and norms interwoven with the above physical attributes.

A comprehensive attempt was suggested later by Bourne (1982) to define urban spatial structure as comprising the form (shape and internal arrangement), interrelationships (organisation), and behaviour and evolution of activities (land uses, the built environment, systems of socio economic activities, and political institutions in the city). These characteristics were classified in four series: Context, Macroform, Internal form and function, and Organisation.

The term "**Context**" includes the following characters:

1. The age and stage of the city's development and it's historical growth.

2. The city's functional character prevailing mode of production and economic base.
3. The city's relationships to an external environment.
4. The city's situation or location within a system of cities (core-periphery contrasts).

Bourne stated his view that the social and occupational composition, travel patterns, job locations and land value gradients would differ for cities with dissimilar economic and production bases. For instance, mining towns do not look or behave like office centres or university towns. The major employment centres for mining towns would be clustered around the mine head and separated from the down town area. Therefore, the journey-to-work is biased away from the central area. In contrast, in office centres cities, employment tends to be more concentrated in downtown and thus the prevailing journey-to-work pattern is more core-oriented.

An interesting series of characteristics were introduced by Bourne as "**Macro-form**" which consists of size of area, population, economic base, income, etc., and geographic shape of the area (archetypal form), physical landscape on which the city is built (site and topography), and type and configuration of transportation system. The transportation system plays an important role in shaping the form of city as can be noticed that cities which were developed during a period of dependence on public transit have different urban form than those which were based entirely on the automobile. Transit oriented cities have different housing types, higher densities, on street shopping and different pattern of interaction and behaviour.

The third series of criteria "**Internal form and function**" relates to urban pattern that can be easily measured and quantitatively analysed. The main elements are density, diversity, concentricity, sectorality, connectivity (linkages) and directional bias or directionality. Combining these elements, one can have a comprehensive picture of the geometry of city. For each of these elements several parameters can be measured as follows: for density, average density and shape of density gradients can be measured. Homogeneity can be described as degree of mixing or segregation of uses, activities, and social groups.

Concentricity would give an idea about the degree to which uses are organised zonally around the city centre. Sectorality is the degree to which uses and activities are organised sectorally about the city centre. Connectivity is defined as the degree to which nodes or subareas of the city are linked by networks of transportation or social interaction. Directionality is the degree of elliptical orientation in interaction patterns such as residential migration. Conformity is the degree of correspondence between function and form. Substitutability is the degree to which different urban forms developed for one function, can be used for another. The last two descriptive terms refer to the relationship between form and function.

The final set of characteristics " **Organisation**" is the most complex and difficult to measure empirically, it consists of the following elements:

1. Organisational principles: the underlying mechanism or principle that we have assumed to be the prime determinant of urban spatial patterning.
2. Cybernetic properties, including sensitivity of elements in urban form to external change and nature of the feedback linkages between these elements.
3. Regulation, the internal instruments available for shaping urban structure and growth.
4. Goal orientation: whether observed changes in urban structure are directed to specific goals or objectives and if so, whose objectives?

1.2.3 Trends in Urban Form for Canadian Cities

Bourne is one of the researchers that took the lead to investigate trends of urban form for Canadian cities. He generally tested five hypotheses of restructuring for contemporary Canadian cities:

1. Continued and rapid decentralisation of population and employment and outward movement of capital investment from inner city to suburbs.

2. Increasing levels of social diversity and spatial polarisation.
3. The emergence of an elite inner city.
4. A deepening spatial separation and mismatch between jobs and labour.
5. The appearance of a new multinucleated urban form.

Bourne (1989) looked at whether this trend suggests the emergence of new urban forms. His empirical investigation of the 27 largest urban areas in Canada, confirmed the hypotheses of continued decentralisation of population and employment, and an increasingly diverse social and ethno-cultural landscape but they did not support the hypotheses of segregation of residential levels by income nor the emergence of an elite inner city. There was also a wider spatial mismatch between the distribution of jobs and labour primarily for inner city. In addition, he found out that despite of the rapid suburbanisation of employment, multi-nucleated urban form was not emerged by that time, 1989.

Later, Anderson, Kanaroglou and Miller (1993) supported some of Bourne's findings for trends in urban form of Canadian cities. Two major findings for the Canadian cities are:

1. An increasing concentration of population and economic activities into urban areas.
2. Dispersion of population and economic activities within urban areas (urban sprawl).

The authors stated that the traditional city with its single centre of intense activity and its few outlying nodes of activity along major transit routes no longer exists. What exists in Canada is a multinodal city which combines concentration and dispersion.

Urban sprawl was observed with various characteristics such as:

1. An outward expansion of the metropolitan boundary that separates urban from rural land uses:

2. A general decline of intensity of all forms of land uses as measured by population and employment densities:
3. An existence of transport networks that provide high connectivity among points, even in peripheral parts of city:
4. A segregation of residential from other land uses, with residences locating in peripheral suburbs.

The sprawl as additional population resides at a long distance from the CBD, created a demand for retail and other services in periphery of the city. That trend in spatial structure encouraged the emergence of peripheral centres and a transition from concentric or radial form of the city to multinucleated form. The degree of sprawl for a multinucleated city depends upon how tightly land use activity is clustered around peripheral centres.

1.2.4 The Link between Urban Form, Travel Pattern and Energy Consumption

The literature shows ambitious efforts to explore the link between urban form and travel patterns in cities and consequently energy use in travel. Two groups of researchers introduced two different approaches to study this link. The first group believes that land use patterns affect every aspect of household travel behavior from trip rates to mode choice. The second group is a small group of skeptics who question whether land use patterns matter in this age of auto ownership, super highways, and low cost travel. The first group is in favor of compact development, transit-oriented developments, mixed-use activity centers, and job-housing balance. The second group say that households in dense cities make less use of automobiles and more of alternative modes, but these households are also smaller and poorer than suburban households and therefore would make less use of automobiles wherever they lived.

Recent work by Richardson and Gordon (1994) represents the second group point of view. They argue that reversing suburbanisation and decentralization would not reduce energy consumption or air pollution levels. Longer trip-journeys are a temporary disequilibrium problem as polycentric metropolitan areas develop with subcentres that compete with the central business district. Even if trip lengths are reduced through increases in urban density, then more trips would be created so that there would be no net savings. Their conclusion is that air pollution can be achieved through newer and more efficient vehicles (technological fix), but planners would have no effect or contribution to that matter.

On the contrary, Newmann and Kenworthy (1989) lead the first group of researchers, in their study of urban form, transport and energy use in 32 cities from North America, Europe, Asia and Australia. They support the belief that energy use in cities is a function of population density, job density, and city center dominance.

Other studies were conducted in several European cities to investigate energy use for different urban forms. The research carried out in Norway and Sweden (1993) showed that at the individual town level, a dense pattern of urban development gives the lowest levels of per capita energy consumption. The annual energy consumption per capita increases with the increase in urban area per capita. Meanwhile, at the regional level, a more decentralized pattern gives the lowest levels of energy consumption provided that certain density thresholds are exceeded. Also, a study conducted in Oslo showed that distance to central Oslo and area per capita were the only two significant variables. As distance increases, energy use for transport increases, and as area per capita increases, energy increases. The investigation of twenty two Norwegian towns showed that high population density in inner and central areas of towns were significant variables.

Another study was conducted in the UK by Banister (1995) for both Oxford and Banbury cities. The main aim was to determine whether there were significant relationships between energy use measures and physical size of settlement, economic and social structure.

Density, open space, and size of area were found to be significant factors affecting energy use per trip. Meanwhile, employment in area, household size, and density were significant factors influencing energy use per person. The study showed density as a main key variable, as density decreases energy use per trip and person increases. Open space was also significant showing the need to make cities more compact but maintain attractiveness. Also, the size of urban area affected energy use significantly, and social and economic factors were important in the analysis. In addition, employment was found to be significant, emphasizing that it is important to locate suitable jobs near to residents, but not jobs which will be taken by long distance commuter from outside. Also, household size and car ownership were significant in some cases.

A general theme in the previous studies is that density is considered the major factor influencing energy use, then comes the size of area, followed by the socio-economic characteristics.

However, one general note on all the previously mentioned studies is that, economic and political aspects were not captured in the analysis. Planners and researchers made the investigation less problematic to come up with uncertain conclusions that can not be generally applied. Also, little if any attention has been paid to life-style and individual preferences and how these factors would affect travel behavior and consequently energy use in transport more than density.

Other researchers looked at urban form but from a different angle, they focused on accessibility in terms of ease access to desired activities to regional activities, rather than density. A recent study performed by Reid Ewing (1995) can be considered different than the previously mentioned studies in terms of considering accessibility as a major factor and testing the hypothesis of the independent effects of land use on household travel behavior, controlling for socio-demographic differences among households.

Ewing argues that accessibility, in terms of easy access to desired activities to regional activities, has much more effect on household travel patterns than does density or land use

mix in the immediate area. The benefit of accessibility is primarily in the form of shorter auto trips rather than shifts to alternative modes, the more activities available within a given travel time the better the "accessibility" of a location. Two types of accessibility were investigated: residential accessibility which refers to the ease of access to activities from one's place of residence, and destination accessibility which refers to ease of access to activities from other activities such as work, school, shopping, or recreational sites.

The results showed that trip rates depend primarily on socio-demographic variables, secondarily on land use variables. Holding socio-demographic variables constant, households whose workplaces were more accessible to other activities made more work-related trips. Also, larger households made more non-work-related trips, so did higher-income households. Households with more accessible workplaces made fewer non-work-related trips. Average trip time depended entirely on land use variables. Households living in the most accessible neighborhoods spent less in travel than did those living in the least accessible neighborhoods. The number of vehicles per household member was the most significant factor for the mode shares, transit use declined as household size and income increased and the less accessible a residence was to other activities, the more the carpooling occurred.

Ewing concluded his study with valuable comments that accessibility is a key issue influencing travel time and rates. Placing households with the same socio-demographic characteristics in more accessible residential locations will cut down significantly on their vehicular travel and also, good regional accessibility cuts down on household vehicular travel to a far greater extent than does localized density or mixed use. Accessibility of residences to a mix of land use reduces vehicular travel. Meanwhile, good accessibility of workplaces to other activities has countervailing effects on vehicular travel: it reduces average length of work-related trips and reduces the number of trips made independent of work, but at the same time, it greatly increases the number of trips made in connection with work. The balance would likely shift in favor of accessible workplaces if accessibility would be improved to the point where employees could visit other activities on foot.

Recently, spatial variation in travel behavior within the GTA was investigated by Ghaeli and Hutchinson (1994). They discussed differences in travel behavior for inner stable suburbs and growing areas, outer stable and growing suburbs, and central as defined by trip generation rates.

The analysis showed that household characteristics and travel behavior were quite similar for both low and high growth zones in older stable suburbs and central area, while significant differences exist in travel characteristics between high and low growth zones in outer suburbs. The household total trips and work trip rates were significantly influenced by location, household size and vehicle ownership. Transit access had an important influence on commuting trips in central area. There were significant differences in travel behavior between low and high growth areas in old suburbs. The labor force in low and high growth areas with good access to transit had similar levels of transit use. The longest trip lengths were associated with commuting linkages between growing and stable areas. The trip length distributions were very similar for commuting trips that occurred within old stable areas and for commuting trips that occurred within growing areas. The authors concluded their work with a comment that a significant increase in the share of public transport commuting is likely to be achieved by concentration of population and employment activities at locations with good transit access.

A general conclusion from this tour of the literature is that, there are two different line of thoughts regarding the relationship between spatial structure and travel demand. Also, within the first group of researchers, there is a variety of key variables that affect travel patterns and consequently energy use. Many researchers focused only on one attribute to explain variation in travel behavior. A number of them focused on density attributes, others looked at accessibility as a key variable affecting travel more than density. Socio-economic characteristics were also considered as influencing variables. The second group of researchers is a small group of skeptics who do not believe that land use patterns matter in this age of auto ownership, super highways, and low cost travel.

In this thesis attempts will be made to consider a combination of several attributes that present spatial structure since it is believed that each of them play different roles influencing travel patterns in one way or another rather than considering only one factor such as density. Attempts will also be made to test several hypothesis that were mentioned in the literature. The details of the main objective of the current work is included in the following section.

1.3 Direction for the Current Study

For a given particular travel pattern, energy use depends upon the modes of travel used, the energy efficiency of the various vehicles being operated, travel speeds and congestion levels, etc. Ultimately, transportation energy consumption is dominated by the energy used by private automobiles. Automobile energy use, in turn, is highly correlated with the total number of vehicle kilometres travelled (VKT). Therefore, in this thesis, VKT is taken as the primary surrogate for the amount energy consumed in executing the travel patterns. VKT is a convenient summary measure which reduces the highly dimensional nature of travel demand combining together the number of trips, the spatial distribution of these trips, the modes and routes chosen to execute these trips.

The departure point in this study will be an investigation of the spatial distribution of the explanatory variables of the GTA urban form, and travel demand. Prior to undertaking any rigorous statistical analyses, spatial maps will be generated using the MapInfo to explore several urban structure issues across the GTA (detailed discussion is included in section 3.1).

Following will be an investigation of the relationship between travel demand and each of the explanatory variables and then tests of several hypothesis of this relationship such as density, degree of sprawl, accessibility, and level of self containment. Also, correlation among some of the explanatory spatial structure characteristics will be investigated, then attempts will be made to control for some of these variables while testing for others.

Finally, before starting the stepwise regression analyses to test the explanatory power of a combination of spatial structure variables to explain variation in travel demand in the GTA, attempts will be made to select a proper form presenting the relationship between travel demand and spatial structure variables.

Chapter Two

DATA DESCRIPTION AND ESTIMATED MEASURES

2.1 Introduction

The chapter includes a detailed description of the extracted data and estimated measurements used in the current study. A number of the available variables in the 1986 Transportation Tomorrow Survey (TTS) database were extracted to reflect the spatial structure in the GTA and the travel-related data. The data were extracted for the GTA 1986 zone system which includes 1366 entries for the six municipalities: Metro, Durham, York, Peel, Halton and Hamilton Wentworth. The distribution of the zones for these municipalities is as follows:

Municipality	Zones
Metro	1 - 460
Durham	501 - 710
York	801 - 978
Peel	1101 - 1325
Halton	1401 - 1563
Hamilton	1601 - 1731

2.2 Geographical Information

Geographical data were extracted for each zone such as the area of each zone in square meters, X and Y co-ordinates for the centroid of the zone, etc. Then various measures were calculated to characterize the urban structure of the GTA such as:

1. Distance from the centroid of each zone to the Metro Toronto CBD defined as zone 408 (Bay and King area) as the centre of activity in downtown Toronto. This distance was chosen to reflect a measure of dispersion or sprawl of the zones from the Metro Toronto CBD.

2. Distance from the centroid of each zone to the Hamilton CBD defined as the weighted centroid of employment concentration in Hamilton-Wentworth, was estimated for zones in Hamilton-Wentworth, Halton and Peel regions to reflect a measure of dispersion or sprawl of the zones from the Hamilton CBD.

2.3 Population

A number of attributes were extracted for each zone to reflect characteristics of people residing in these zones such as:

1. The number of people that reside in each zone (population).
2. Population density was estimated for each zone as the ratio of number of people per square km.
3. Total labour force in each zone defined as the number of employed people in each zone.
4. Employment participation rate was estimated as the ratio between the total labour force / population and this factor was thought of to represent an economic factor characterising the zone.

2.4 Employment

A number of attributes were extracted for each zone to reflect employment opportunities in these zones such as:

1. Employment excluding work at home was extracted from Census 86 data representing the number of employment opportunities in each zone (attraction).
2. Employment density was estimated as the number of employment opportunities per square km for each zone.

3. Number of people that work at home
4. Number of employment opportunities within the 5 km buffer from the centroid of each zone was estimated using the buffer technique in Mapinfo.
5. The ratio of the opportunities of work within the 5 km buffer to the number of the labour force in the centre zone for each buffer was estimated and considered as a factor that reflected the match between jobs and labour (self containment).
6. Location of high employment concentration of more than 5000 employee/square km was considered as employment nodes (or employment centres), details of this selection will be shown in the next chapter.

2.5 Accessibility

Accessibility of people to employment opportunities was defined by two measures:

1. Accessibility of people to jobs was estimated as the number of opportunities of employment within 5 km from the centroid of each zone per adult residing in this zone.
2. Distance from the centroid of each zone to the nearest employment node was estimated and considered to reflect accessibility to the nearest employment concentration.

2.6 Demographic Characteristics

A number of attributes were extracted to reflect the demographic characteristics in each zone as follows:

1. Age characteristics: number of children (age 0 to 10), number of youth (11 to 15) and number of adults (age 16 over) were extracted from the data base.

2. Driving license: both the number of males and females with and without driving licenses were extracted for each zone. The number of adults with driving license was computed as the summation of male and female with driving license.
3. Number of people who have a full time job, part time job, work at home, or are a full time student.

2.7 Car Ownership

Car ownership: the number of households with no vehicles, one vehicle, and more than two vehicles were extracted. The percentages of households with no vehicle and two or more vehicles were calculated as a percentage of the total households in each zone. This percentage was considered to be an economic factor for each zone.

2.8 Trips

The following trip information was extracted from the TTS database:

1. The produced 24 hour auto drive trips from each zone.
2. The produced 24 hour passenger trips from each zone.
3. The attracted 24 hour auto drive trips to each zone.
4. The attracted 24 hour passenger trips to each zone.
5. The produced 4 hour transit trips from each zone.
6. The attracted 24 hour transit trips to each zone.
7. Transit use in each zone was also characterized by the percentage of total 24 hour trip (production and attraction) done by transit.

2.9 Vehicle Kilometres

The travel-related data used in this study were obtained from the 1986 Transportation Tomorrow Survey (TTS) database [Data Management Group, 1987]. In order to achieve as comprehensive a representation of trip-making as possible, 24-hour trip totals are used throughout the study. In order to keep the analysis as simple as possible, only two trip types (or "purposes") are considered in the analysis: home-based work trips and non-work trips.

2.9.1 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 modelling definitions relating to HBW trips are useful in this application since it allows us to aggregate work-trip making by home zone (and hence relate it to the residential population and employed labour force) and by work zone (and hence relate it to employment).

HBW_{ij} = 24-hour home-based-work trips between production (home) zone i and attraction (work) zone j

then

$$HBW_{ij} = HW_{ij} + WH_{ji} \quad [1]$$

where

HW_{ij} = 24-hour home-to-work trips from origin (home) zone i and destination (work) zone j

WH_{ji} = 24-hour work-to-home trips from origin (work) zone j and destination (home) zone i

and

$$\begin{aligned}
 P_i &= \text{24-hour HBW trip productions for (home) zone } i \\
 &= S \{HW_{ij} + WH_{ji}\} \quad [2]
 \end{aligned}$$

$$\begin{aligned}
 A_j &= \text{24-hour HBW trip attractions for (work) zone } j \\
 &= S \{HW_{ij} + WH_{ji}\} \quad [3]
 \end{aligned}$$

Similarly, HBW VKT "produced" by each residential zone is given by:

$$PVKT_i = S \{HW_{ij} * D_{ij} + WH_{ji} * D_{ji}\} \quad [4]$$

where D_{ij} is the equilibrium road distance travelled between zone i and zone j (see below for calculation of this term), and a similar term HBW VKT "attracted" by each employment zone can be written.

2.9.2 Non-Work (NW) Trips

All non-HBW trips were included in the Non-Work trip category. For these trips origins and destinations are used, rather than productions and attractions. It is common in travel demand modelling to divide non-work trips into Home-Based-Non-Work (which might then be analysed on a production/attraction basis similar to HBW trips) and Non-Home-Based trips (which are analysed on an origin/destination basis). To keep the analysis at this stage of the research as simple as possible, the single all-purpose trip category has been adopted. Given this, origin/destination based aggregation of trips is both computationally straightforward and conceptually preferred.

Two points should be noted concerning these trip type definitions, both of which ultimately derive from the nature of the TTS database. First, it should be noted that the 1986 TTS is known to underestimate non-home-based trip-making. Thus, estimates of total trip-making based on 1986 TTS data are likely to be biased downwards at least somewhat.

Second, a far better categorization of travel behaviour for our purposes would be into work and non-work trip chains, where a trip chain is a connected sequence of trips beginning and ending at home, and work and non-work trip chains would be defined by whether work is included in the trip chain or not. Unfortunately, the TTS database consists of "unlinked" trips, which are very difficult to consistently "link" together into complete trip chains. While this may well be a task for future work, it was not something which could be undertaken in the present study. Hence, the simpler trip-based definitions given above were used. Note, however, that these definitions systematically underestimate the portion of total travel attributed to home-work-home trip-making since intermediate stops "break up" the HBW trips into "other" types of trips. For example, if a worker stops on the way to work to drop a child at day-care, the simple HW trip now becomes two trips: a home-based-non-work trip (home to day-care drop-off) and a non-home-based trip (day-care drop-off to work).

Again to keep the analysis as simple as possible for the sake of this research, only two travel modes are considered: auto drive all way mode and transit mode. Points to note about these modes include:

1. The use of auto drive all way underestimates auto usage somewhat since it ignores auto drive trips to commuter rail and subway stations (park & ride). These "mixed mode" trips are included in the all-mode totals, but do not contribute to the auto drive calculations in this analysis.
2. Walk/cycle trips were collected in the 1986 TTS only for work and school trips. Thus, non-work/school trips only include vehicular (auto and transit) trips. This does not bias auto usage calculations but it does result in some underestimation of total trip generation rates.

Vehicle kilometres travelled (VKT) for a given zone origin-destination (O-D) pair were calculated using the EMME/2 road network assignment procedure. Observed 1986 peak-period vehicle trips were assigned to the 1986 network using the EMME/2 deterministic

user equilibrium assignment procedure [INRO, 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. These O-D VKTs were then summed by origin or destination, as appropriate to generate zone-based VKT totals (as in equation [4] above).

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. This probably systematically overestimates 24-hour VKT, since it may be possible for people to use more direct routes during less congested time periods (certainly is difficult to argue *a priori* for longer non-peak routes).

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 centroid). In order to provide an estimate of intrazonal trip distances, average straight-line distances for intrazonal work and non-work trips observed in the 1986 TTS were computed for each zone using the trip origin and destination geocodes provided in the database. These intrazonal trip length estimates were then added to interzonal trip distance matrix generated by the assignment algorithm. An improved estimate of intrazonal trip lengths from these same data would be to use a shortest-path algorithm within a Geographic Information System (GIS) to compute "actual" O-D distances, given the actual street network within the zone.

Chapter Three

SPATIAL DISTRIBUTION OF URBAN STRUCTURE AND TRAVEL DEMAND ACROSS THE GTA

3.1 Introduction

This chapter includes an investigation of the spatial distribution of a number of explanatory variables of the urban form of the GTA, and travel demand. Prior to undertaking any rigorous statistical analyses, spatial maps were generated using MapInfo to explore the following issues:

1. Does the GTA urban form consist of a single centre with concentration of activities in the CBD or is it a multi-nodal form which combines concentration and dispersion? Is there evidence of sprawl or decentralisation of population and employment in the GTA?
2. The decline in density of all forms as measured by population and employment densities in the peripheral suburbs. Is there a segregation of residential from employment in peripheral suburbs?
3. Existence of focal points of high employment concentration in the GTA (multi-nucleated urban form).
4. The spatial match between the distribution of jobs and labour across the GTA.
5. Transit usage across the GTA presented as percentage of the 24 hours produced or attracted trips made by transit.
6. Travel demand across the GTA: produced and attracted work and non-work trips.

3.2 The Distribution of Population in the GTA

Population density was estimated as the number of persons per square km in each zone. The population density in the GTA varied from 0 to 40,000 person per square km as shown in Map1. The spatial distribution of population density showed evidence of sprawl or decentralisation of population in that many zones at considerable distance from the Metro Toronto CBD which had densities of 1000 to 5000 person per square km. This includes zones located north of Metro boundary such as the urbanised areas of southern York Region, and west of Metro such as Mississauga and Brampton.

Similarly, the spatial distribution of population density in Hamilton-Wentworth Region showed sprawl with respect to distance to the Hamilton CBD, and a decline of densities at the surrounding boundary. Therefore, Hamilton-Wentworth can be considered by itself another node of activities with variation of population density that occurred in a similar pattern as in Metro Toronto. Also, there was another node, however less strong than Hamilton, located east of Metro Toronto in Durham Region centred in Oshawa.

For the sake of the current study, zones with population density greater than 5000 person per square km were considered as high population concentration locations. There were 192 zones in the GTA of high density representing 14% of the total observations. The majority of these observations (79%) were located in Metro. A summary of these locations is shown in the following table.

ZONE	Region	#Observation
1 to 460	Metro	151
632	Durham	1
1128 - 1273	Peel	17
1608 - 1695	Hamilton-Wentworth	23

Since that there is quite a variation in the spatial distribution of population density across the GTA, it was decided to run separate analyses for Metro Toronto, Hamilton-Wentworth and the suburban areas as at least a partial control for geographical location.



Population Density / Square Km

POP by Popdenskm

- 5000 to 40000 (192)
- 1000 to 5000 (502)
- 100 to 1000 (187)
- 0 to 100 (485)

Map 1 The Spatial Distribution of Population Density in the GTA

3.3 The Distribution of Employment Density in the GTA

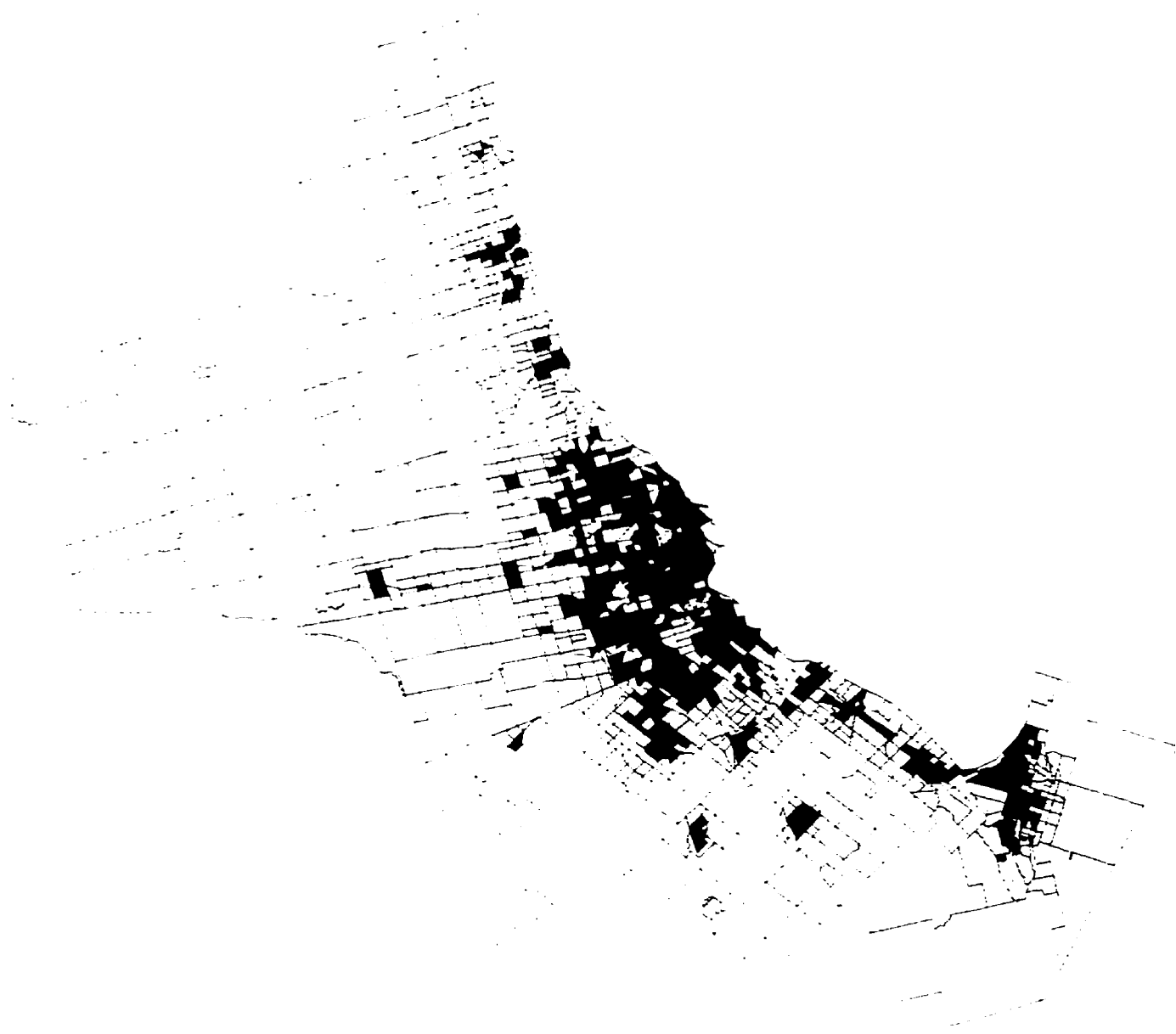
Employment density was estimated as the number of employment opportunities per square km within each zone. The number of people who work at home were excluded from these employment figures. The employment density varied from 0 to 500,000 opportunities per square km across the GTA as shown in Map2.

The spatial distribution of employment density across the GTA showed an outward expansion of employment with sprawl at long distances from the Metropolitan CBD (zone 408) where significant number of employment opportunities were located out side of the Metro boundary. However, there was also a general decline in density with distance from the Metro CBD, with less than 100 employment opportunities per square km at the peripheral suburban areas.

The spatial distribution of employment density for Hamilton-Wentworth region showed Hamilton as another major node of activities. There were locations with employment densities more than 5000 employee per square km in the core of Hamilton. Therefore, it was decided to was deal with Hamilton-Wentworth region as a separate self contained area and run a separate analysis for it.

Also, there were other two nodes of employment observed east of Metro Toronto area in Durham region such as Pickering and Ajax.

For the sake of the current research work, locations of employment densities greater than 5000 employees per square km were considered as focal points (nodes) of high employment concentration. There were 91 zones of high employment concentration (nodes) representing 7.8% of the total employment observations in the GTA as shown in Map 3. The majority of these observations (79%) were observed in Metro Toronto. A summary of these locations of high employment density is shown in the following table.

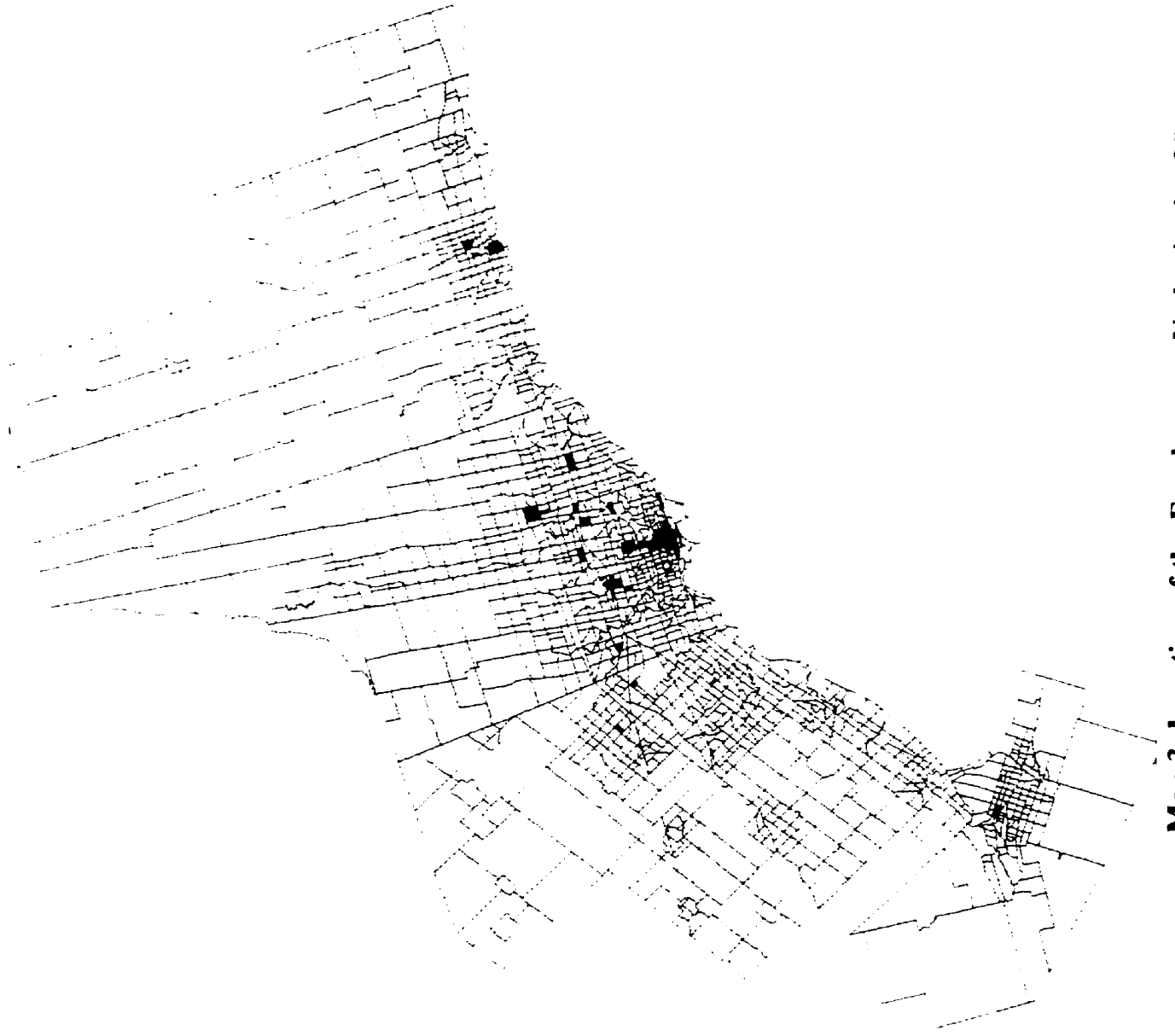


Employment Density / Square Km

EMPLY by empdens

5000 to 500000	(91)
1000 to 5000	(318)
500 to 1000	(172)
100 to 500	(324)
0 to 100	(259)

Map 2 The Spatial Distribution of the Employment Density in the GTA



Employment Density / Square Km

EMPLY by empdens

- 5000 to 500000 (91)
- 0 to 5000 (1274)

**Map 3 Location of the Employment Nodes in the GTA
(Employment Density > 5000 Employee / Square Km)**

ZONE	Region	Observations	Employment Center
1 - 437	Metro	72	3,4,5,6,7,9,10,11,12,13,14
612 - 636	Durham	5	2
858	York	1	6
1113-1315	Peel	6	8,15,16,18
1614-1640	Hamilton-Wentworth	7	1

A number of these zones were located adjacent to each other and hence were considered as one employment center (node). In addition, there were other locations with high employment density that were located in one zone and hence considered by itself as an employment node. In total, eighteen employment nodes were defined across the GTA.

A summary of the average employment and population density, and the estimated distance from the weighted centroid of each node to Metro Toronto CBD (zone 408) is shown in the following table.

For the sake of the current research work, distances from the centroid of each zone in the GTA to the weighted center of these nodes were estimated. Then, the distance from each zone in the GTA to the nearest employment node was considered as a measure of accessibility to employment.

The location of these employment nodes in the GTA with respect to Metro Toronto CBD (zone 408) and the average population and employment densities for each node are shown in the following two plots, as well as the table.

The plots show the sprawl of employment locations in the GTA and the spatial mismatch between the distribution of employment opportunities at the nodes and people residing at the same location. The spatial mismatch between jobs and people were found in all locations of employment nodes except in three locations: nodes 6, 9, and 12 in Metro.

Hemp node	Dist from CBD	Avg. Empdens	Avg. Popdensity
13	825.03	41634.26	10988.84752
9	4729.86	5100.00	3853.416667
11	5276.46	5120.00	0.000
12	5739.59	10724.29	10015.71429
10	9592.70	7190.00	2960
3	10848.76	6174.00	1252
4	13363.49	7415.00	4167.083333
7	14108.81	10436.67	4869.111111
5	17575.29	7865.00	4362.416667
14	17923.97	5210.00	480.000
6	19204.74	5090.00	4928.583333
16	20348.64	14840.00	0.000
17	21603.17	5980.00	2490.000
15	21891.51	6470.00	0.000
18	28025.16	6120.00	240.000
8	29537.55	7485.00	3872.916667
2	49337.16	7872.00	2046.0000
1	58728.14	19047.14	3400

Figure 1 Location of Employment Nodes in the GTA with respect to Metro CBD

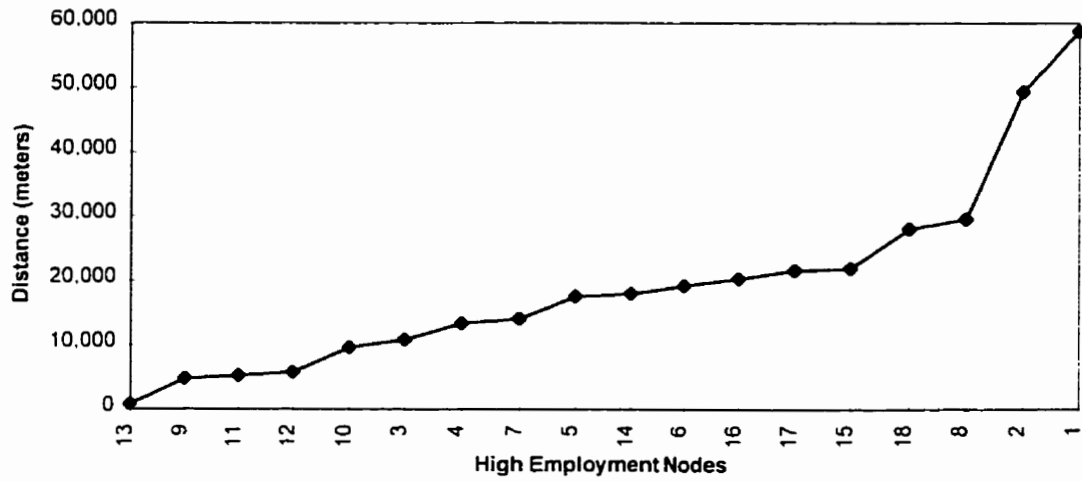
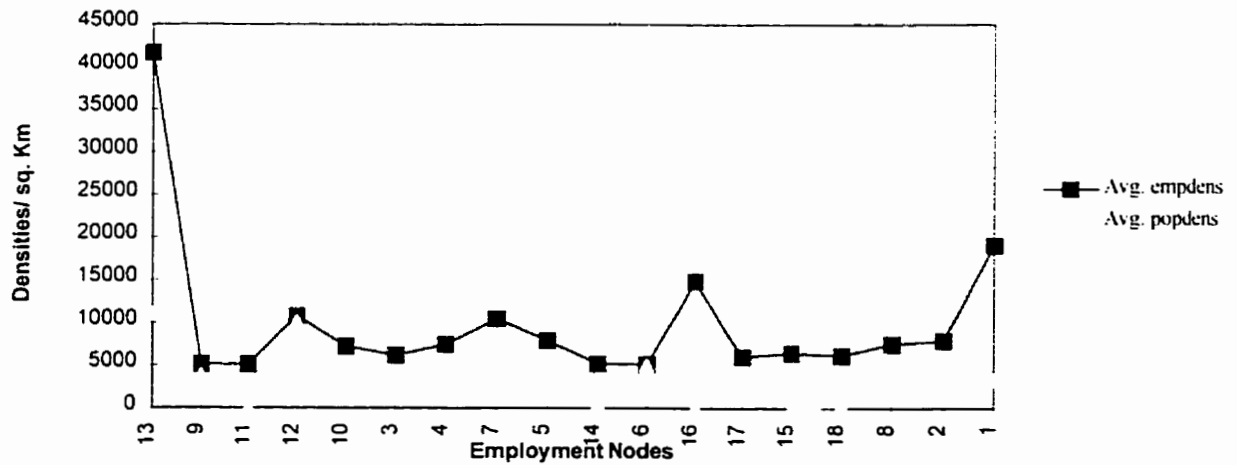


Figure 2 Employment and Population Density at Employment Nodes in the GTA



The direct conclusion from the previous investigation of spatial distribution of population and employment in the GTA is that the urban form of the GTA is not a single centre form with concentration of activities in the CBD. Rather, the form of the GTA has become a multi-nodal form which combines both concentration and dispersion.

3.4 Accessibility to Employment Locations in the GTA.

A simple measure of accessibility of people to employment is the number of available opportunities of employment within each zone (employment density). However, zone boundaries are arbitrary geographical boundaries. A person living in one zone may work just across the street and yet still be considered as working in another zone if the zone boundary was crossed. The understanding of this fact lead to estimating another measure of accessibility to jobs within a certain buffer area from the zone of residency. The number of employment opportunities within 5 km from the centroid of each zone per each adult residing in this zone was computed using the Mapinfo buffer technique. Several values of buffers were tried, however, the 5 km buffer resulted in obtaining results for all the observations in the GTA database (1366 observations).

The spatial distribution of opportunities of employment within 5 km from the centroid of each zone showed an outward expansion of development with additional employment locations at long distance from Metro CBD (zone 408) as shown in Map 4. This supports the hypothesis of sprawl occurrence and decentralisation of employment in the GTA.

Also, the spatial distribution of the ratio of these employment opportunities within 5 km buffer per each worker residing in the centre zone is shown in Map 5. Care should be taken when matching the previous two maps. There were two types of locations that are of high accessibility to jobs. Some locations with high access to jobs, also have high population density and therefore the ratio between people and jobs was moderate. The second type of locations were the ones of high access to employment with

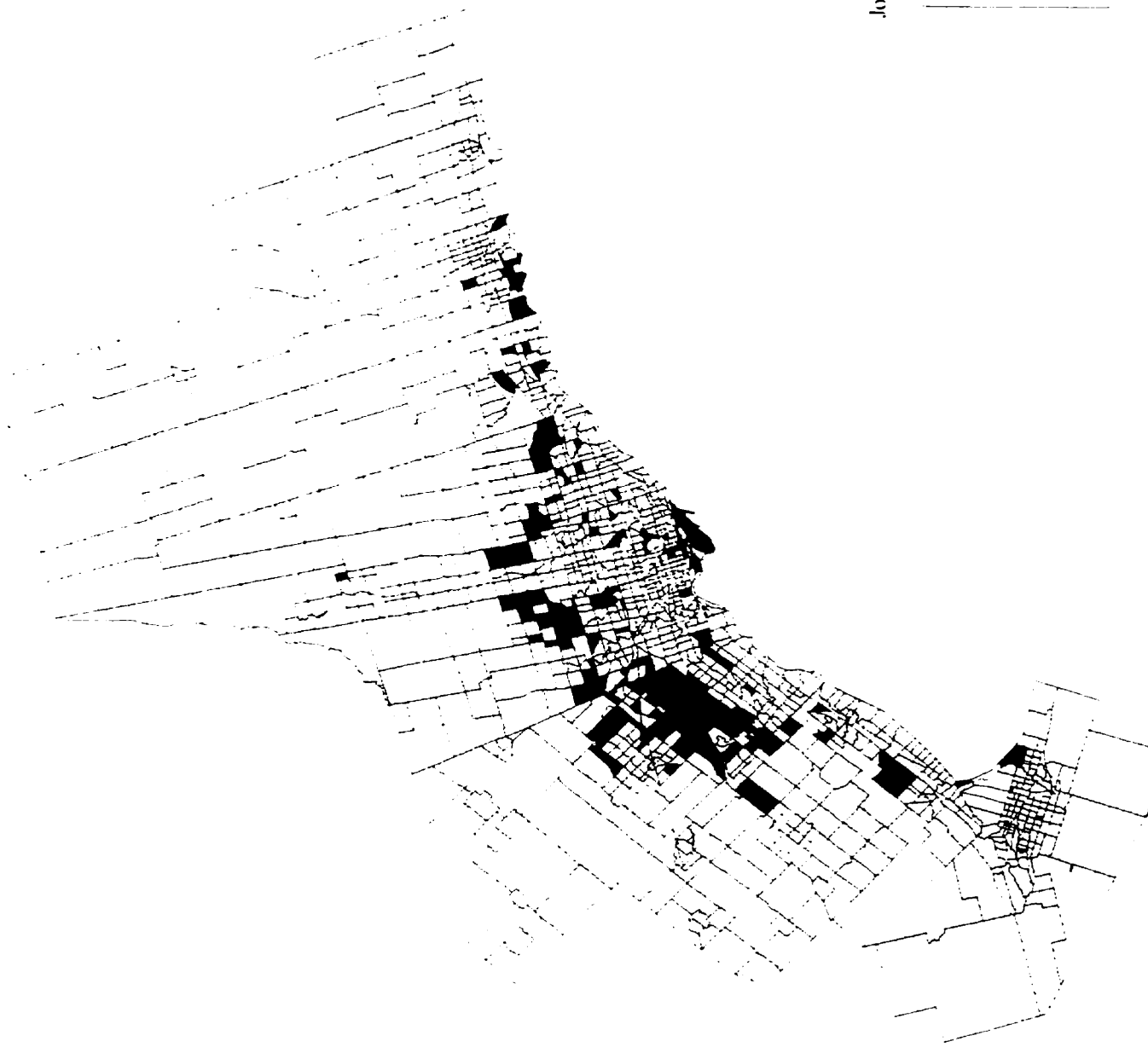


Jobs within 5 Km Buffer

JOBWRK by jobbuf5

■	300000 to 600000	(123)
■	100000 to 300000	(390)
■	50000 to 100000	(244)
■	10000 to 50000	(338)
■	5000 to 10000	(86)
■	0 to 5000	(184)

Map 4 The Spatial Distribution of the Jobs within 5 Km Buffer in the GTA



Jobs within 5 Km Buffer / Labour Force

JOBWRK by Jobbuf5_labour

■	5000 to 150000	(41)
■	1000 to 5000	(90)
■	500 to 1000	(84)
□	100 to 500	(276)
□	0 to 100	(874)

Map 5 The Spatial Distribution of the Jobs within 5 Km Buffer per Labour Force in the GTA (Self Containment Ratio)

lower population density and therefore the ratio was high. Although downtown Toronto has a very high access to jobs within 5 km buffer, it also has high population density which made the ratio moderate. The ratio is the measure used in the analysis since it provides a better measure of worker's accessibility to jobs.

One of the most interesting observations from these maps is the evolution of the employment nodes as discussed before. There are many examples of a fair accessibility to employment opportunities occurring in the northern zones of Metro boundary (southern zones of suburbs) at the same level like the core of Metropolitan Toronto. Similar patterns were observed in Brampton, Mississauga and Hamilton-Wentworth and Durham (Pickering, and Ajax).

3.5 The Spatial Match between the Distribution of Jobs and Labour

For the sake of the current study, the ratio of employment opportunities within 5 km buffer per labour force residing the centre zone was considered a measure of self containment ratio. This spatial match between the distribution of jobs and labour in the GTA is shown in Map 5.

There were 21 zones with high accessibility to employment shaded in red where the ratio was more than 100 opportunities per worker residing in these zones. Fifteen out of the 21 zones were located in Metropolitan Toronto, one in Hamilton, 4 in Peel and one just north of the Metro boundary.

The mismatch between jobs and labour or the segregation of residential locations from employment as measured by this ratio of job per labour occurred often in the peripheral suburbs, as indicated by a ratio less than 0.5.

The spatial match between the employment and labor force in Hamilton-Wentworth showed the core of Hamilton (CBD) as employment node with a ratio of jobs per labor higher than 100. The industrial zones and other major employment locations such as McMaster

University had also high ratios of jobs per labor ratios. However, there were still surrounding areas (suburban area) which had a ratio less than 0.5.

3.6 Car Ownership in the GTA

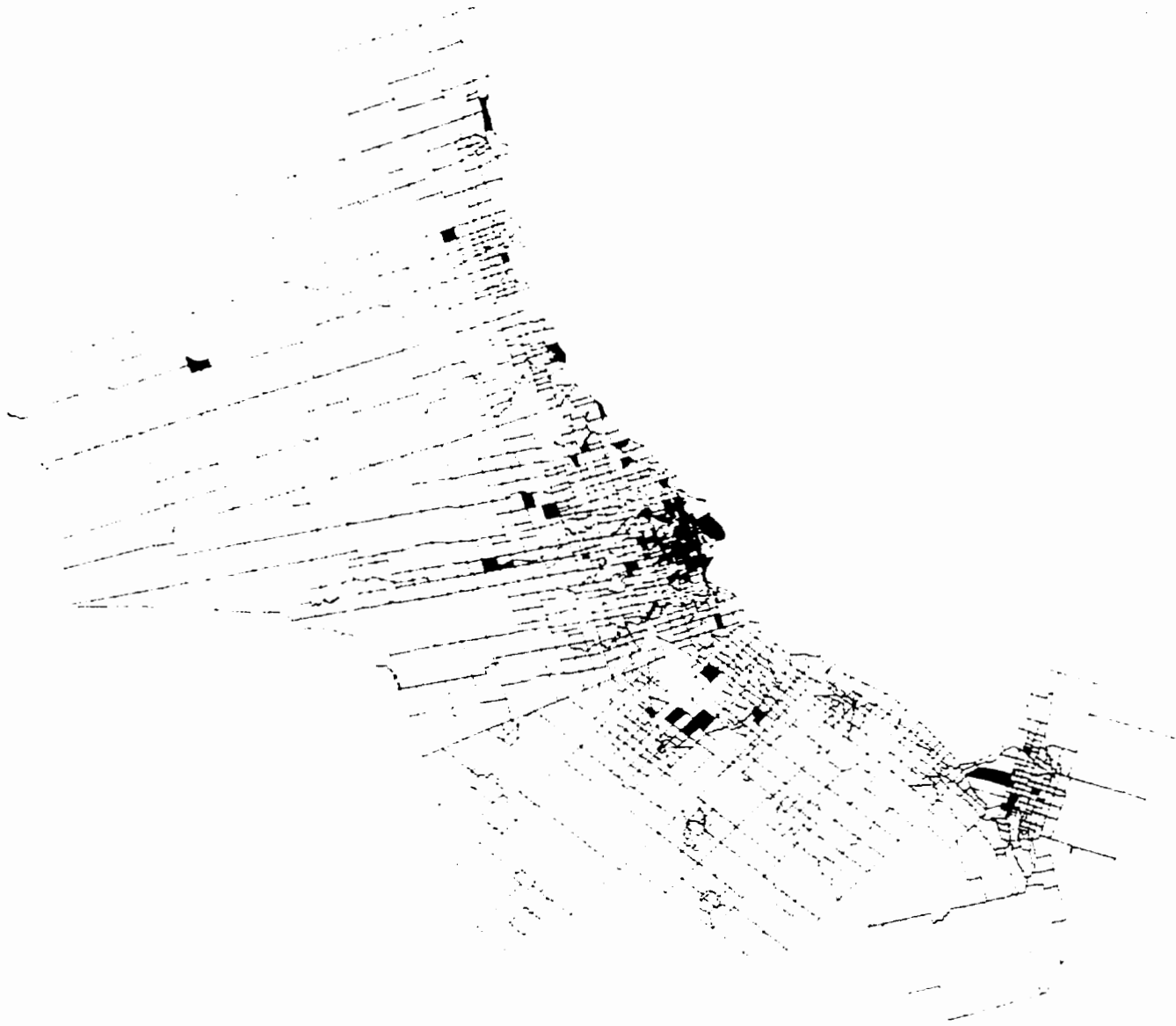
Two measures for low and high car ownership were extracted from the TTS database in the form of the percentage of households in each zone that had no vehicles, and the percentages with two or more vehicles. Also, these percentages were considered to reflect in one way or another an economic factor for each zone. The spatial distribution of these percentages are shown in Map 6 and 7.

Car ownership was quite high in the suburban areas where more than 50% of the households have more than two vehicles. Meanwhile, there were 291 zones in the GTA that had less than 30% of its households with more than two vehicles. Seventy two percent of these zones were located in Metropolitan Toronto which shows indirectly the effect of having a good transit system (TTC) in Metro. Also, this reflects the sprawl and relocation of high income and vehicle dependent people out side the Metro boundary. The same pattern was observed in Hamilton-Wentworth where the car ownership was low in the core of the city and high in the suburban areas.

Generally, those zones with less than 30% of households that had two or more vehicles were located either where transit system access was good as in the core of Metro and Hamilton, or in areas with moderate level of lifestyle. For instance, 19% of these zones were locations of high employment concentration centres with density greater than 5000 employees/square km. Meanwhile, these locations of high employment concentration included more than 30% of household with no vehicles since they were mostly served by transit or non residential locations as shown in Map 7.



Map 6 The Spatial Distribution of the Households with 2 or more Vehicles in the GTA



Percentage of Household
 AUTO by veh 0 percent

■	30 to 100	(129)
▨	10 to 30	(320)
□	0 to 10	(741)

Map 7 The Spatial Distribution of the Households with No Vehicles in the GTA

3.7 Travel Demand across the GTA

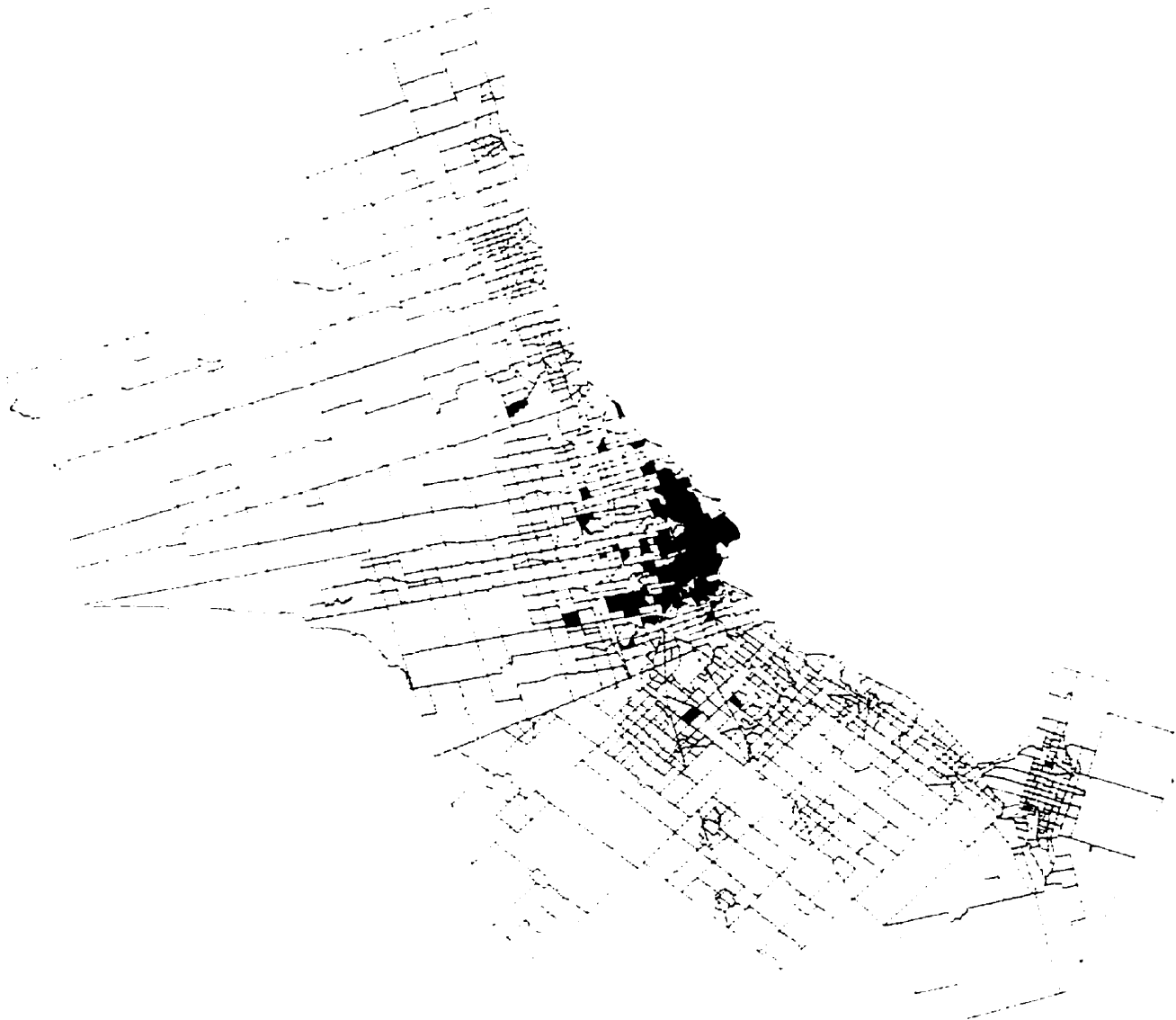
3.7.1 Transit Usage in the GTA

For the time limitation of this research work and the complexity of selecting the appropriate variables that reflect the characteristics of the transit system in the GTA, it was decided to consider the observed transit usage as an explanatory variable reflecting in one way or another the availability and performance of the transit system in each zone. This measure was computed as the percentage of the produced and attracted trips made by transit over 24 hours.

The spatial distribution of transit usage for both produced and attracted trips in the GTA is shown in Map 8 and 9. These maps indicate that more than 50% of the total (work and non-work) produced or attracted trips in the core of Metropolitan Toronto were made by transit (red and blue shaded zones) reflecting the effect of the availability of the intensive transportation system in Metro.

It is also interesting to notice that the population sprawl and employment relocation out of Metro boundary have resulted in an increase in cross boundary travel. However, there is an obvious decline in transit usage for both produced and attracted trips for zones out of Metro boundary. The cross boundary travel mode choice depends on many factors, one of them is the accessibility to a reliable public transit facility.

The availability of local public transit and GO rail in Peel Region affected the transit usage in Mississauga and Brampton where 10% to 25% of the produced trips were done by transit (yellow shades). The zones of high percentage of transit usage were located at the end of GO rail facilities (blue shades out of Metro).



Percentages of Produced Trips by Transit

VEHTRANS by Trans_pro

■	0.5	to	0.7	(24)
■	0.25	to	0.5	(176)
▨	0.1	to	0.25	(368)
░	0	to	0.1	(789)

Map 8 The Spatial Distribution of Produced 24-hour Trips by Public Transit



Percentages of Attracted Trips by Transit

VEHTRANS by Trans. attr

- 0.5 to 0.7 (123)
- 0.25 to 0.5 (176)
- 0.1 to 0.25 (373)
- 0 to 0.1 (785)

Map 9 The Spatial Distribution of the Attracted 24-hour Trips by Public Transit

A similar pattern for transit usage was observed in Hamilton-Wentworth where 25% to 50% of the produced or attracted trips were done by transit in the core of Hamilton (CBD) and then a decline of transit usage occurred in the surrounding suburban areas.

3.7.2 Travel Demand VKT in the GTA

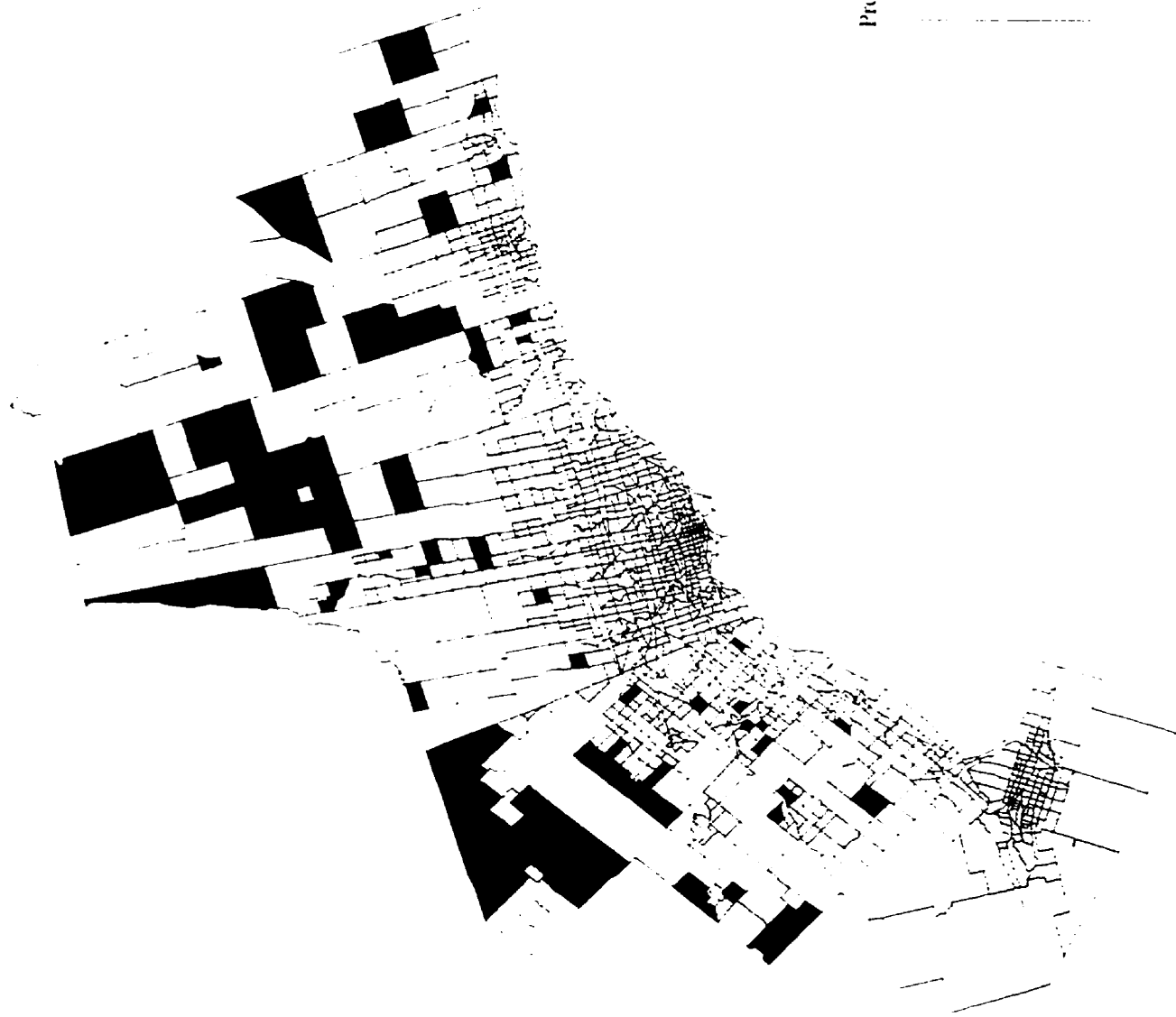
The spatial distribution of the produced VKT per adult for work trips is shown in Map 10. The average produced VKT for work trips from most of Metropolitan Toronto zones was around 10 km/adult. This shows the effect of both the self containment form of the city and the effect of having an intensive public transit system. However, the travel demand outside of the Metro boundary shows both the sprawl and vehicle dependency in the suburban areas.

A similar pattern was observed for Hamilton-Wentworth region where short work VKT were produced in the core of the region. Meanwhile, the majority of the surrounding suburban areas produced work VKT of average of 10 to 30 km/adult with 11 observations of more than 50 km/adult scattered at the far peripheral suburbs (shaded in red).

The attracted VKT per employee to the majority of Metropolitan Toronto zones had a maximum value of 30 km per employee with very few observations of more this value. Longer attracted VKT per employee for work trips were observed at the suburban zones out of both Metro and Hamilton-Wentworth boundaries (Map 11).

The 23 observations with more than 200 attracted work VKT per employee occurred at zones with very low employment and population densities. These very large values may be caused by an error in EMME/2 network analysis or caused by the normalization per adult in locations with low population, or because of the nature of land use development at these locations.

The spatial distribution of the produced non-work trips VKT per adult is shown in Map 12. The majority of observations (88%) in the GTA varied from 0 to 30

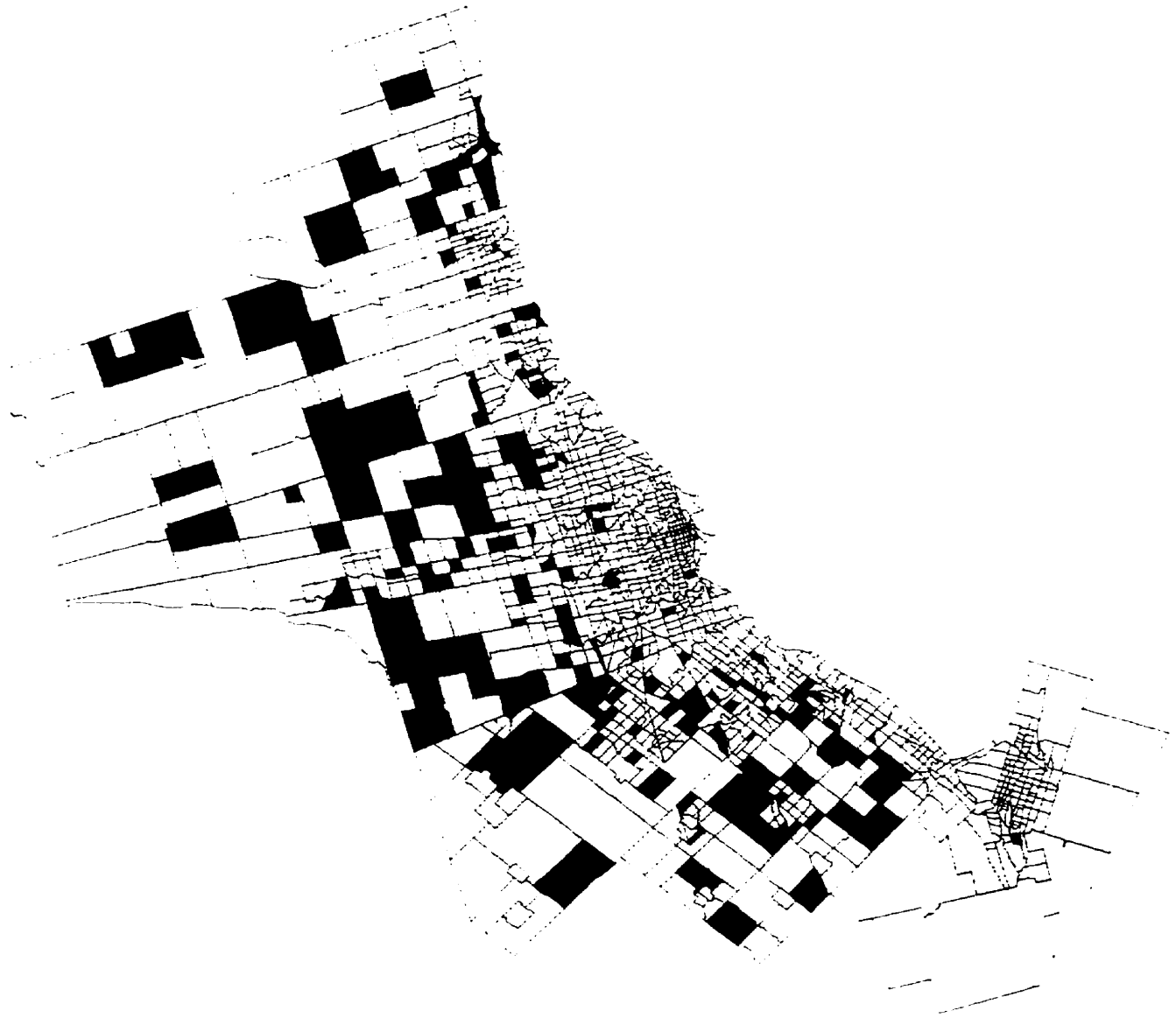


Produced Work VKT per Adult

MAPVKT by Pwkadult

- 50 to 100 (11)
- 30 to 50 (52)
- 10 to 30 (493)
- 0 to 10 (810)

Map 10 The Spatial Distribution of Produced Work VKT per Adult in the GTA

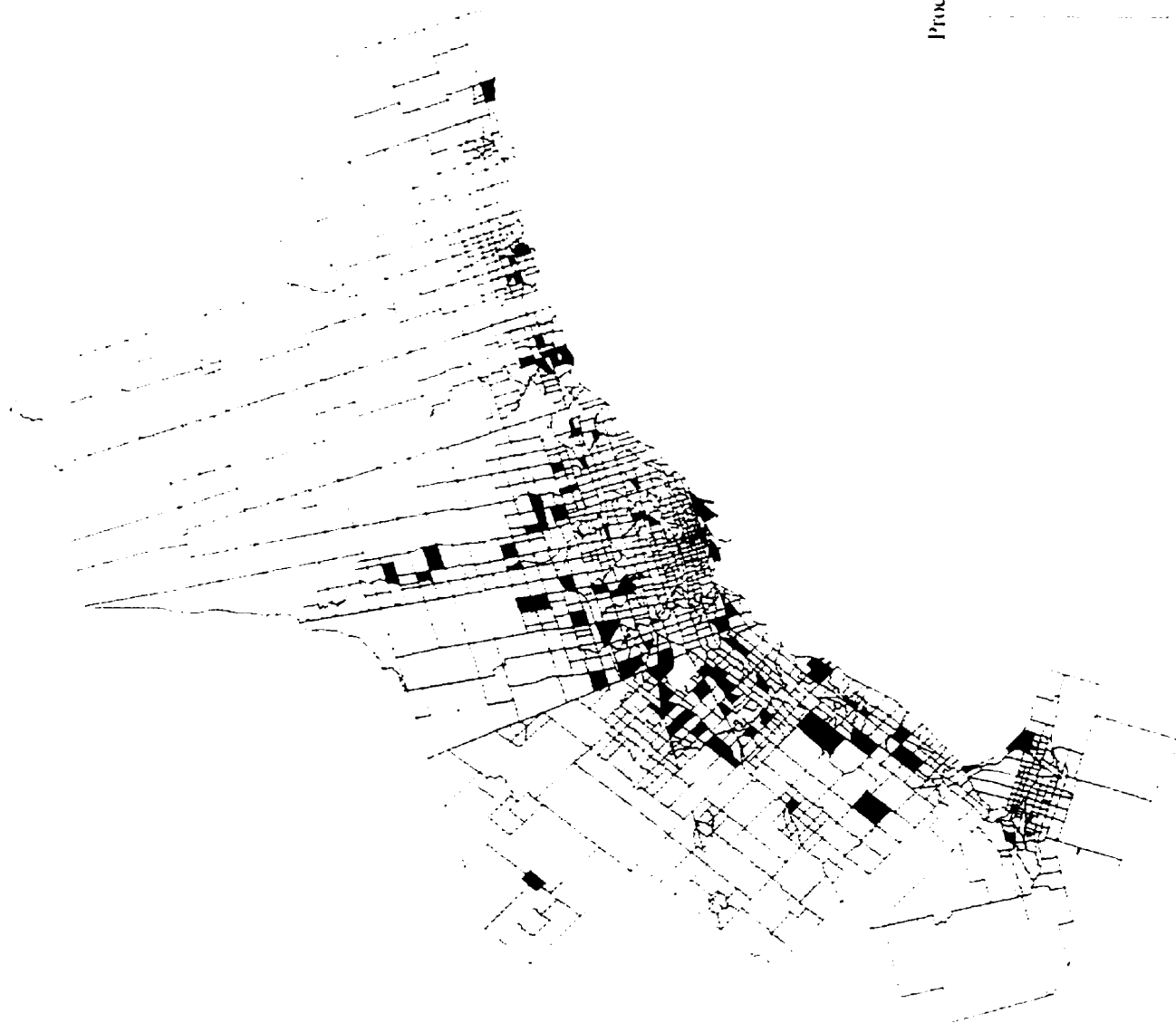


Attracted Work VKT per Employee

MAPVKT by Awkempxh

■	200 to 1630	(23)
■	100 to 200	(50)
■	50 to 100	(92)
■	30 to 50	(120)
■	0 to 30	(1081)

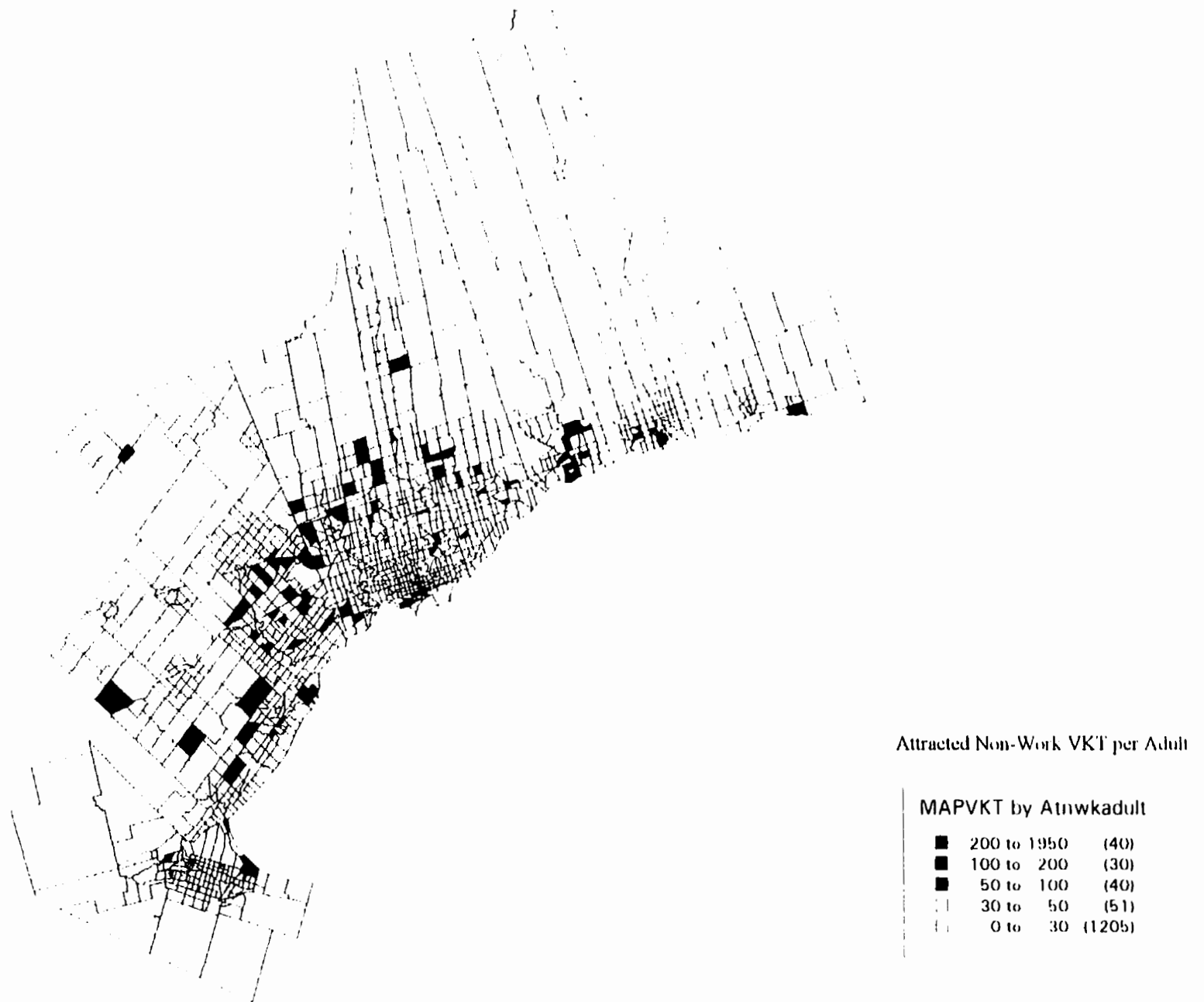
Map 11 The Spatial Distribution of Attracted Work VKT per Employee in the GTA



Map 12 The Spatial Distribution of Produced Non-Work VKT per Adult in the GTA

km per adult. In Metro, the majority of the produced non-work trips were less than 30 km per adult which again reflected the effect of self containment and the accessibility to the transit system. However, there were 42 observations with more than 200 VKT/adult observed in zones with low population and comparatively high employment densities.

A very similar pattern was observed for the attracted non-work trips where 88% (Map 13) of the observations in the GTA varied from 0 to 30 km/adult. However, there were 40 observations of more than 200 VKT/adult which occurred at low population and relatively high employment density. As mentioned earlier, these observations may be caused by an error in EMME/2 networking analysis or caused by the normalization per adult in locations with low population, or because of the nature of land use development at these locations (Pearson Airport, recreational areas such as Harbour front, etc.)



Map 13 The Spatial Distribution of Attracted Non-Work VKT per Adult in the GTA

Chapter 4

EXPLORATORY ANALYSIS AND TESTS OF HYPOTHESIS OF SPATIAL STRUCTURE AND TRAVEL DEMAND IN THE GTA

4.1 Introduction

This chapter includes an exploratory analysis of the relationship between the spatial structure characteristics of the GTA and the associated travel demand (VKT). First, investigations of the relationship between travel demand and each of the explanatory variables were made. Second, tests of several hypothesis of this relationship and spatial structure characteristics such as density, degree of sprawl, accessibility, and level of self containment were performed. Then, a brief discussion is included about correlation among some of the explanatory spatial structure characteristics, followed by several attempts to control for some of these while testing for others.

4.2 The Relationship between the Dependent and Explanatory Variables

As mentioned earlier in the literature review, there are some researchers who supported the belief that travel demand in cities is a function of population density, job density, and city center dominance. Other researchers focused on accessibility as a major factor affecting travel behavior. In the current study, analyses were performed to test these hypothesis in the GTA.

Early trials were performed to investigate the spatial distribution of travel demand (dependent variable) and spatial structure characteristics (explanatory variables) using Mapinfo, as shown in Chapter 3. Other trials are made here to investigate the nature of the relationship (if any) between the dependent and explanatory variables in order to select a form representing this relationship.

First, plots of produced and attracted work trips versus each of the explanatory variables were developed. Then, correlation analyses were undertaken to test the relationship between travel demand and density, degree of sprawl, accessibility to employment, and level of self containment.

For the sake of testing these hypothesis, correlation analyses were conducted between the travel demand measure and spatial structure measure that correspond to each of these hypothesis. The analyses were done for the four locations: Metropolitan Toronto, Hamilton-Wentworth, and suburban areas 1 (Halton and Peel) and suburban area 2 (York and Durham), to test differences and similarities between the four geographical locations.

However, since that evidence of correlation between some of the explanatory variables was found, it must be noted that no final conclusions can be drawn from these analyses until a control is maintained for the other possible influential factors such as socio-economic factors, accessibility or access to transit, etc. Attempts to maintain control for some of these variables and test for others are presented at the end of this chapter (section 4.4), where a comparison is made between results of testing the hypotheses controlling only for the geographical locations and results obtained under the control of location and other explanatory variables.

Also, at the end of this chapter, a detailed discussion of the technique of stepwise regression is included. This technique will be used to explore the ranking of the power of spatial structure variables to explain variation in travel demand in the next chapter.

4.2.1 Explanatory Variables

For the sake of the current discussion, the following explanatory variables were selected to present spatial structure characteristics in the GTA:

Density

For density, two measures were looked at as representatives of residence and employment density

- Population density (Popdens)
- Employment density (Empdens)

Sprawl (decentralisation of population)

Sprawl or decentralisation of residency is measured as the distance from the CBD (either Metro or Hamilton).

- Distance from the CBD (distCBD)

Accessibility

Accessibility of people to employment opportunities was defined by several measures such as:

- Employment opportunities within 5 km buffer from the centroid of each zone per adults residing in this zone (Jobbuf5adult)
- Distance to nearest employment node (dist nearest node)
- Distance to the weighted centroid of employment concentration in Hamilton (dist Hamilton CBD).

Self Containment Ratio

The spatial match between the distribution of jobs and labour (self containment ratio) was defined as the ratio of employment opportunities within the zone / total labour force residing in this zone

Demographic Characteristics

The following measures were selected as demographic characteristics that explain variation in travel demand:

- % children of age 0 to 10 (children)
- %Adult with Driving license (adultlic)
- %full time job, %part time job, and %work at home.
- Employment participation rate (emplevel) = total labour force / population

Car Ownership:

Two measures were selected to represent the low and high level of car ownership:

- % household with no vehicles (hhl0veh)
- %more than two vehicle were extracted (hhl2plusveh)

Transit Use

- Percentage of the produced and attracted trips made by transit in the 24 hours (Transp%).

4.3 The Relationship between Travel Demand and Spatial Structure

Two dimensional plots and correlation analyses were developed between the dependent variable and each of the explanatory variables for the four locations (Metropolitan Toronto, Hamilton-Wentworth and the Suburban areas). The suburban areas were split in two different geographical locations: suburban area west of Metro including Peel and Halton Regions, and suburban areas north and east of Metro including York and Durham Regions. This split in two regimes was made to account for variation in spatial structure, land use development and transit system between the two regimes.

The purpose of this investigation is to study the nature of the underlying relationship and explore differences and similarities between the geographical locations. For the sake of comparison between graphs, attention is drawn to difference in scales of these graphs.

4.3.1 The Relationship between Travel Demand and Density

4.3.1.1 VKT/Adult versus Population Density and VKT/Employee versus Employment Density

Similarities were observed between the four locations, in terms of a reduction in produced work VKT per adult with the increase in population density (Figures 1 - 4) . However, the variation lies in the degree of scatter in travel demand at the four locations. Scatter in travel demand was found to be higher in suburban areas compared to Metro. On the other hand, variations in population density were higher in Metro than the suburbs.

The plots of produced work VKT per adult versus employment density did not show a clear pattern. However in Metro, there was a drop of travel demand with the increase in employment density, with more observed scatter in travel demand in Metro than at other locations.

For attracted work VKT per employee, similar findings were found where a reduction in travel demand occurred with the increase in employment density (Figures 5 - 8). However, there were few locations of high employment densities and yet had high values of attracted VKT per employee. These locations may not be well served by transit, and hence attraction trips were vehicular dependent. Generally, more scatter was observed in travel demand in suburban areas than in Metro or Hamilton.

Figure 3 Produced Work VKT per Adult versus Population Density in Metro

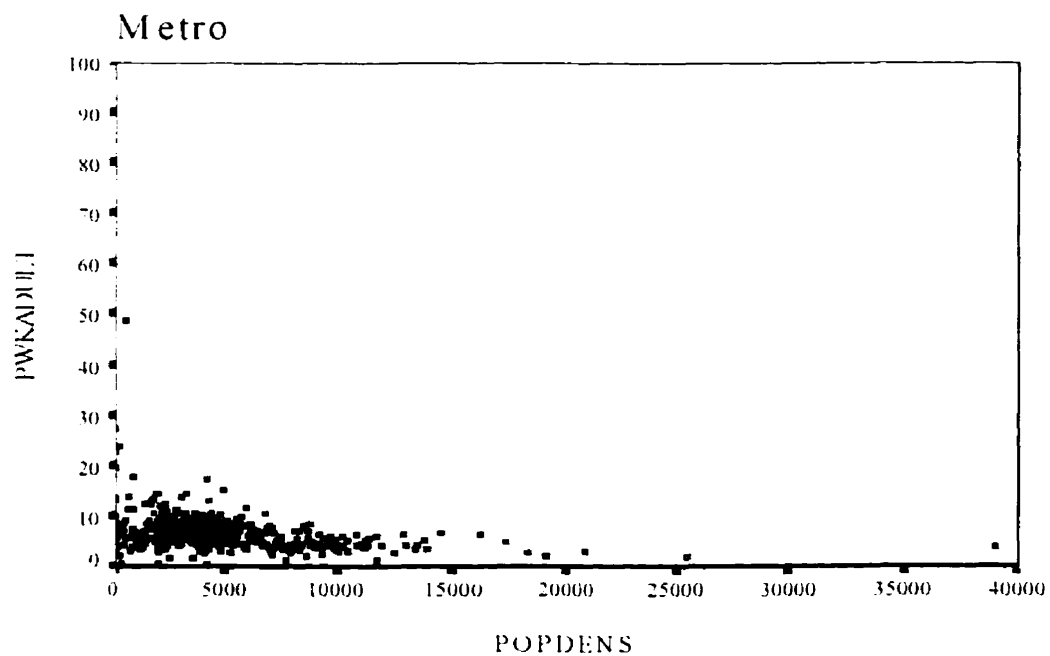


Figure 4 Produced Work VKT per Adult versus Population density in Hamilton

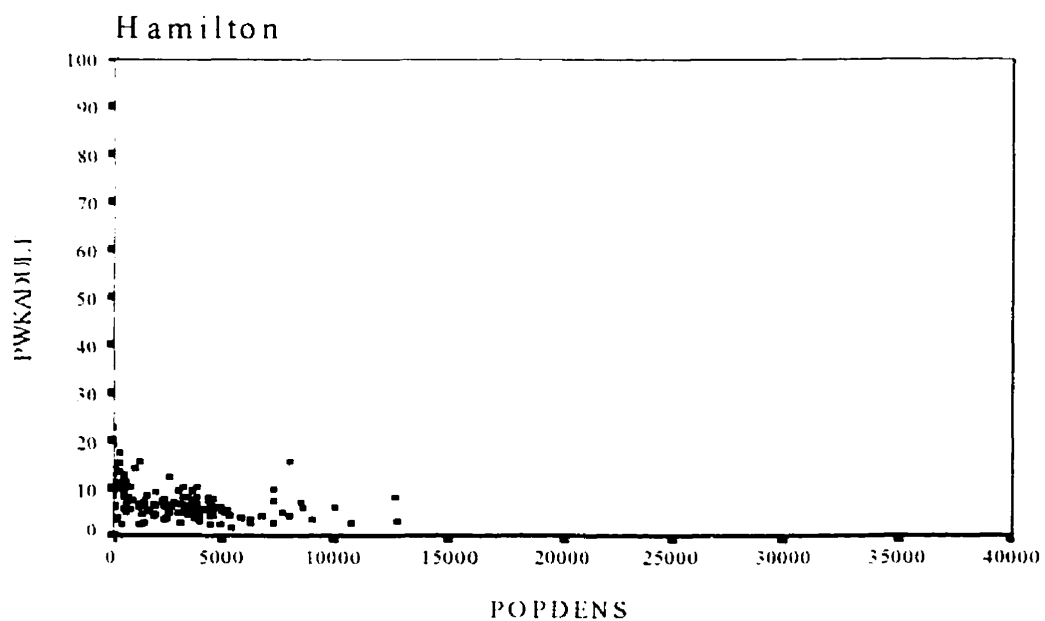


Figure 5 Produced Work VKT per adult in Suburban area 1

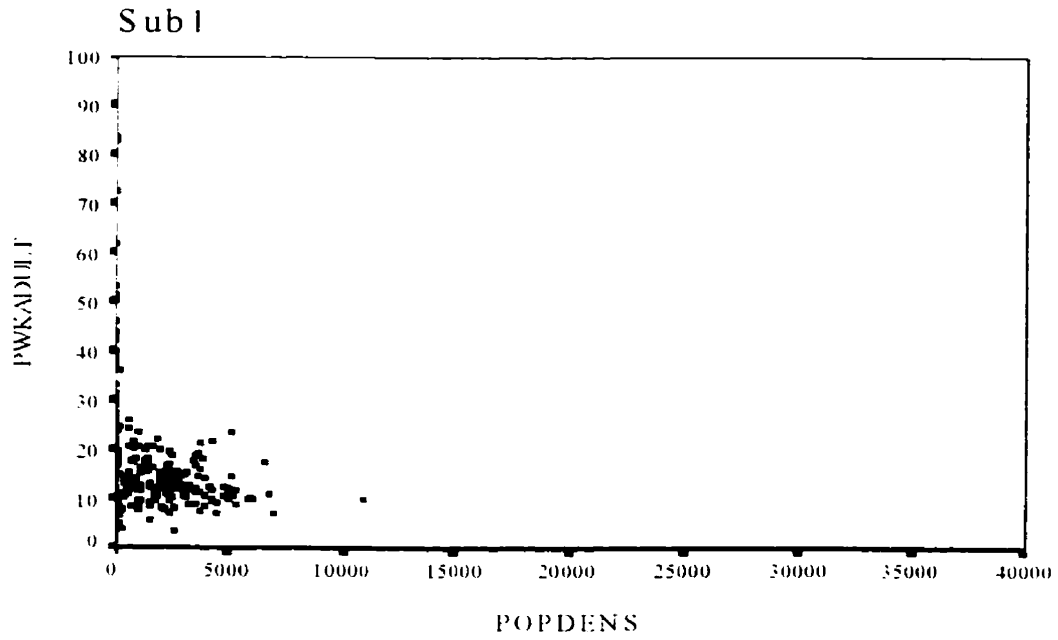
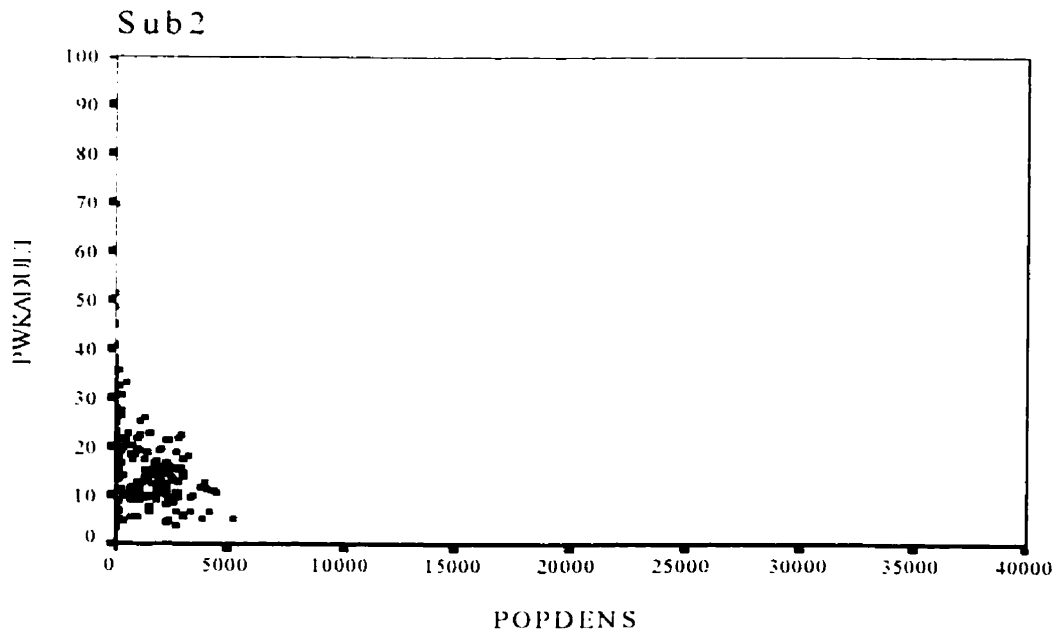


Figure 6 Produced Work VKT per Adult versus Population Density in Suburban area 2



4.3.1.2 Testing the Density Hypothesis

4.3.1.2.1 Population Density

Produced work VKT per adult was found to be significantly correlated (at the 5% level) with population density for the four locations. However, the highest correlation was found in Hamilton-Wentworth where population density explained 14.6% of variation in produced travel VKT (square value of correlation coefficient .382).

For non-work trips, density was negatively correlated with both produced and attracted VKT per adult and significant at the 5% level except in Hamilton region. These results suggest that variations in non-work travel demand in Hamilton are influenced by other factors than density.

Reduction in non-work VKT per adult with the increase in density, was steeper in suburban area 2 (north and east of Metro) than in suburban area 1 (west of metro). This finding may indicate that placing more households in suburban area 2 than in suburban area 1 would result in more sensitive variations in travel demand.

	Metro	Hamilton	Suburban area	Suburban area
Pwkadult	-.245**	-.382**	-.209**	-.233**
Awk/employee	NA	NA	NA	NA
Pnwkadult	-.247**	-.146	-.308**	-.238**
Anwk/adult	-.239**	-.148	-.323**	-.264**

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

Figure 7 Attracted Work VKT per Employee versus Employment Density in Metro

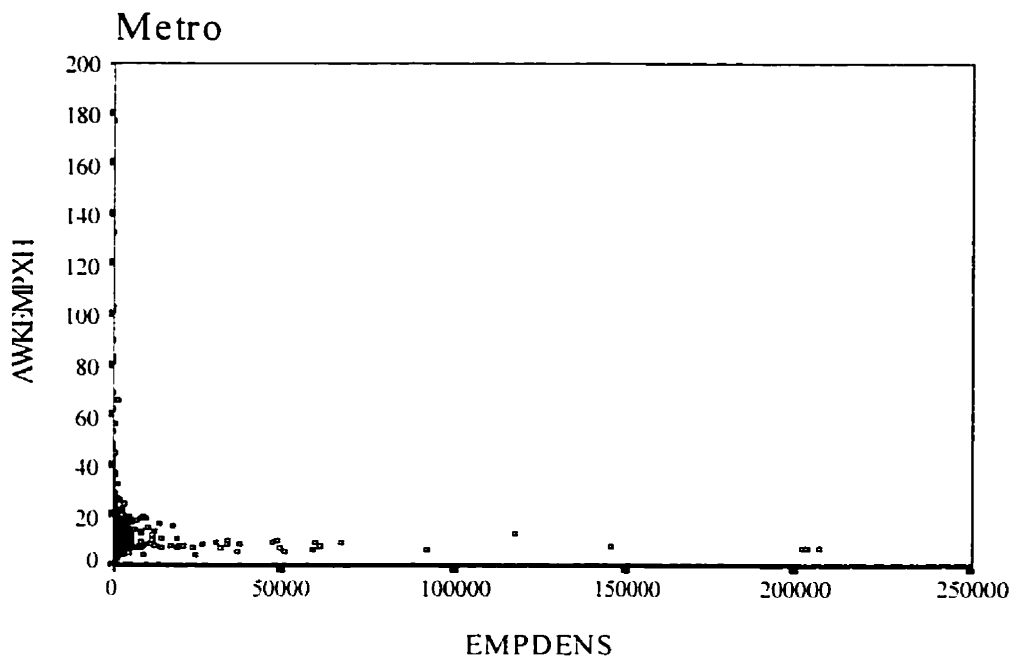


Figure 8 Attracted Work VKT per Employee versus Employment Density in Hamilton

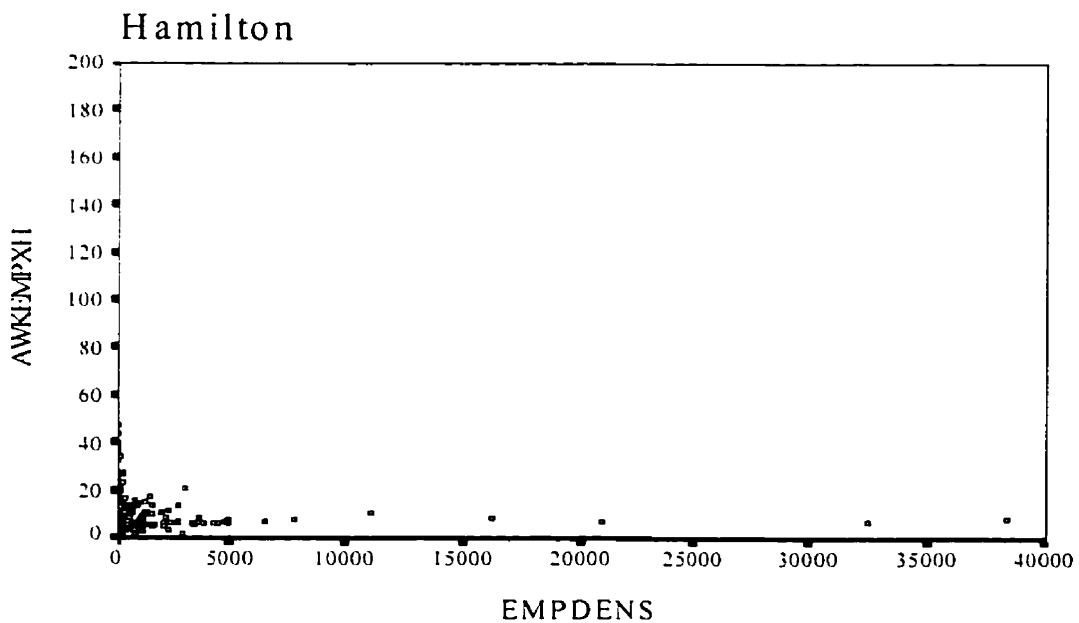


Figure 9 Attracted Work VKT per Employee versus Employment Density in Suburban area 1

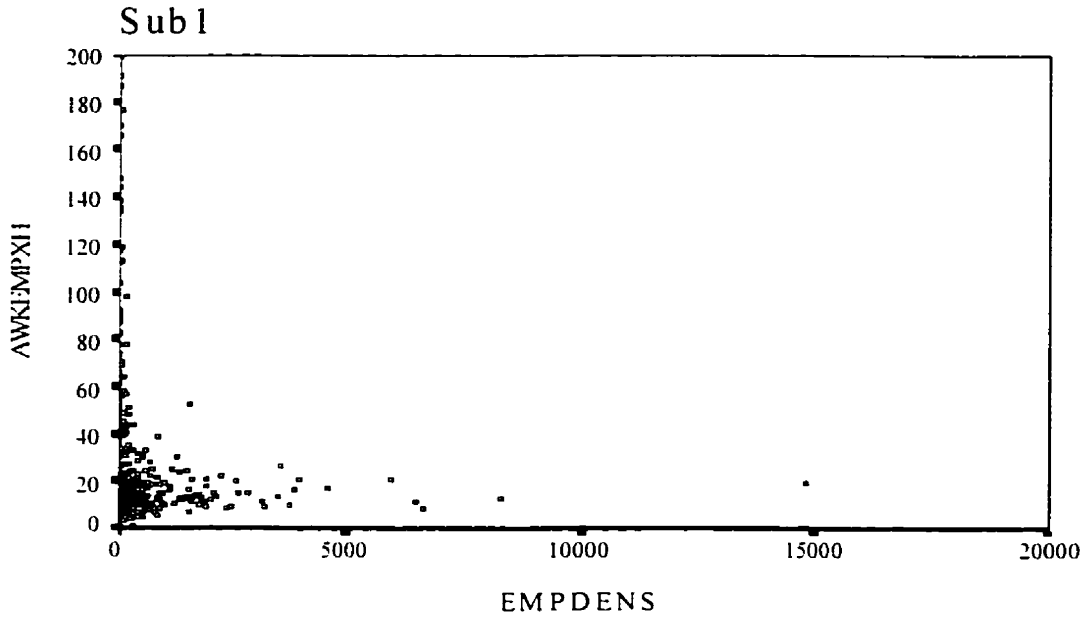
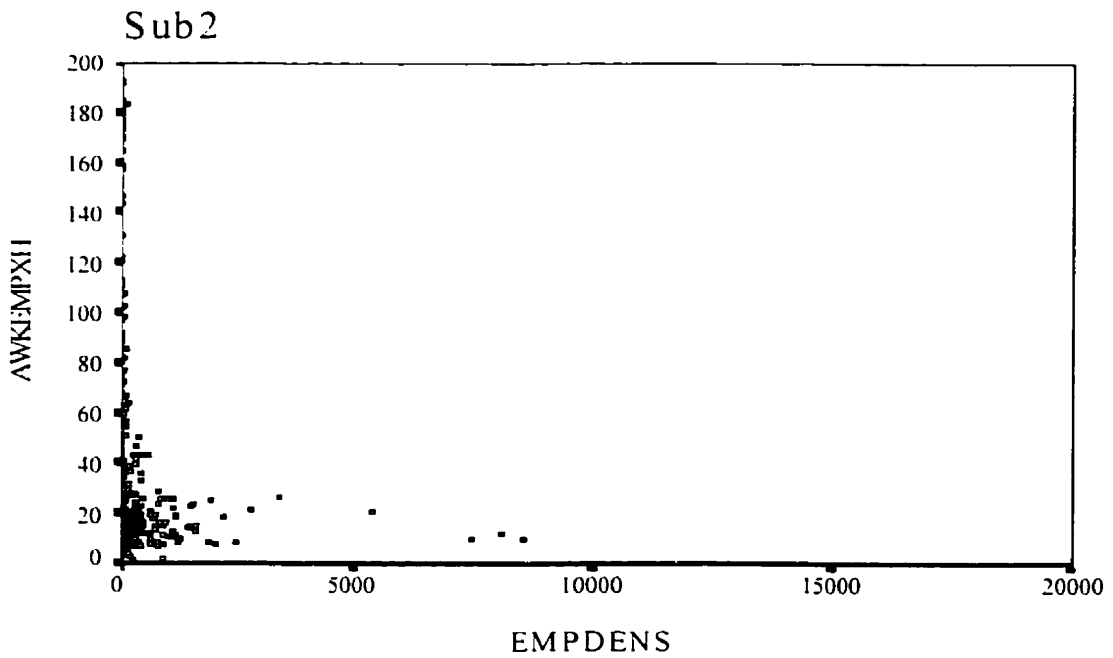


Figure 10 Attracted Work VKT per Employee versus Employment Density in Suburban area 2



4.3.1.2.2 Employment Density

Similar analyses were done to test the explanatory power of employment density for variation in travel demand in the GTA. It was found that employment density was significantly correlated at the 5% level with both produced and attracted work trips for all locations except in Hamilton. This measure of density explained more variations in suburban area than in Metro Toronto.

For non-work VKT per adult, employment density was positively, and significantly correlated at the 5% level. An interesting finding is that this measure explained more variation in non-work trips than the case for work trips in Metro and Hamilton regions. This reflects the generated non-home based activities at employment locations.

	Metro	Hamilton	Suburban area	Suburban area
Pwkadult	.100*	-.134	-.211**	-.204**
Awk/employee	-.126**	-.083	-.126*	-.125*
Pnwkadult	.500**	.761**	.242**	.139*
Anwk/adult	.496**	.763**	.203**	.113*

The direct conclusion drawn from these findings is that, under the assumption of controlling for geographical spatial location but not for other spatial structure variables, density was found to be an influential factor in determining travel demand in the GTA. However, as will be discussed later, since there is correlation between some of the spatial structure measures, one can not draw strong conclusions until a control for other factors such as socio-economic factors, accessibility or access to transit, etc. is maintained. A detailed discussion of the stepwise regression analysis to explore ranking of the spatial structure variables and their power to explain variation in travel demand will be presented in the next chapter.

4.3.2 The Relationship between Travel demand and Degree of Sprawl

4.3.2.1 Travel Demand versus Distance from CBD

As discussed earlier in chapter 3, observations of dispersion of population and employment concentration were observed in the GTA. For the sake of the current discussion, sprawl was defined as additional population residences or employment opportunities located at a long distance from the CBD. For both scenarios of Metro and suburban area 2, distance from the Toronto CBD was considered as a measure of sprawl, meanwhile, for both suburban area 1 and Hamilton-Wentworth, the two measures, distances from Metro CBD and Hamilton CBD, were considered.

A general trend was observed for the relationship between produced work VKT per adult and distance from the CBD for the four locations (Figures 9 - 12). There was an increase in travel demand with the increase in degree of sprawl. However, variations and scatter in travel demand were observed much more in suburban areas than in Metro and Hamilton. Also, the relationship between degree of decentralization of residency and travel demand was stronger in Metro than in other locations.

A similar trend was found for the relationship between travel demand and degree of decentralization of employment locations (Figures 13 - 16). Generally, there was an increase in attracted work VKT per employee with the increase in distance from the CBD. That trend was clearer in Metro and Hamilton than in the suburbs, where much scatter occurred and distance from the CBD would not explain much the variation in travel demand.

Figure 11 Produced Work VKT per Adult versus Distance to the CBD in Metro

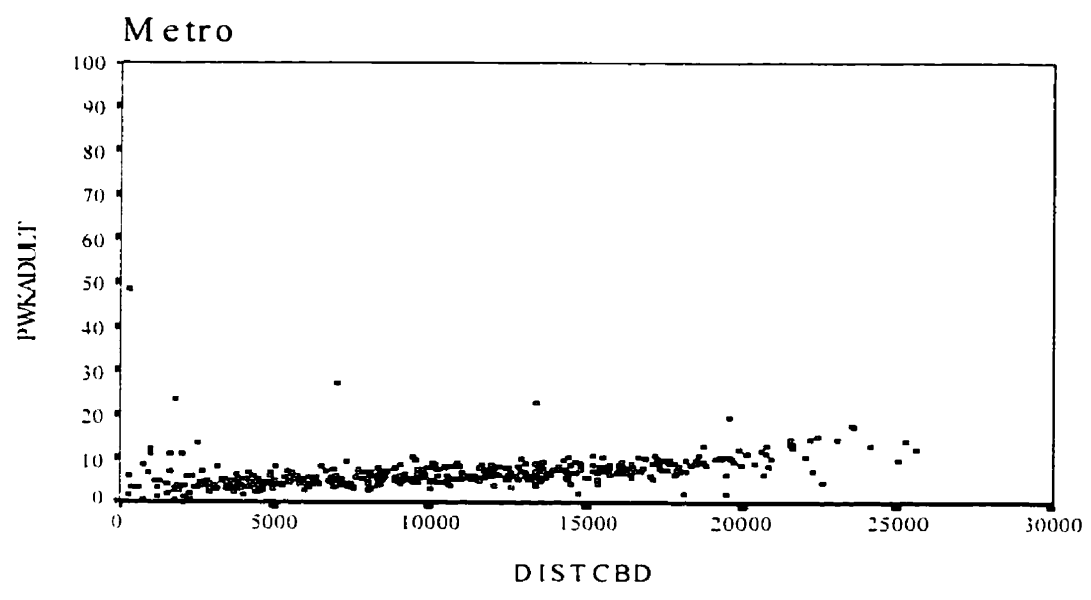


Figure 12 Produced Work VKT per Adult versus Distance to the Hamilton CBD in Hamilton

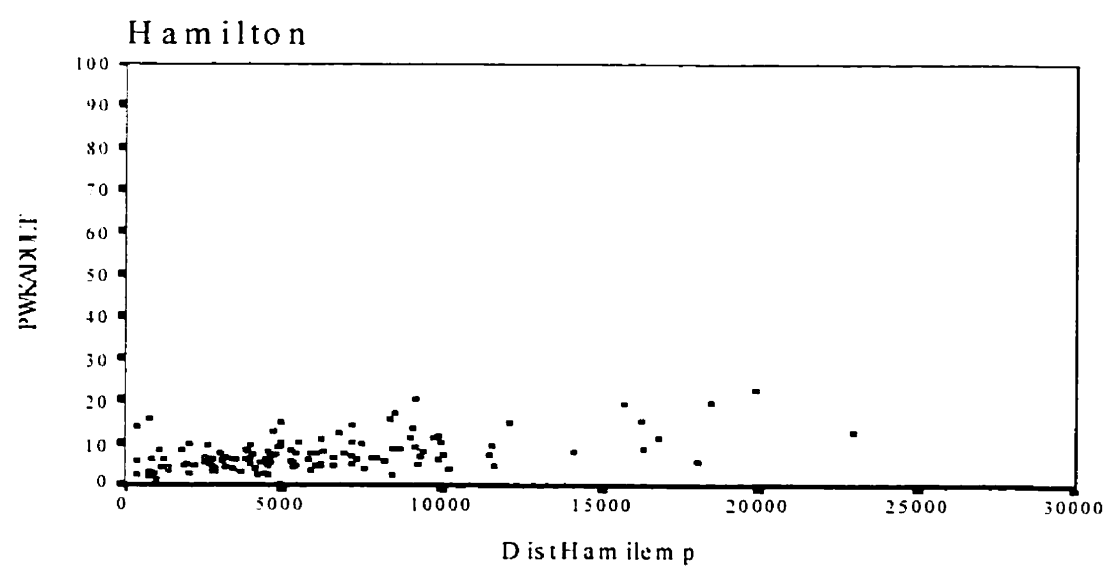


Figure 13 Produced Work VKT per Adult versus Distance to the CBD in Suburban area 1

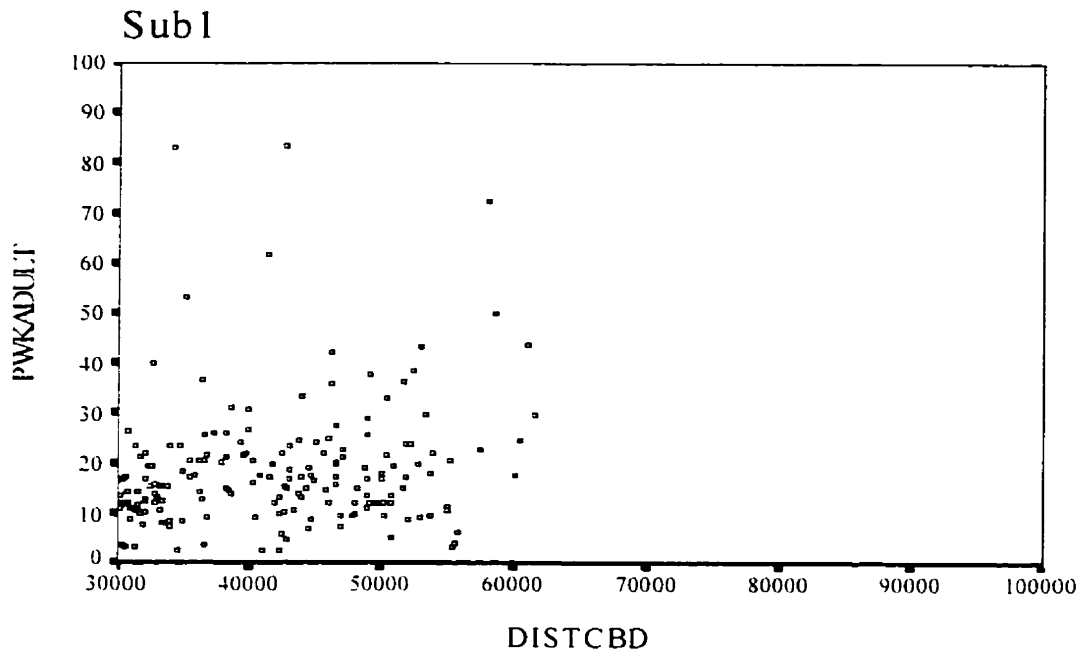


Figure 14 Produced Work VKT per Adult versus Distance to the CBD in Suburban area 2

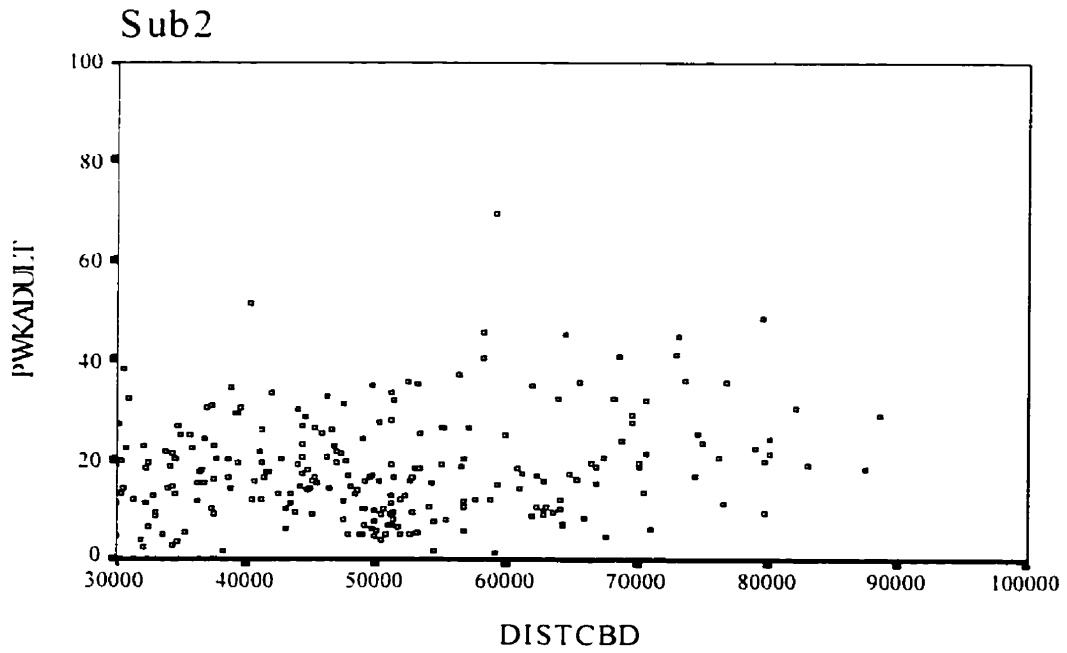


Figure 15 Attracted Work VKT per Employee versus Distance to the CBD in Metro

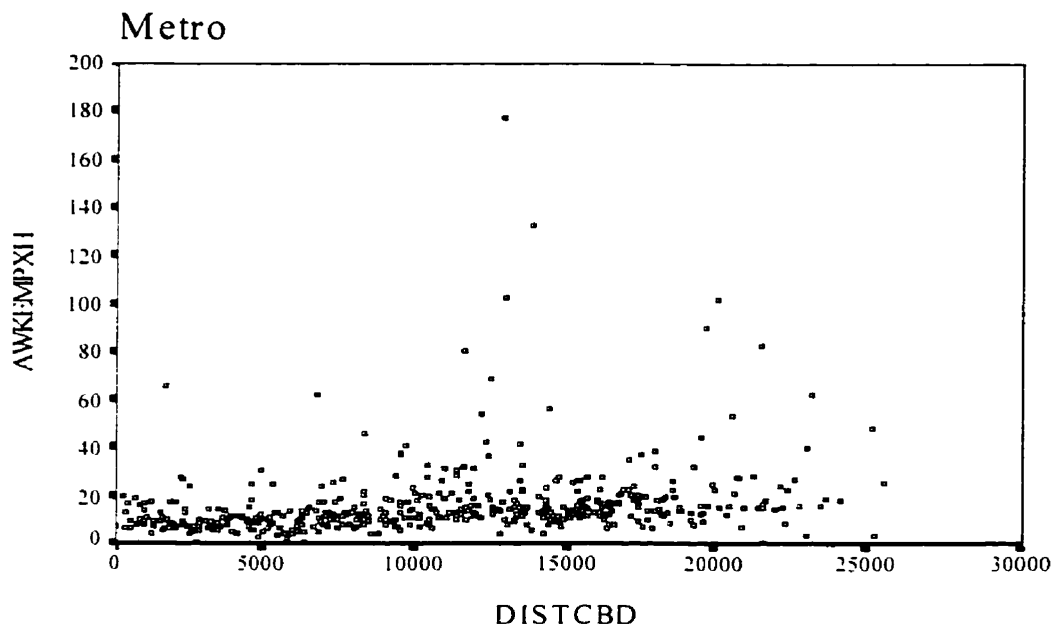


Figure 16 Attracted Employment VKT per Employee versus Distance to the Hamilton CBD in Hamilton

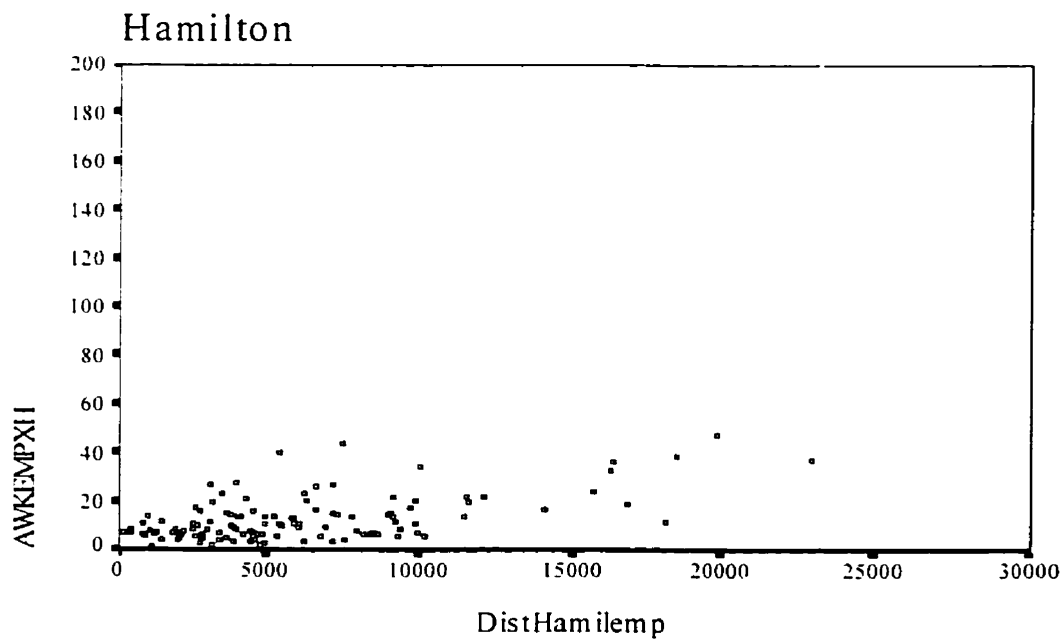


Figure 17 Attracted Work VKT per Employee versus Distance to the CBD in Suburban area 1

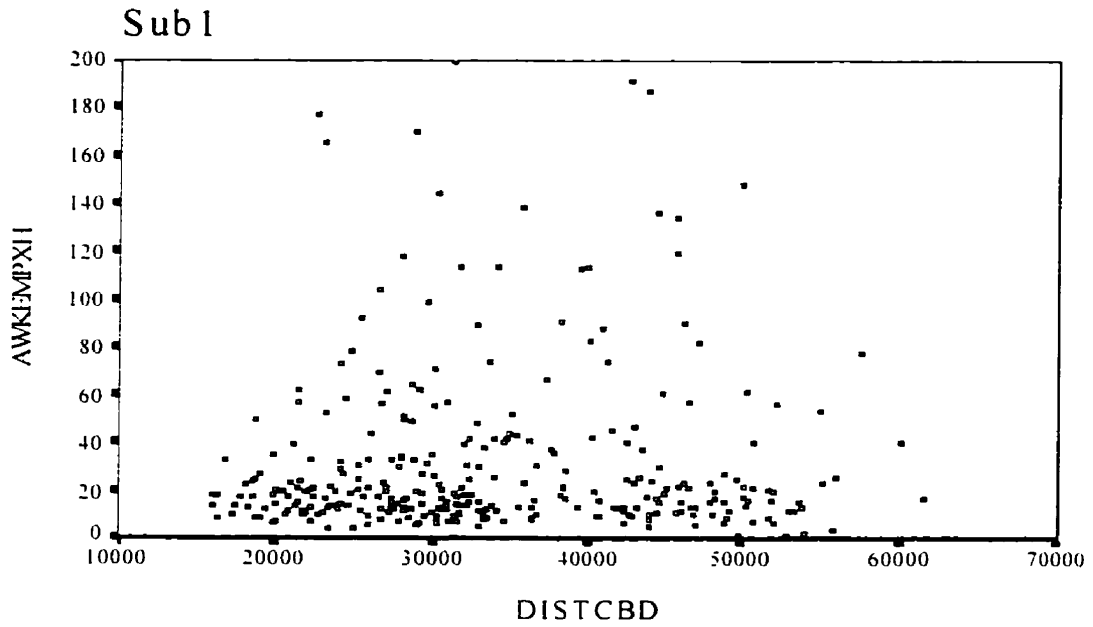
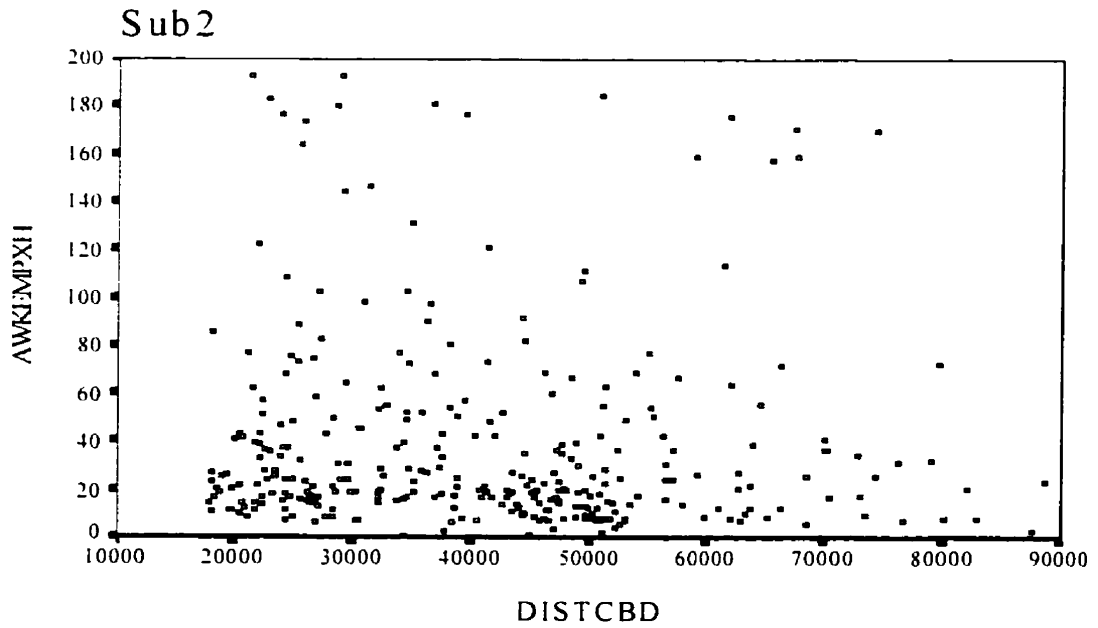


Figure 18 Attracted Work VKT per employee versus Distance to the CBD in Suburban area 2



4.3.2.2 Testing the Relationship between Travel Demand and Degree of Sprawl

The correlation between travel demand measures and distance from the CBD was developed. The results showed that there were significant correlation between travel demand (most of trip types) and distance from the CBD for the four locations. Distance from the CBD explained high percentages of variation in produced work VKT per adult, varying from 6.6 % (square value of correlation coefficient) in suburban areas to 14.4% in Metro Toronto. That is also the case for attracted work VKT per employee in Metro and Hamilton, where correlation was significant at the 5% level. However, these findings were not valid for suburban areas, where there was considerable variation in travel demand, and the degree of sprawl in suburban areas did not explain these variations.

For produced non-work trips, there was significant negative correlation with distance from the CBD indicating less non-work trips produced at the outer areas. Meanwhile, attracted non-work trips was positively and significantly correlated with distance from CBD where more vehicular demand were observed at locations further from the CBD, reflecting the influence of the transit system in serving non-work trips in Metro but not in the suburbs.

DistCBD	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.379**	.339**	.258**	.258**
Awk/employee	.238**	.177*	.015	-.068
Pnwkadult	-.061	-.023	-.137*	-.173**
Anwk/adult	.496**	.763**	.203**	.113*

Meanwhile, considering distance from Hamilton CBD as a measure of dispersion for both suburban area 1 and Hamilton-Wentworth, it was found out that this distance was positively

and significantly correlated with both produced and attracted work trips in Hamilton, and only significant for produced VKT per adult in suburban area 1.

A general conclusion from these findings, is that the degree of sprawl explained to a great extent variation in vehicular travel demand in the GTA, and is expected to influence travel demand especially in locations which are not well served by transit.

Dist Hamilton CBD	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	NA	.543**	.171**	NA
Awk/employee	NA	.180*	.055	NA
Pnwkadult	NA	-.125	.062	NA
Anwk/adult	NA	-.123	.039	NA

4.3.3 The Relationship between Travel Demand and Accessibility to Employment

The purpose of this analysis is to test the relationship between vehicular travel demand and accessibility of residential locations to employment opportunities. The following measures were selected to test this hypothesis:

- Employment opportunities within 5 km buffer from the centroid of each zone per adults residing in this zone.
- Distance to nearest employment node.

As mentioned earlier in section 3.3, employment locations of densities greater than 5000 employee per square km were considered as employment nodes in the GTA and distance from the centroid of each zone to the nearest employment node was considered a measure of accessibility to employment concentration.

4.3.3.1 VKT vs. Distance to the Nearest Employment Node

For the four location regimes, a general trend was observed in the relationship between produced work VKT per adult and distance to the nearest employment node (employment concentration greater than 5000 employee per square km) as shown in Figures 17 - 20. There was an increase in produced work VKT per adult with the increase in distance to the nearest employment node, although the degree of scatter in travel demand differed at the four locations.

Also, attracted work VKT per employee was plotted versus distance to the nearest employment node to test whether the attractiveness of each zone would get higher as it gets closer to employment nodes. However, much variation was observed in attracted work VKT per employee at the four locations, especially in suburban areas, suggesting that this measure did not explain variation in travel demand.

4.3.3.2 VKT vs. Jobs within 5 km Buffer per Adult

Generally at the four locations, there was no pattern observed in the plots between produced work VKT per adult and employment opportunities per adult within 5 km from the centroid of each zone. Also, correlation between produced work VKT per adult and accessibility to jobs within the 5 km buffers was not found to be significant at the 5% level, as shown in the table below. However, this factor explained more variation in produced travel demand at suburban areas than the case at the cities. The higher the accessibility to jobs within the 5 km, the less the produced VKT per adult. Since this measure of accessibility did not explain much variation in travel demand, it will not be considered as an explanatory variable of travel demand in the GTA.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.012	.055	-.093	-.098
Awk/employee	NA	NA	NA	NA
Pnwkadult	NA	NA	NA	NA
Anwk/adult	NA	NA	NA	NA

Figure 19 Produced Work VKT per Adult versus Distance to the Nearest Employment Node in Metro

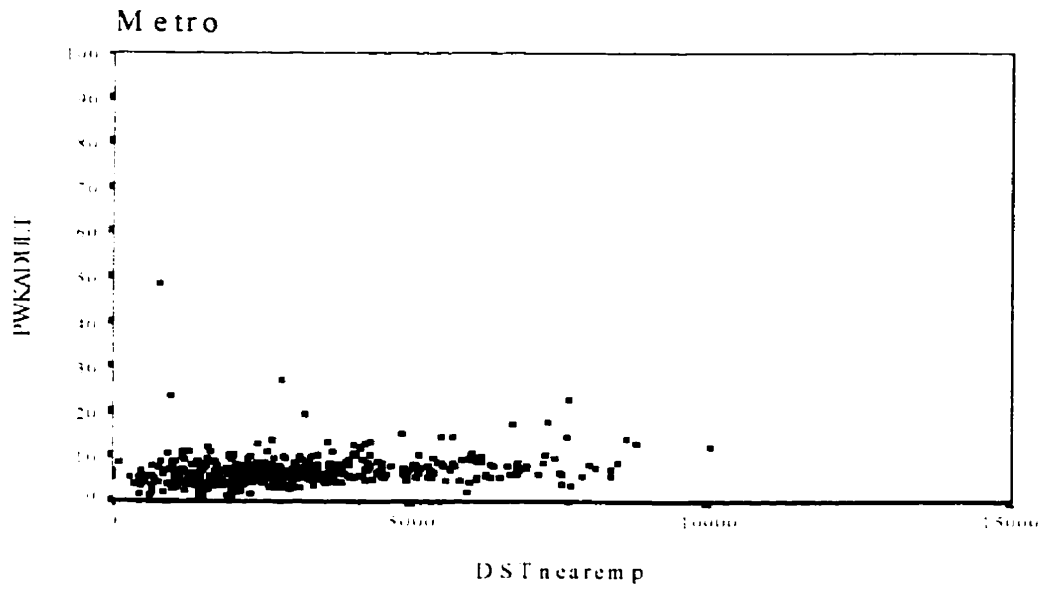


Figure 20 Produced work VKT per Adult versus Distance to the Nearest Employment Node in Hamilton

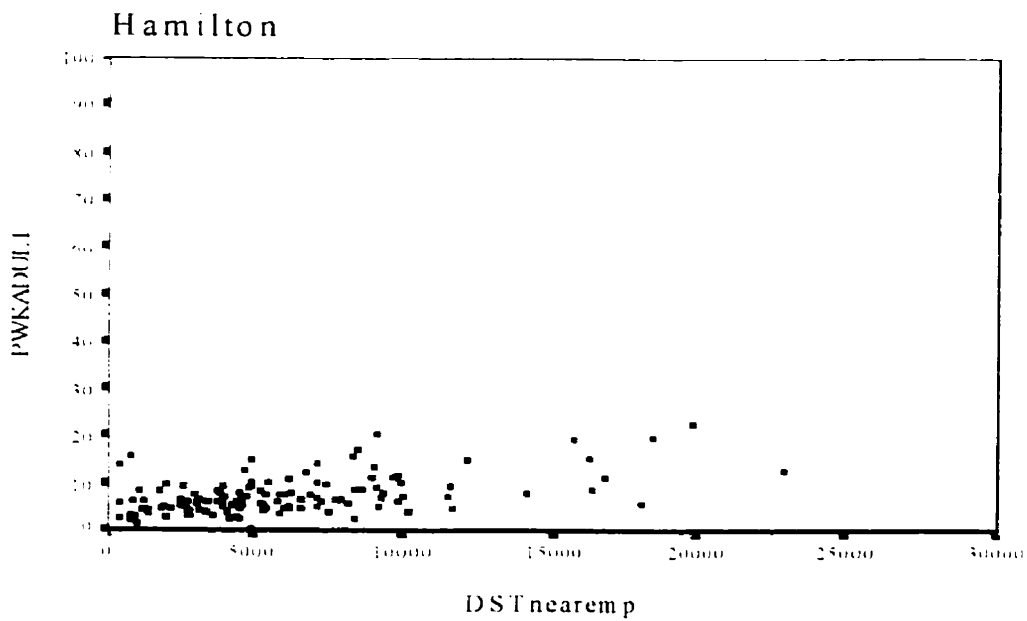


Figure 21 Produced Work VKT per Adult versus Distance to the Nearest Employment Node in Suburban area 1

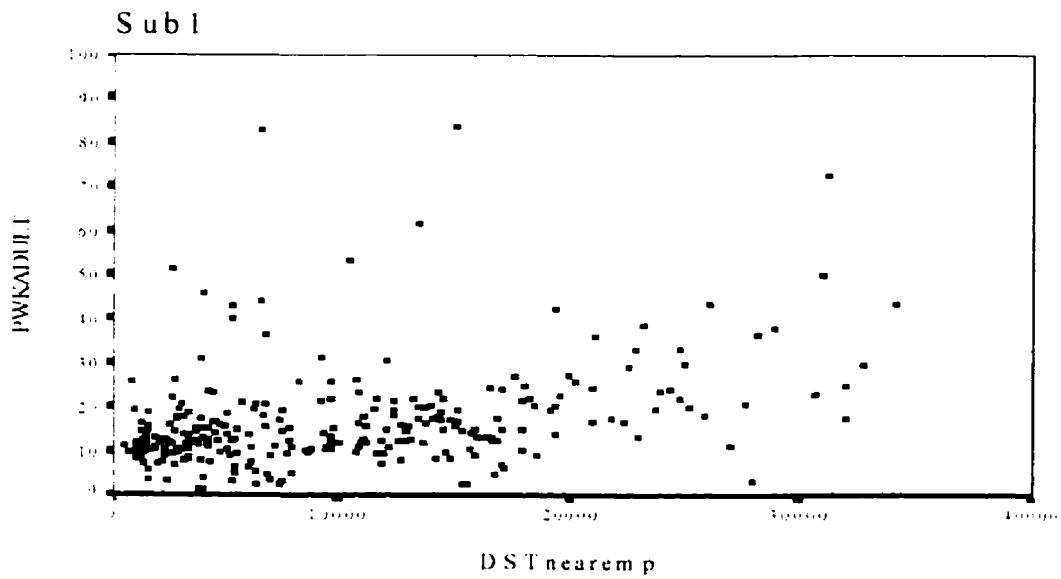
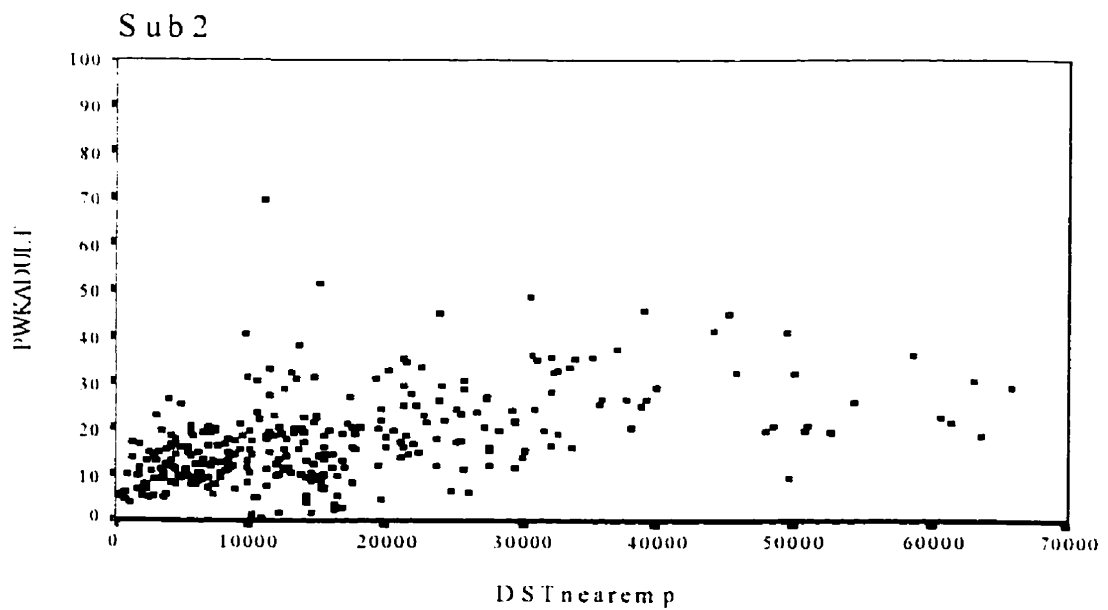


Figure 22 Produced Work VKT per Adult versus Distance to the Nearest Employment Node in Suburban area 2



4.3.3.3 Testing the Relationship between Travel Demand and Accessibility to Employment

It was found out that correlation between produced work VKT per adult and distance to the nearest employment node was significant at the 5% level. The longer this distance, the higher was the observed produced work VKT per adult. This measure explained around 25% for variation in travel demand for Hamilton and suburban area 2 under the assumption of not controlling for other factor. Meanwhile, attracted work VKT per employee was not significantly correlated with distance to the employment node except for Hamilton region.

Also, non-work VKT per adult was negatively correlated with the discussed measure but not significant at the 5% level except for Metro Toronto. The further the distance from the employment node, the less attractive the site became for non-work trips.

In conclusion, accessibility to employment nodes were influential on travel demand. However, the explanatory power of this measure was found to be not significant to explain variation in travel demand in the GTA.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.221**	.543**	.319**	.484**
Awk/employee	.067	.180*	.056	.040
Pnwkadult	NA	NA	NA	NA
Anwk/adult	-.107*	-.123	-.081	-.064

4.3.4 The Relationship between Travel Demand and Self Containment Ratio

The spatial match between the distributions of jobs and labour is defined by the ratio of employment opportunities within 5 km buffer from the centroid of each zone per labour force residing in the centre zone, and considered as a measure of self containment.

It should be noted that locations of high employment concentrations had higher ratios of jobs to labour which reflected a mismatch between jobs and labour in this specific zone, however, high employment concentration zones may still be accessible to surrounding residential zones. The judgement on self containment should be considered on larger areas, perhaps on a planning district or regional level. However, for the sake of the current discussion, the ratio of Jobs within 5 km buffer to labor force will be considered as a spatial measure of self containment on a zonal level.

4.3.4.1 VKT vs. Self Containment Ratio

The two dimensional plots did not show a clear pattern for the relationship between produced work VKT per adult and spatial match between jobs and labour for Metro and Hamilton (Figures 21 - 24). However, there was a negative trend for this relationship in both suburban area 1 and 2 which suggests that self containment ratio may explain variation in travel demand in suburbs more than in the city.

A general pattern was observed at the four locations for the relationship between attracted work VKT per employee and self containment ratio. There was a drop in attracted travel demand with the increase in this ratio. However, the scatter and variations in observations were much more in suburban areas than in Metro and Hamilton.

Figure 23 Produced Work VKT per Adult versus Self Containment Ratio (jobs within 5 km buffer / labor) in Metro

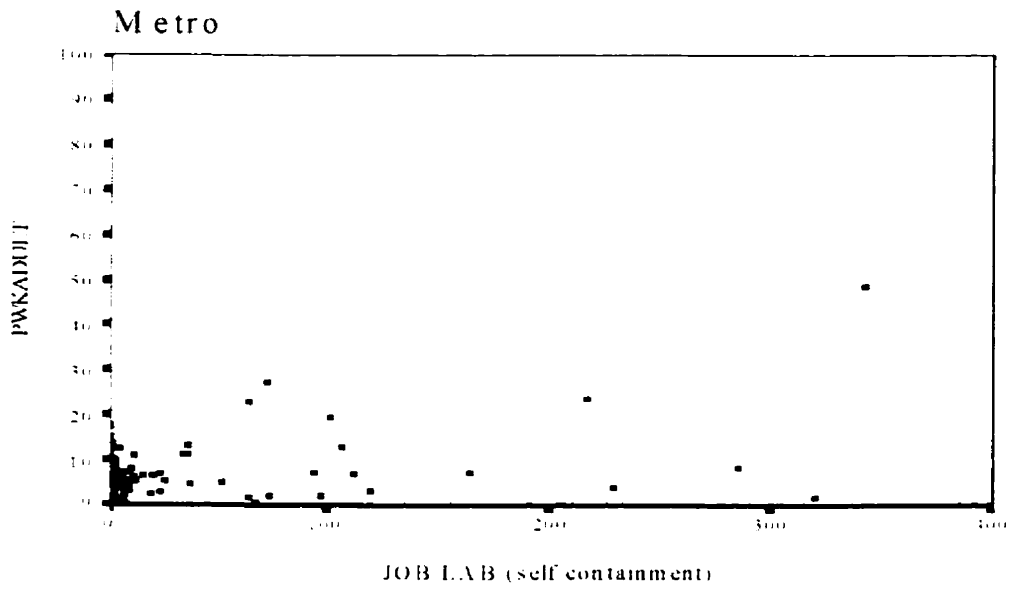


Figure 24 produced Work VKT per adult versus Self Containment Ratio (jobs within 5 km buffer / labor) in Hamilton

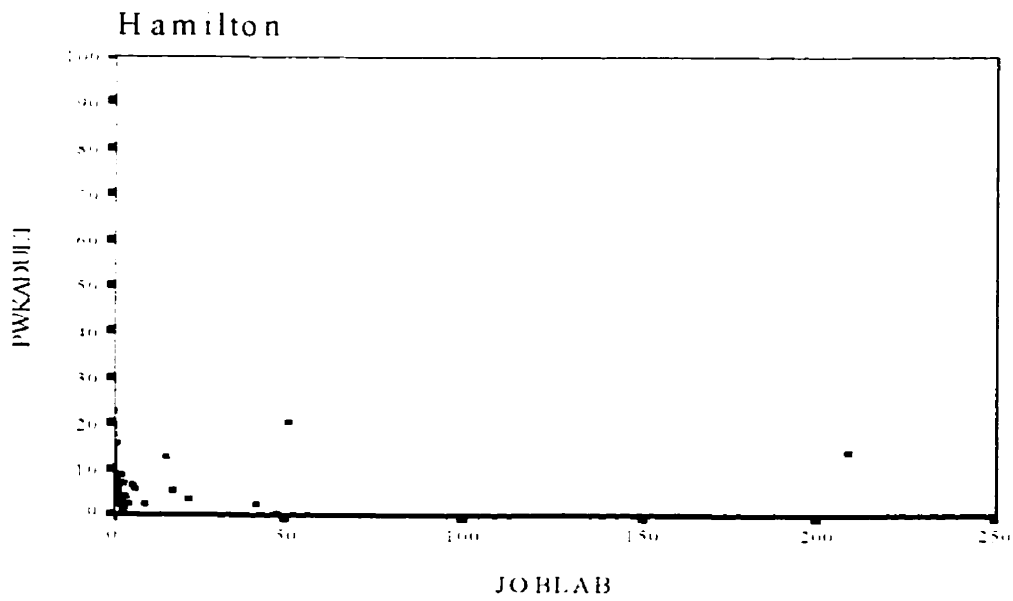


Figure 25 Produced Work VKT per Adult versus Self Containment Ratio (jobs within 5km buffer / labor) in Suburban area 1

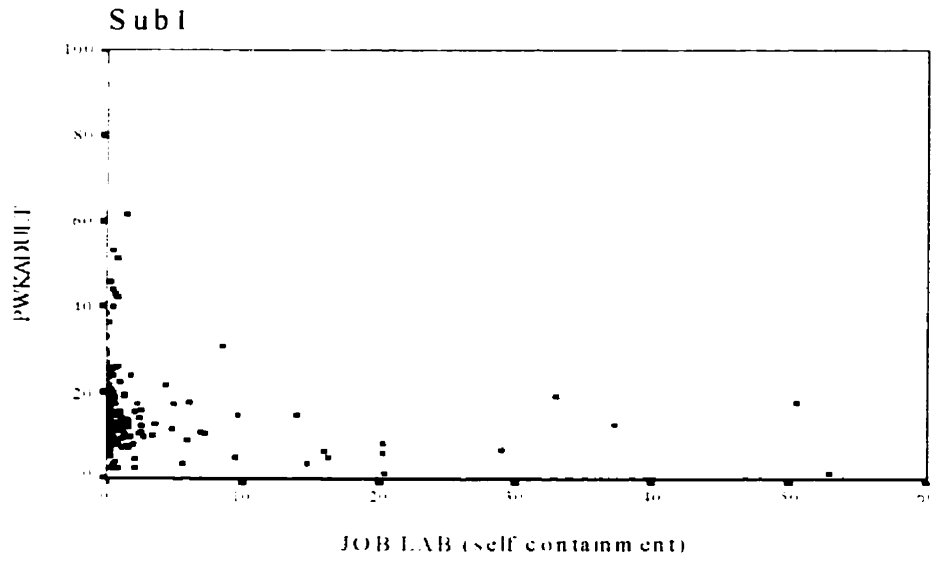
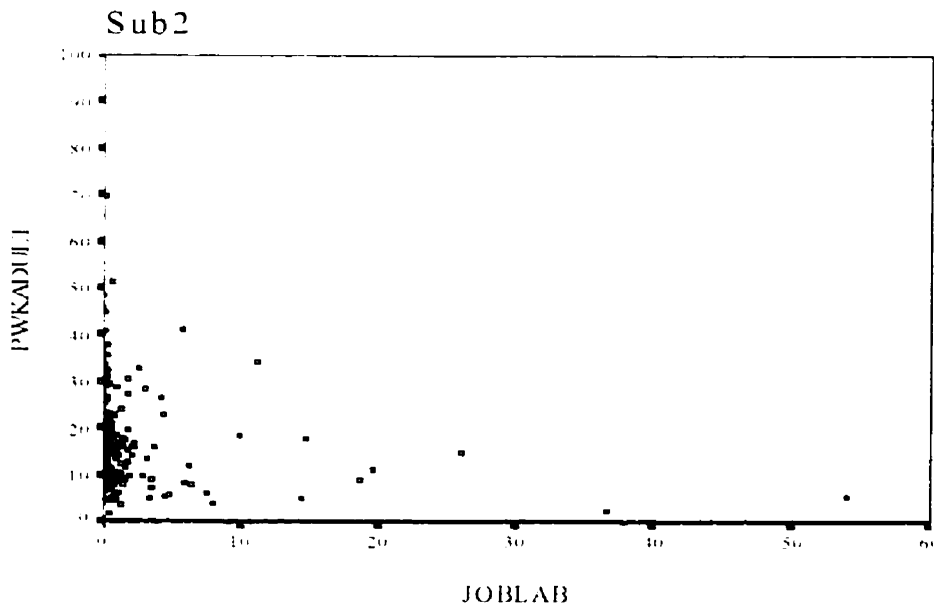


Figure 26 Produced Work VKT per Adult versus Self Containment Ratio (jobs within 5 km buffer / labor) in Suburban area 2



4.3.4.2 Testing the Relationship between Travel Demand and Self Containment

In Metro Toronto, self containment ratio varied from 0 to 17012. The distribution of this ratio versus distance from the CBD showed two groups of data: very high and low ranges. It should be noted that when this ratio is high, it indicates the vicinity to high employment concentrations and low concentration of residences.

Metro data were split into two ranges of self containment ratios to test differences and similarities between the two groups. Around 50% of the Metro observations had a ratio less than 100 (mean of 45.35). A downward slope was observed for produced work VKT per adult versus the ratio less than 100, while there was no clear pattern for the ratio greater than 100.

Correlation between produced work VKT per adult and this ratio was negative and significant at the 5% level. Also, there was a negative correlation between attracted VKT per worker and this ratio, however, correlation was not significant at the 5% level. For non-work trips, both produced and attracted VKT per adult was not significantly correlated with this ratio, as shown in the following table.

On the other hand, for self containment ratio greater than 100, it was found that variations in work VKT were not significantly correlated with this ratio. However, for both produced and attracted non-work VKT per adult, correlation with this ratio was high, positive, and significant at the 5% level. This reflects the generated non-work trips at locations of high employment concentrations.

Similar analyses were repeated for self containment ratio less and greater than 50 for confirmation of the previous findings. Consistent results were obtained as summarised in the table below.

	Ratio < 100	Ratio > 100	Ratio < 50	Ratio > 50
Pwkadult	-.416**	.080	-.436**	.049
Awk/employee	-.097	.010	-.029	-.014
Pnwkadult	.082	.679**	.115	.694**
Anwk/adult	-.058	.667**	.087	.682**

In Hamilton-Wentworth, this ratio varied from 0 to 4775 with 77 % of observations with a ratio less than 100 (mean of 43.35). There were only 29 observations with ratios greater than 100 including 6 observations greater than 300. In suburban area 1, around 58% of total observations had a ratio less than 100 and the rest of observations with ratios greater than 100. Meanwhile, for suburban area 2, this ratio varied from 0 to 3317 with 83% less than 100. Therefore, it was decided to consider the value of 100 as the break point between high and low groups for the rest of analyses.

Analyses were conducted for Hamilton and suburban areas for the two regimes of ratios less and greater than 100. For the ratio less than 100, it was found out that produced work VKT per adult was negatively correlated with self containment ratio and significant at the 5% level. Within the range of 100, the higher this ratio the less produced travel demand. However, when the ratio was higher than 100, correlation was not significant at the 5% level.

For the ratio less than 100, correlation between attracted work VKT per employee and this ratio was negative, but not significant at the 5% level, except for Hamilton-Wentworth, where the self containment ratio was significantly correlated with all types of trips. This result shows that within the range of 100, attracted demand dropped by the increase in this ratio reflecting people's preference to work close to home.

For the ratio higher than 100 both produced and attracted non-work VKT per adult, were highly and positively correlated with this ratio reflecting the attracted non-work at locations of higher employment concentrations.

In conclusion, the ratio of spatial match between employment opportunities and labour was found to significantly influence travel demand in the GTA. However, selecting the measure for testing self containment and the ratio of a good match is open for discussion and further study. For the sake of the current study, this ratio will be tested in combination with other possible measures selected to explain spatial structure of the GTA as will be discussed in the next chapter.

Ratio less than 100

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	-.416**	-.545**	-.246**	-.249**
Awk/employee	-.097	-.441**	-.051	-.029
Pnwkadult	.082	-.452**	.047	.129*
Anwk/adult	-.058	-.477**	.049	.091

Ratio greater than 100

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.080	.235	-.084	-.068
Awk/employee	.010	-.018	.188	-.080
Pnwkadult	.679**	.966**	.427**	.246
Anwk/adult	.667**	.969**	.442**	.279*

4.3.5 The Relationship between Travel Demand and Demographic Characteristics

The relationship between travel demand and a number of explanatory variables representing demographic characteristics was tested to check whether there was correlation between these variables.

4.3.5.1 VKT vs. Adult with Driving License

There was a positive slope for the relationship between produced work VKT per adult and percentage of adults with a driving license in each zone for both Metro and Hamilton. However, more scatter was observed for both suburban areas 1 and 2 and no clear pattern can be seen for the underlying relationship (Figures 25 - 28).

The correlation between travel demand (VKT) and availability of driving license was significant at the 5% level at both locations of Metro and Hamilton. However, for suburban areas, this explanatory variable did not explain variation in produced work and non-work trips.

Figure 27 Produced Work VKT per Adult versus Percentage of Adults with Driving License in Metro

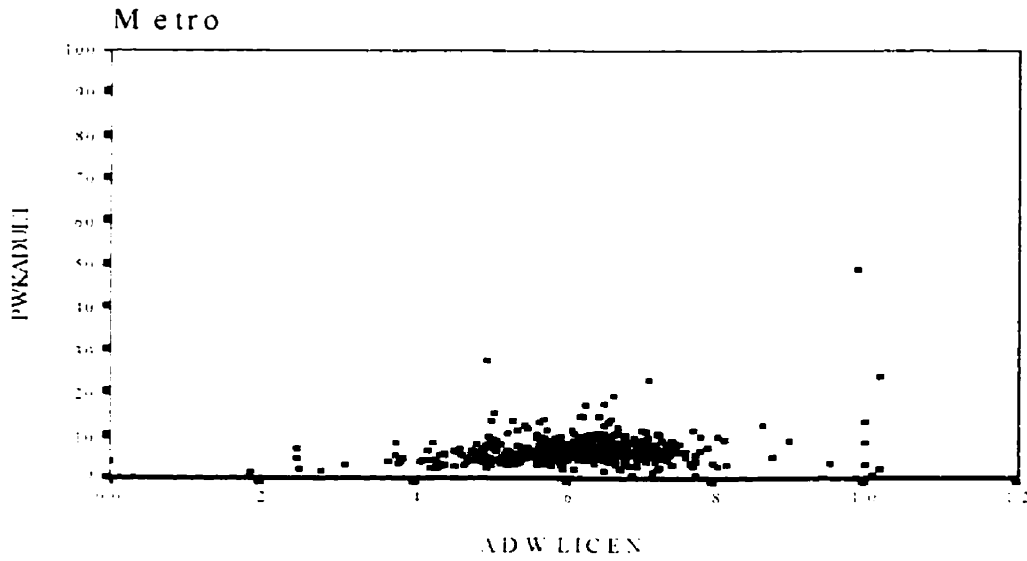


Figure 28 produced Work VKT per adult versus Percentage of adults with Driving License in Hamilton

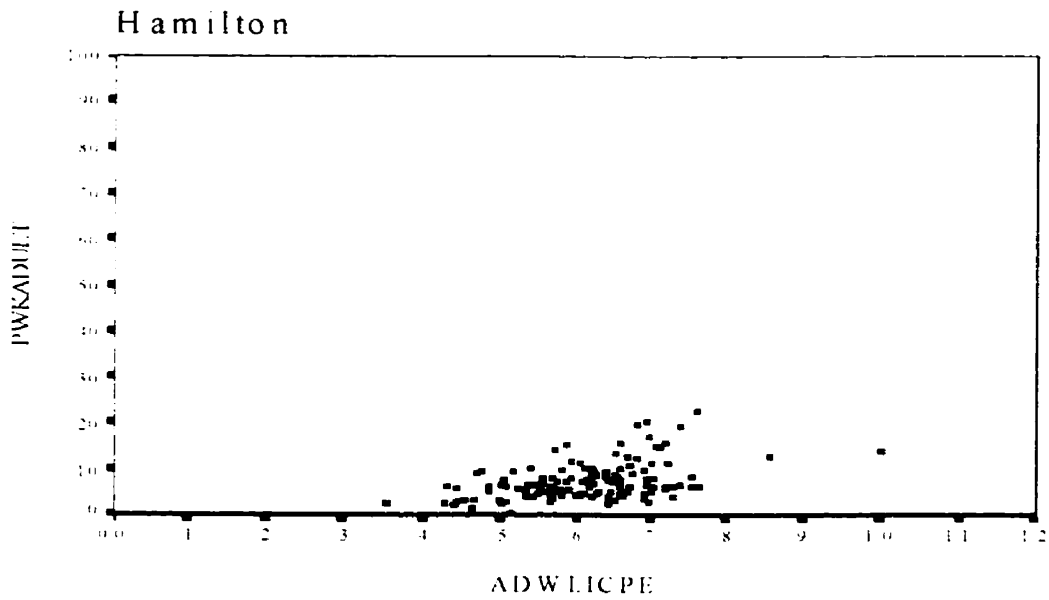


Figure 29 Produced Work VKT per Adult versus Percentage of Adults with Driving License in Suburban area 1

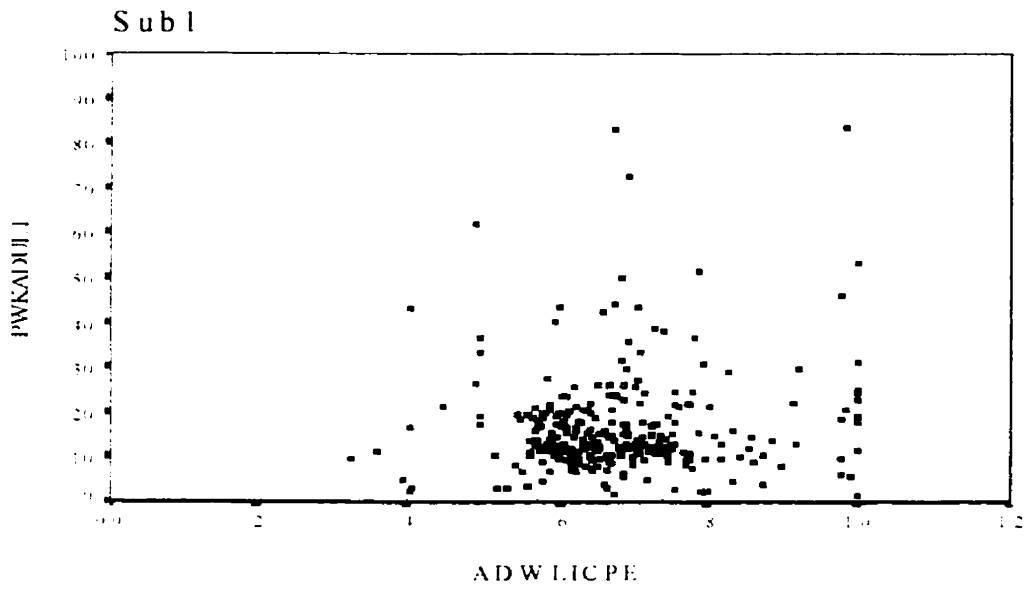
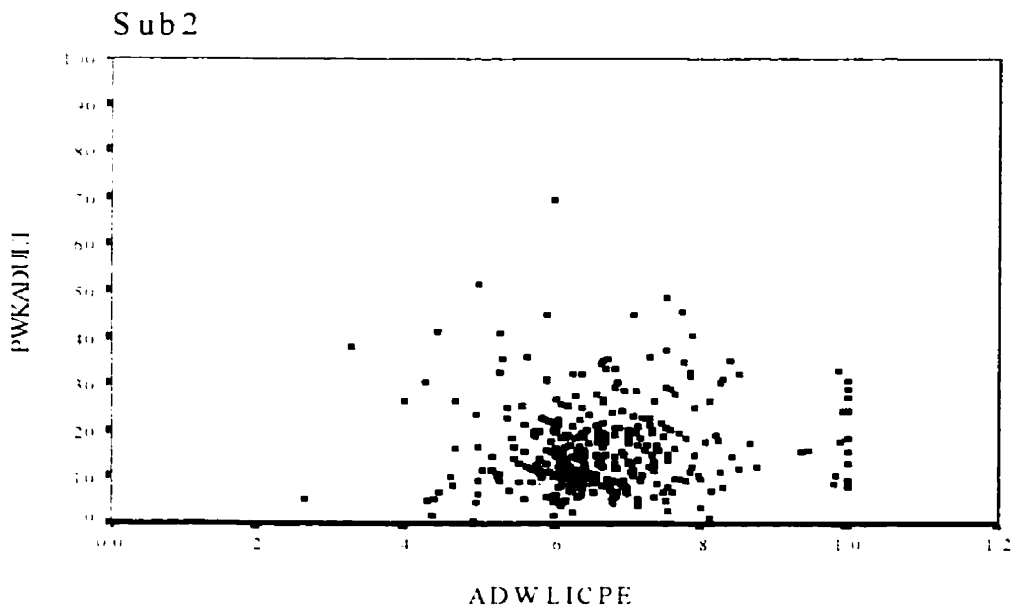


Figure 30 Produced Work VKT per Adult versus percentage of Adults with Driving License in Suburban area 2



	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.139**	.492**	.062	-.008
Awk/employee	NA	NA	NA	NA
Pnwkadult	.098*	.313**	.094	.070
Anwk/adult	NA	NA	NA	NA

4.3.5.2 VKT vs. Employment Participation Rate

As mentioned earlier in Chapter 2, Section 2.3, the ratio of employed people to total population is considered as an indication of employment participation level in each zone. There was a positive trend for the relationship between produced work VKT per adult and employment participation rate, and this rate was found to be significant for all locations except in Metro. This observation matches the intuitive expectation that the higher this ratio, the higher produced of work trips, except in locations which are well served by transit like Metro.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.060	.337**	.239**	.357**
Awk/employee	NA	NA	NA	NA
Pnwkadult	NA	NA	NA	NA
Anwk/adult	NA	NA	NA	NA

4.3.5.3 VKT vs. % Full Time Employed Labor Force

There was significant correlation between both produced and attracted non-work trips and percentage of people who have a full time job at all locations except in suburban area 1.

The higher this percentage in cities (Metro and Hamilton), the more produced or attracted VKT per adult. However, this finding was not valid for produced non-work trips in suburban area 2.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	-.039	.131	-.020	0.0
Awk/employee	NA	NA	NA	NA
Pnwkadult	.188**	.218*	.082	-.154**
Anwk/adult	.190**	.213*	.080	.139*

4.3.5.4 VKT vs. % Part Time Employed Labor Force

Similar analysis was performed between travel demand and percentage of part time employees. There was a negative correlation between both produced and attracted non-work VKT per adult and this percentage. However, for produced work trips, the results differed from one location to another. These analyses indicated that percentage of full time and part time employed labor force can be considered as influential demographic factors for both work and non-work travel demand.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.091	-.251**	.146*	-.078
Awk/employee	NA	NA	NA	NA
Pnwkadult	-.148**	-.288**	-.162**	-.186**
Anwk/adult	-.152**	-.295**	-.178**	-.190**

4.3.5.5 VKT vs. %People Who Work at Home

The correlation between this variable and travel demand differed from one location to another, with higher percentages located in suburban areas than in Metro. There was a positive correlation between travel demand and % people work at home in all locations except in Metro, where correlation was negative for both work and non-work trips, and produced work trips in suburban area 1.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	-.117*	.135	-.097	.109
Awk/employee	-.095	.124	.049	.155**
Pnwkadult	-.139**	.063	.033	.017
Anwk/adult	-.136**	.078	.048	.046

4.3.5.6 VKT vs. % Children

Interestingly, the correlation between travel demand and percentage of children in each zone was significant for most of the cases as shown in the table below. The power of this explanatory variable in combination with others will be tested later in the next chapter.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.176**	.264**	.064	.212**
Awk/employee	NA	NA	NA	NA
Pnwkadult	-.143**	-.238**	-.134*	-.063
Anwk/adult	-.148**	-.239**	-.147*	-.086

4.3.6 The Relationship between Travel Demand and Car Ownership

4.3.6.1 VKT vs. Percentage of Household with No Vehicles

As intuitively expected there was a downward slope in the relationship between produced work VKT per adult and percentage of households with no vehicles in each zone. The correlation was also significant at the 5% level in all locations. However, it was not the case for non-work trips where correlation was positive and significant for all locations except Metro. It should be noted that zones with high percentages of households with no vehicles were mostly located in the vicinity of the CBD of the cities or where there was a strong transit system as shown in Map 8. This finding may suggest that zones with low car ownership were the same zones with high population density and correlation here reflected the effect of density or other factors such as transit influence.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	-.377**	-.381**	-.239**	-.208**
Awk/employee	NA	NA	NA	NA
Pnwkadult	.007	.535**	.391**	.120*
Anwk/adult	NA	NA	NA	NA

4.3.6.2 VKT vs. Percentage of Household with Two or More Vehicles

Generally, there was a positive slope for the relationship between produced work VKT per adult and percentage of households with 2 or more vehicles at the four locations. This suggests that the more number of vehicles available in the household, the more likely the use of this mode for work trips, given that the number of vehicles in household reflects both income and lifestyle. Also, it is observed that the slope of the relationship was steeper in suburban areas than in Metro and Hamilton, reflecting the effect of transit system on travel demand and lifestyle in the outer areas.

Also, correlation between produced work trips and high level of car ownership, defined as percentages of households with more than 2 vehicles in each zone, was significant and positive at the four locations. Meanwhile, there was a negative correlation in the case of produced non-work trips. This result is somewhat surprising, however, it may reflect the important role which employment plays in producing non-work trip origins. High non-work trip production zones may well have relatively low numbers of households with more than 2 vehicles.

	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	.415**	.578**	.395**	.313**
Awk/employee	NA	NA	NA	NA
Pnwkadult	-.066	-.219*	-.023	-.173**
Anwk/adult	NA	NA	NA	NA

4.3.7 The Relationship between Travel Demand and Transit Use

4.3.7.1 VKT vs. Percentage of Transit Use

The effect of transit access in Metro can be seen clearly from Figures 29- 32, where there was a clear drop in produced work VKT per adult with the increase in transit use. Comparing the four locations, the highest transit use dropped from around 0.7 in Metro to around 0.4 or less in other locations. However, generally there was a drop in both produced and attracted work trips with the increase in transit use. Meanwhile, similar correlation was obtained for non-work trips in suburban areas, however, it differed for Metro and Hamilton.

Figure 31 Produced Work VKT per Adult versus Percentage of Produced 24- Hour Trips Made by Transit (Transit use) in Metro

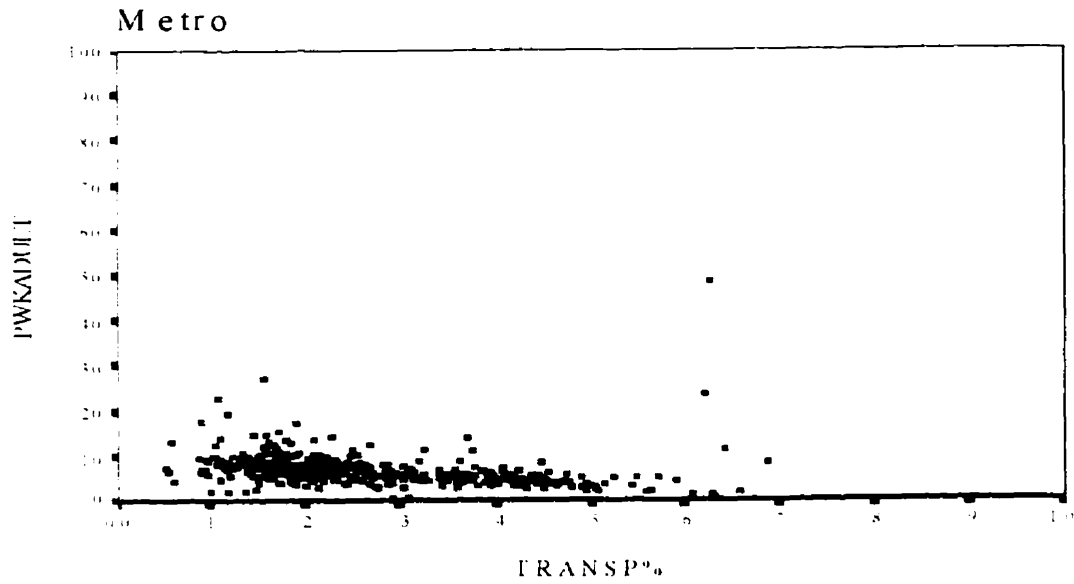


Figure 32 Produced work VKT per Adult versus Percentage of Produced 24- Hour Trips made by Transit (Transit use) in Hamilton

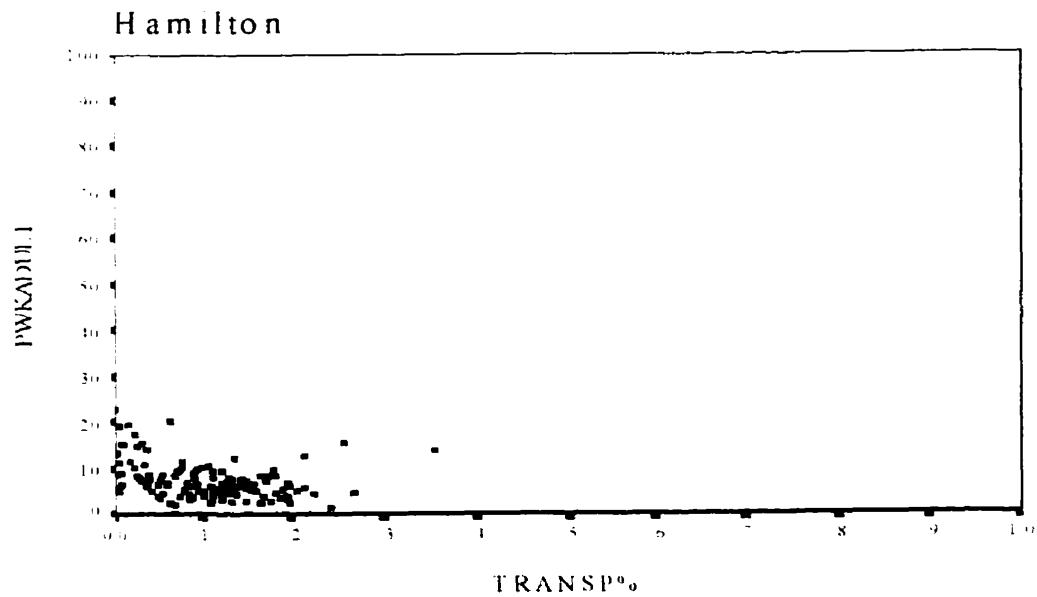


Figure 33 Produced Work VKT per Adult versus Percentage of Produced 24-hour Trips Made by Transit (Transit use) in Suburban area 1

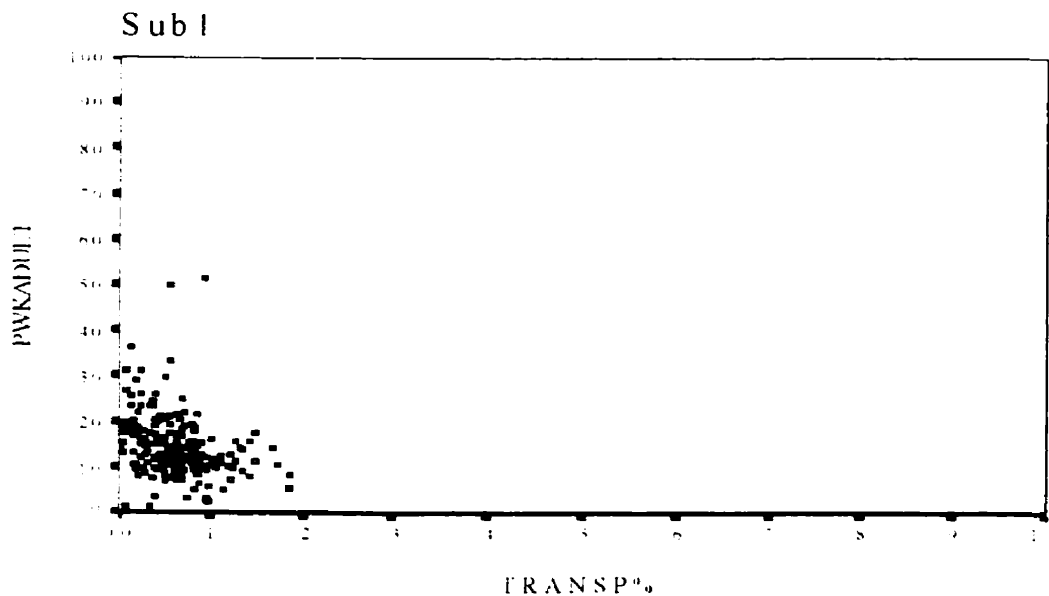
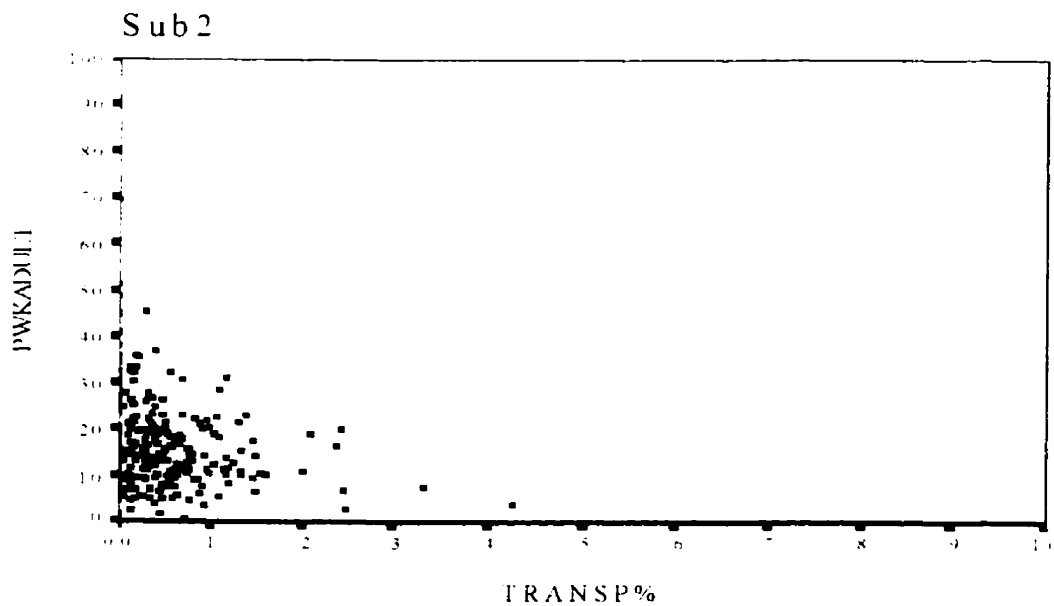


Figure 34 Produce Work VKT per Adult versus Percentage of Produced 24-Hour Trips made by Transit (Transit use) in Suburban area 2



	Metro	Hamilton	Suburban area 1	Suburban area 2
Pwkadult	-.270**	-.370**	-.276**	-.189**
Awk/employee	-.289**	-.256**	-.079	-.045
Pnwkadult	.064	.334**	-.005	-.147**
Anwk/adult	.090	.311**	-.054	-.172**

4.4 Controlling for Some of the Explanatory Variables

As mentioned earlier in this chapter, analyses were performed to test the relationship between density, degree of sprawl, accessibility to employment, level of self containment and travel demand in the GTA. Separate correlation analyses were conducted between travel demand and spatial structure measures that correspond to each of these hypotheses.

However, evidence exists of correlation between some of the explanatory spatial structure characteristics as shown in the following table. Therefore, strong conclusions could not be drawn from these previous analyses. Rather, the purpose of this analysis was to get an indication of the power of each explanatory variable to explain variation in travel demand in case of ignoring the influence of other variables.

Based on our understanding to the fact of spatial correlation, and auto correlation between the explanatory variables, it was decided to conduct several attempts to maintain control on some of the possible influential variables. Then a comparison would be made between the early results of testing the hypothesis, controlling only for the geographical locations, and the new results obtained under the control of location and other explanatory variables.

Following is a discussion of an example of correlation between population density and some of the explanatory variables as shown in the table:

	Metro	Hamilton	Suburban 1	Suburban 2
Population density	1.00	1.00	1.00	1.00
Employment density	.009	.018	.142**	.304**
Distance to Metro CBD	-.426**	-.238**	-.278**	-.098
Distance to Hamilton CBD	NA	-.469**	-.008	NA
Dist. to nearest employment node	-.261**	-.469**	-.391**	-.343**
Jobs within 5 km / adult	-.244**	-.128	-.270**	-.168**

** Correlation is significant at the 0.01 level

Population density was not correlated with employment density in cities. however. it was positively and significantly correlated at the 5% level in the suburbs. Meanwhile, there was correlation between population density and accessibility to employment concentration nodes for the four locations. The further the distance to these nodes the less population density was observed which indicates that people prefer to locate close to place of work or employment activities locate close to concentrations of people.

In addition, there was a significant negative correlation, at all locations except Hamilton, between population density and opportunities of work within 5 km buffer per adult. This shows that the greater the population density in a zone, the less accessible to employment opportunities within 5 km from the centroid of this zone, which indicates the extent of segregation between residential and employment locations in the GTA. Also, population density was negatively correlated with degree of sprawl in all locations and significant at the 5% level except in suburban area 2.

4.4.1 Controlling for Population Density

Since it was found that population density was an influential issue in determining travel demand in the GTA (section 4.3.1.2.1), the following analysis was performed on a selection of zones with population density greater than 5000 person/square km. in Metro and Hamilton-Wentworth, as one control on population density.

Twenty four percent of the Metro zones had high population density as described in the table below. Most of these zones were clustered around the Metro Toronto CBD, however, there was still quite a number of them at the periphery of the Metro boundary as shown in Map 1, Chapter 3

The ratio of jobs to labor (self containment measure) for these zones, varied from 6 to 660 with a mean of 126. There was also considerable variation in car ownership level in these zones: on average 28% of the households had no vehicles, and 23% of the households had 2 or more vehicles.

The produced work and non-work VKT per adult residing in these zones was relatively short compared to other locations in Metro with a mean of 5.5 km. However, the attracted VKT per employee working in these zones was longer than the produced, but still relatively short compared to other locations in Metro.

	N	Minimum	Maximum	Mean	Std. Deviation
POPDENS	151	5016.830	39061.92	8592.60	4106.53
EMPDENS	151	146.74	91717.62	5470.82	11981.4
JOBUFLAB	151	6.562	663.305	126.220	122.809
DISTCBD	151	346.14	20855.78	7334.72	4896.34
EMPLEVEL	151	.4318	.8272	.587792	6.5E-02
HHL0VEH	151	.005	.727	.28788	.12988
HHL2plusVEH	151	.000	.581	.23066	.10950
PWKADULT	151	.101	12.032	5.58182	1.94680
AWKEMPXH	151	.737	132.729	13.7783	12.33742
PNwkadult	151	.823	46.782	5.19365	5.62724
AtNwkadult	151	.946	52.951	5.32115	5.73857
Valid N (listwise)	151				

For Hamilton-Wentworth region, 18% percent of the zones had population density greater than 5000 person/square km as described in the following table.

	N	Minimum	Maximum	Mean	Std. Deviation
POPDENS	23	5045.561	12742.09	7578.32	2283.52
EMPDENS	23	189.43	11049.59	2329.02	2396.18
JOBUFLAB	23	14.447	145.140	69.5812	34.47559
DistHamilemp	23	815.66	9315.59	3277.94	2378.73
EMPLEVEL	23	.3240	.6556	.479896	8.2E-02
HHL0VEH	23	.055	.650	.23883	.12906
HHL2plusVEH	23	.066	.452	.24841	.10361
PWKADULT	23	1.797	15.894	5.58459	2.97478
AWKEMPXH	23	1.637	15.655	7.19760	3.27292
PNwkadult	23	2.253	13.348	5.11894	2.20995
AtNwkadult	23	3.158	10.740	5.44053	1.95884
Valid N (listwise)	23				

Again, most of these zones were clustered around the Hamilton CBD and several zones at the east end of Hamilton close to the industrial area, as shown in Map 1, Chapter 3. The ratio of jobs to labor (self containment measure) varied from 15 to 145 with a mean of 70. The three major employment locations in the region was at the CBD, the east end of Hamilton where the industrial area is located and at the west end where McMaster University is located as shown in Map 3, Chapter 3.

The vehicular travel demand in these zones was relatively short compared to other locations in the GTA, the produced work and non-work VKT per adult residing in these zones had means of 6 and 7 km, respectively.

Similar to Metro Toronto, there was a variation in car ownership level in the zones of high population density in Hamilton, with a mean of 23% of the households having no vehicles, while 25% of the households had 2 or more vehicles.

Similar analyses to the ones performed earlier to test several urban form hypothesis, were repeated to investigate similarities and differences in results when analyses were run for a specific data set controlling for population density with values greater than 5000 person per square km.

4.4.1.1 Testing the Relationship between Degree of Sprawl and Travel Demand

First, correlation analysis was done to test the relationship between degree of sprawl and travel demand in the selected zones. There were some differences in the obtained results here than the ones in section 4.3.2.2. However, the results were consistent for Metro where degree of sprawl significantly explained variation in the vehicular demand for all type of trips. That was not the case for Hamilton, where correlation between travel demand and degree of sprawl was negative, but not significant at the 5% level. The Hamilton results may suggest that zones with high population densities were well served by transit, and therefore had negative correlation with the vehicular demand.

Distance from the CBD

	Metro	Hamilton
Pwkadult	.722**	-.045
Awk/employee	.461**	-.148
Pnwkadult	-.209*	-.263
Anwk/adult	-.199*	-.343

4.4.1.2 Testing the Relationship between Accessibility to Employment and Travel Demand

Similar analysis were repeated for testing the relationship between accessibility to employment and travel demand in the selected zones. Again, the power of accessibility to employment nodes to explain variation in travel demand, differed for the studied zones than the previous general case explained in section 4.3.3.1. For instance, in Metro, the studied measure explained more variation in produced work VKT per adult from the high population density zones than the case for all zones. However, in Hamilton, it explained less variation than before except for attracted non-work trips and the sign of correlation was different, suggesting that trends were different for high densities than for low.

	Metro	Hamilton
Pwkadult	.359**	-.045
Awk/employee	.113	-.148
Pnwkadult	NA	NA
Anwk/adult	-.207	-.343

4.4.2 Controlling for Degree of Sprawl

For the sake of the current analysis, suburban areas is defined as all zones in the GTA excluding Metro (zone 1 to 460) and Hamilton-Wentworth (zone 1601 to 1673). In the current discussion, suburban areas were sliced in three ranges based on distance from the CBD as follows:

1. Suburban area A: Distance to the CBD (zone 408) from 16 Km to 40 Km.
2. Suburban area B: Distance to the CBD (zone 408) from 40 to 65 Km
3. Suburban area C: Distance to the CBD (zone 408) from 65 to 90 Km

Analyses were conducted for suburban area "A "and "C "to investigate the relationship between some of the explanatory spatial variables and travel demand under the condition of controlling for degree of sprawl. Then a comparison is made between the previously obtained results of testing the hypothesis controlling only for the geographical locations and the new results under the control of degree of sprawl.

Almost one third of the zones in the GTA were located at a distance of 16 to 40 km from the Toronto CBD (suburban area A) as shown in the table below.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
POPDENS	431	.000	10912.30	1049.28	1591.513
EMPDENS	431	.00	14844.54	503.553	1171.855
JOBFLAB	323	.08	3317.89	210.585	455.1046
EMPLEVEL	330	.0000	1.0000	.551489	.159225
HHL0VEH	330	.000	1.000	4.1E-02	9.77E-02
HHL2plusVEH	330	.000	1.000	.65667	.24553
PWKADULT	330	.000	83.113	14.6750	9.27836
AWKEMPH	395	.000	1623.417	52.1329	118.0144
PNwkadult	330	.000	196.299	22.3321	33.46848
AtNwkadult	330	.000	181.515	21.6479	29.59808
Valid N (listwise)	305				

At these zones, the ratio of jobs to labor (self containment measure) varied from 0 to 3318 with a mean of 210, which indicates that it included many high employment concentration zones. There was considerable variation in the car ownership level in these zones: some zones included all households with no vehicle, and others included all households with 2 or more vehicles. However, the mean percentage of households with no vehicle was zero, and 66% for households had 2 or more vehicles, which reflects the high car ownership level in suburban areas.

The produced work and non-work VKT per adult residing in these zones was relatively higher than the case in Metro and Hamilton. The attracted VKT per employee working in these zones was longer than the produced, and still relatively higher than other locations in Metro and Hamilton.

Meanwhile, the outer range of the suburban area "C" that was located at a distance more than 65 km from the CBD of Toronto included 3% of all zones in the GTA. These zones had population and employment densities much lesser mean than the previous range of suburban area A. The ratio of jobs to labor (self containment measure) varied from 0 to 34.8 with a mean of 5.5, which is much smaller than the value for suburban area A, indicating the spread and dispersion in residential location in the GTA with much less employment opportunities in the outer suburban areas.

There was significant variation in the car ownership level in these zones: however, again the mean percentage of households with no vehicle is zero and 67% on average was the households that had 2 or more vehicles, which again reflect the high car ownership in the suburban areas.

The produced work and non-work VKT per adult residing in these zones was relatively higher than in Metro and Hamilton. However, the produced trips were longer than the case in suburban area A, but the attracted was much shorter, reflecting less attraction of employment at these zones. The non-work VKT per adult residing in these zones was

shorter comparing to the inner suburbs A, however, much longer than in Metro and Hamilton.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
POPDENS	40	1.203	551.911	60.8471	110.4692
EMPDENS	40	.00	220.48	15.4695	42.3089
JOBUFLAB	38	.00	34.84	5.5670	8.5393
EMPLEVEL	40	.0000	.7146	.469277	.154593
HHLOVEH	40	.000	1.000	5.0E-02	.16780
HHL2plusVEH	40	.000	1.000	.67571	.22908
PWKADULT	40	.000	48.800	22.7533	11.49194
AWKEMPXH	31	.000	303.083	49.0032	70.14532
PNwkadult	40	.264	72.607	13.7647	11.85475
AtNwkadult	40	2.716	64.750	14.8602	10.81219
Valid N (listwise)	29				

4.4.2.1 Testing the Relationship between Population and Employment Density and Travel Demand

Correlation analysis was done to test the relationship between both population and employment density and travel demand under the condition of controlling for degree of sprawl.

For the inner suburban area "A", results were consistent with those obtained earlier under the condition of no control. Population density was significant in explaining variation in travel demand with more explanatory power for non-work trips than before.

However, for the outer suburban area "C", results were different in terms of being not significant at the 5% level, and the explanatory power for variation in travel demand was much less than before.

Population Density

	Suburban "A"	Suburban "C"
Pwkadult	-.133*	-.006
Awk/employee	NA	NA
Pnwkadult	-.330**	-.169
Anwk/adult	-.349**	-.192

Employment Density

	Suburban "A"	Suburban "C"
Pwkadult	-.195**	-.051
Awk/employee	-.126*	-.195
Pnwkadult	.214**	.172
Anwk/adult	.191**	.058

4.4.2.2 Testing the Relationship between Accessibility to Employment and Travel Demand

Correlation analysis was done to test the relationship between accessibility to employment, measured by distance to the nearest employment node, and travel demand under the condition of controlling for degree of sprawl.

For the inner suburban area "A", results were consistent with those obtained earlier under the condition of no control. Accessibility to employment was significant in explaining variation in produced work VKT per adult, but not significant at the 5% level for the other trips.

However, for the outer suburban area "C", results were different in terms of being not significant at the 5% level; however, the explanatory power for variation in travel demand was higher than the case for suburban area A.

	Suburban "A"	Suburban "C"
Pwkadult	.177**	.290
Awk/employee	.010	-.083
Pnwkadult	NA	NA
Anwk/adult	-.030	-.061

4.5 General Discussion and Conclusion

Although there were differences in the results between the two scenarios of controlling and not controlling some of the explanatory variables, it would be extremely difficult to slice the data in the numerous ways that would be required to control all the possible influential variables, other than the one tested at a given time. Such a process would be very complicated since there are many variables involved in the analysis and the final data base would have become very small by the time the control was forced for a number of variables.

Since there is evidence that some of the explanatory variables were related, multicollinearity is said to exist. When multicollinearity exists, values of the least squares point estimates of the parameters, depend on the particular independent variables that were included in the regression analysis. When an independent variable is added to the group that is related to the other included explanatory variables in the run, the least squares point estimates of the regression parameters will change.

Hence, the least squares point estimates are conditional, and they depend upon the correlated explanatory variables included in the regression run. So the parameters do not

really measure the influence of the explanatory variable upon the mean value of the dependent variable. Rather, the parameter measures a partial influence of the explanatory variable upon the mean value of the dependent variable, and the estimated value of the parameter depends on which of the correlated explanatory variables were included in the regression, however, in case of correlation it is hard to separate the contribution of each explanatory variable.

The focus in the current study was not to build an urban form model to explain variation in travel demand, but rather to test the ranking of the possible influential spatial variables, that can explain variation in travel demand. Therefore, stepwise regression techniques were used for this task since the number of the potential explanatory variables was large.

The stepwise regression analyses were performed to test the explanatory power of combination of spatial structure variables to explain variation in travel demand in the GTA, details of these analyses will be discussed in the next chapter. Before performing the regression analysis, the potential explanatory variables were defined on the basis of results obtained in testing the hypothesis and the expectations of the researcher. The screening procedure of the stepwise regression was then used to identify one set of the most influential variables from the set defined previously as potential explanatory variables.

The SPSS package was used in the current study, where the stepwise regression uses the "t" statistics and related probability values to determine the importance or significance of the explanatory variables. It sets up the Probability-of-F-to-enter ≤ 0.05 , and Probability-of-F-to-remove ≥ 0.100 . The stepwise procedures continue by adding explanatory variables one at a time. At each step when a new variable enters the regression, stepwise regression checks the value of "t" statistics of the variables already entered in the model from the previous steps. This check should be made because multicollinearity will probably cause the "t" statistics, related to the importance of the previously entered variables, to change when a new variable is added to the run. If the independent variable has "t" statistics significant at the 5% level, this variable remains, and if not it is dropped and the procedure

continues. The stepwise procedure terminates when all the explanatory variables not in the group are insignificant at the 5% level.

Though the results obtained from the stepwise procedure may be reasonable, it should not be necessarily regarded as the best final functional form for the relationship between travel demand and spatial structure characteristics. However, stepwise regression should be regarded as a screening technique that can be used to determine at least some of the most influential explanatory variables.

Chapter Five

MULTIVARIATE ANALYSIS OF THE RELATIONSHIP BETWEEN TRAVEL DEMAND AND SPATIAL STRUCTURE IN THE GTA

5.1 Introduction

This chapter presents the multivariate statistical analysis performed to investigate the relationship between spatial structure characteristics and associated travel demand. The first section in this chapter deals with attempts to select a proper form presenting the relationship between travel demand and the spatial structure explanatory variables. The second section includes the stepwise regression analysis conducted to test the explanatory power of a combination of the spatial structure variables to explain variation in the travel demand in the GTA.

5.2 The Form of the Relationship between the VKT and Explanatory Variables

The purpose of the analyses performed in this section was to choose a proper functional form to present the relationship between travel demand and spatial structure explanatory variables in the GTA. Early runs were performed using the entire GTA data set (1366 observations) to select a functional form that fit the data the most with high values of R-square and significant coefficients at the 5% level. Then similar runs were conducted for comparison and confirmation using the subset data for Metropolitan Toronto (460 observations).

Generally, two functional forms for the studied relationship were tried. The first was the additive linear form as follows:

Form 1 :

The produced work VKT per adult as a function of population density:

$$\text{Produced VKT/adult} = \text{const.} + b * \text{population density}$$

Form 2 :

The second form was a multiplicative form:

$$\text{Produced VKT/ adult} = \text{const.} * (\text{population density})^b$$

by taking the natural logarithm for both sides, this function was transferred to the linear form as follows:

$$\text{Ln Produced VKT/adult} = \text{const} + b * \text{Ln population density}$$

For the sake of the current discussion, some results were summarized in the following tables showing the two attempts for selecting either form 1 or 2 for the underlying relationship at the four locations.

5.2.1 The Relationship between Produced VKT/Adult and Population Density

Form 2 had higher value of fit (R-square) with higher significance level for the coefficient of the explanatory variable in all locations except in Metro where form 1 performed better.

	Metro	Hamilton	Suburban 1	Suburban 2
Form 1 R-square	.060	.146	.044	.050
t-statistic	-5.175*	-4.64*	-3.668*	-4.131*
Form 2 R-square	.020	.191	.057	.056
t-statistic	-2.914*	-5.345*	-4.111*	-4.308*

* significant at the 5% level

5.2.2 The Relationship between Attracted VKT/ Employee and Employment Density

Form 2 fitted the data more (higher R-square) with higher significance for the coefficient of the explanatory variable consistently in all locations.

	Metro	Hamilton	Suburban 1	Suburban 2
Form 1 R-square	.016	.007	.016	.016
t-statistic	-2.714*	-.940	-2.305*	-2.321*
Form 2 R-square	.132	.312	.276	.253
t-statistic	-8.306*	-7.558*	-11.012*	-10.422*

* significant at the 5% level

5.2.3 The Relationship between the Produced VKT/Adult and Degree of Sprawl

Another test involved the relationship between produced VKT/adult and degree of sprawl represented by the distance to the nearest employment node. Again, form 2 performed better in Metro and suburban area 1 with higher values of fit (R-square) and higher significance for the coefficient of the explanatory variable. However, for Hamilton where distance is estimated to the Hamilton weighted employment centroid and suburban area 2 with distance to Metro CBD, form 1 performed better than form 2 as shown in the following table.

	Metro	Hamilton	Suburban 1	Suburban 2
Form 1: R ²	.143	.295	.066	.066
t-statistic	8.382*	7.26*	4.574*	4.818*
Form 2: R ²	.257	.174	.082	.035
t-statistic	11.883*	5.128*	4.984	3.345*

5.2.4 The Relationship between Produced VKT/Adult and Accessibility to Employment

Accessibility to employment was estimated as the distance to the nearest employment node. form 2 performed better only in case of Metro. For the other locations, form 1 had higher values of R-square indicating a better fit and higher t-statistics for the coefficient of the parameter of the explanatory variable.

	Metro	Hamilton	Suburban 1	Suburban 2
Form 1 R ²	.049	.295	.102	.235
t-statistic	4.65*	7.26*	5.763*	9.998*
Form 2 R ²	.121	.174	.094	.209
t-statistic	7.49*	5.128*	5.366*	9.046*

5.2.5 The Relationship between the Produced VKT/Adult and Ratio of Self Containment

Self containment was estimated by the ratio between the employment opportunities within 5 km buffer to the labour force residing in the centre zone. form 2 performed consistently much better than form 1 for the four locations. Form 2 had higher values of R-square and higher significance values of the parameters of the explanatory variable.

	Metro	Hamilton	Suburban 1	Suburban 2
Form 1 R ²	0.00	0.002	.013	.022
t-statistic	-.276	.534	-1.926	-2.688*
Form 2 R ²	.131	.220	.126	.136
t-statistic	-7.845*	-5.941*	-6.329*	-6.980*

In addition to the above discussed explanatory variables, other demographic variables, car ownership and Transit use were considered to explain variation in the travel demand.

5.2.6 Demographic Characteristics

The following variables were chosen as measures of the people characteristics that were expected to explain the variation in the travel demand:

5.2.6.1 Percentage of Children

The correlation between the travel demand and the percentage of children was found to be significant for most of the trip types and locations (chapter 4, section 4.3.5.6). This explanatory variable will be considered as an additive term to form 2.

5.2.6.2 Percentage of Adults with Driving License

The correlation between the travel demand and the percentage of adults with driving license in each zone was significant at the 5% level at both locations of Metro and Hamilton but not for the suburban areas. However, the power of this variable to explain variation in the travel demand will be tested later in combination with other variables. Therefore, it will be added to form 2.

5.2.6.3 Percentage of Full Time Workers and Part Time Workers

It was found out earlier in Chapter 4 (Section 4.3.5.3 and 4.3.5.4) that the percentage of people who had a full time job was significant in explaining the variation of both produced and attracted non-work trips but not for the work trips. Based on this finding, this percentage will be considered and tested for the non-work trips in combination with the other explanatory variables. Similarly for the percentage of people who had part time jobs, the results showed that it was negatively correlated with both produced and attracted non-work VKT per adult. However, for the produced work trips, the results differed from location to another. Again, this percentage will be tested in combination with the other explanatory variables and thus added to form 2.

5.2.6.4 Employment Participation Rate

Since that the correlation between the produced work VKT per adult and the employment participation rate was found to be significant at the 5 % level for all the scenarios except in Metro (Chapter 4 Section 4.3.5.2), it was decided that this ratio would be added to form 2 to be tested in combination with the other explanatory variables.

5.2.6.5 Car Ownership

As mentioned earlier in Chapter 4, two measures were selected to represent the low and high level of car ownership:

% household with no vehicles (hhl0veh)

%more than two vehicle were extracted (hhl2plusveh)

Since that there were correlation between both measures and travel demand at almost all locations for most of the trip types, it was decided to consider them both in the regression runs in combination with all the other significant explanatory variables. The two variables entered as percentages added to form 2.

5.2.6.6 Transit Use

There was a negative correlation between both produced and attracted work trips and Transit use as was shown earlier in Chapter 4. The percentage of the produced and attracted trips made by transit in the 24 hours (Transp%) will be added to form 2 to be tested in combination with all the other significant explanatory variables.

5.3 Conclusions

Since form 2 generally performed better than form 1 in most of the discussed cases, it was decided to use it in the stepwise regression analysis. However, the demographic characteristics, car ownership and Transit use were added to form 2. Based on the correlation analyses developed earlier in Chapter 4, these explanatory variables will be included as ratios or percentages in an additive form. Thus, for example the final functional form for the produced work trips will be as follows. Note that only few explanatory variables are included in this form to illustrate the functional form. However, all the explanatory variables are included in the multivariate analysis.

$$\text{Ln Pwk VKT / adult} = \text{Const.} + \text{Ln population density} + \text{Ln employment density} + \text{Ln distance from the CBD} + \% \text{ adult with driving license} + \% \text{ children} + \% \text{ households with 2 or more vehicles} + \% \text{ Transit use, etc.}$$

This function is a transferred from the original form of :

$$\text{Produced VKT/ adult} = \text{Const.} * (\text{population density})^b * (\text{employment density})^c * (\text{distance from the CBD})^d * e^{(\% \text{ adult with driving license})} * e^{(\% \text{ children})} * e^{(\% \text{ households with 2 or more vehicles})} * e^{(\% \text{ Transit use})}, \text{ etc.}$$

5.4 Stepwise Regression Analysis

The stepwise regression technique was used to test the explanatory power of combination of the spatial structure variables for the variation in travel demand. A number of potential explanatory variables was defined for each type of trip based on the obtained results from the hypothesis testing and logical expectations. Then a screening procedure of the stepwise regression was used to identify one set of the most influential variables to the variation in travel demand as discussed earlier in Chapter 4 (Section 4.5).

5.4.1 Produced Work VKT per Adult

The explanatory variables for produced work VKT per adult were selected based on the correlation analyses performed previously in Chapter 4. Only variables that were significantly correlated at the 5% level with travel demand were considered in the stepwise regression runs as follows:

- Density: population and employment density
- Sprawl: distance to Toronto CBD, distance to Hamilton CBD
- Accessibility: distance to the nearest employment nodes
- Self containment: jobs within 5 km buffer / labor force
- Demographic variables: % children, % full time workers, % part time workers, % work at home, % adult with driving license, employment participation rate
- Car ownership: % households with no vehicles, % households with 2 or more vehicles
- Transit use: % of trips made by transit

5.4.1.1 Technique of Entering the Explanatory Variables

Two attempts were made to investigate whether to include all the explanatory variables in one stepwise regression run using this procedure to screen the selected potential variables and identify one set of the most influential variables, or to start with some of the explanatory variables which were related to the urban form of the city and then add the rest of the explanatory variables one at a time.

Since it is believed that the final results of the two procedures would be the same, the basic question was "Would the second procedure of running the analysis in steps add a new vision of understanding of the studied issue? In order to investigate that, the two procedures were applied to Metro Toronto data base.

The first trial was conducted in the following steps. The first run included three basic urban form variables representing density and sprawl: population density, employment density and distance to the CBD. The results showed that distance to the CBD entered first explaining 25.7% of the variation in produced work VKT per adult, and then employment density came next while population density dropped from the significant list. Both variables of employment density and distance from the CBD explained 26.6% of the variation in travel demand in Metro.

Then, a measure of accessibility to the nearest employment node and self containment ratio were added to the previous combination of explanatory variables. The results did not change where only distance to the CBD and employment density were significant at 5% level while all the other variables dropped from the final significant set.

Then, a measure of car ownership (% households with 2 or more vehicles) was added to the previous group of explanatory variables. Some changes occurred, however, still distance to the CBD entered first, then car ownership entered second where both variables explained 30.4% of the variation in travel demand. The rest of the variables dropped from the stepwise regression where they were not significant at the 5% level.

When Transit use percentage was added to the previous group of explanatory variables, no changes in the final result occurred since this variable was not significant at the 5% level.

Then some of the demographic explanatory variables such as percentage of children and workers who work at home were added to the previous group of variables. The results showed that four significant variables entered in the following order: degree of sprawl, car ownership, percentage of children and workers who work at home. These four variables explained 33.1% of the variation in travel demand in Metro.

The second trial of stepwise regression was conducted by entering all the potential explanatory variables in the same run. The result is summarized in the following table showing the order by which the significant explanatory variables entered the stepwise regression and the magnitude of the explanatory power is shown by the R-square value after each entry.

Entered Variable	R²
Ln distCBD	.257
HHL2+veh	.304
Emp. Partic	.326
% children	.358
%Wk at home	.365
Ln dist nearest node	.372

Thus, it was found out that both procedures would lead to the same result of getting the most influential set of the explanatory variables. In the first procedure, the order of entering the explanatory variable in each step would not affect the final result of getting the most influential variables. However, each step would show the significance of the entered

variables, and the explanatory power of the combination of the entered explanatory variables to variation in travel demand.

Meanwhile, in the second procedure, where all the explanatory variables are included in the same run, the stepwise technique continues by adding explanatory variables one at a time. In each step when a new variable enters the regression, stepwise regression checks the value of "t" statistics of the variables already entered in the model from the previous steps. If the independent variable has "t" statistics significant at the 5% level, this variable remains and if not it is dropped and the procedure continues. The stepwise terminates when all the explanatory variables not in the group are insignificant at the 5% level.

Therefore, for the simplicity and consistency of the following analyses at each location, it was decided to define first the potential explanatory variables for each type of trip, and include all of them in the same stepwise regression run. Then the screening procedure of this technique would identify one set of the most influential variables to the variation in travel demand.

5.4.1.2 Multivariate Analysis of Produced Work VKT per Adult

Similar stepwise regression analyses were conducted at the other three locations, and the obtained results are summarized in the following table. The order by which the explanatory variables entered the regression run is shown in the table with the magnitude of the explanatory power shown by the R-square value after each entry.

Metro		Hamilton		Suburban 1		Suburban2	
Variable	R ²	Variable	R ²	Variable	R ²	Variable	R ²
Ln distCBD	.257	HHL2+veh	.355	Ln emp density	.145	Ln dist nearest	.242
HHL2+veh	.304	Emp. Partic	.471	Ln job/labor	.211	Emp. Partic	.343
Emp. Partic	.326	Ln emp	.517	HHL2+veh	.256	% Transit use	.367
% children	.358	% part time	.547	Emp. Partic	.295	Ln job/labor	.389
%Wk at home	.365	% children	.563	% children	.369	% part time	.407
Ln dist nearest	.372	% adult	.587	Ln dist nearest	.380		

This investigation shows that for each location, variation in produced work VKT/adult was explained by a different combination of explanatory variables. Also, the explanatory power for each one of the significant variables differed from location to another.

For instance, the degree of sprawl in Metro presented by the distance from the CBD was the most powerful explanatory variable to explain 25.7% of variation in the produced VKT. Meanwhile, car ownership was the most powerful explanatory variable in Hamilton, and employment density for Suburban area 1 and accessibility to employment for suburban area 2.

The measure of high car ownership explained variation in travel demand at all locations except in suburban area 2 where Transit use came to be significant at the 5% level. The same results were observed for percentage of children. Meanwhile employment participation rate was significant at all four locations in explaining variation in travel demand.

The summary of the “t” statistic and the coefficient of the combination of explanatory variables that remain in the final run are included in the table shown below. The term “NO” means that this variable was not significant at the 5% level.

For Metro Toronto, 37.2% of the variation in the produced work VKT per adult was explained by the explanatory variables entered in the order of: distance from the CBD, the car ownership, employment participation rate, % of children, % of work at home and accessibility to the nearest employment node.

For Hamilton, car ownership was the most influential variable for explaining variation in the work production, then entered employment participation rate followed by employment density and percentage of part time people with negative effects on work production. Percentage of children and adults with driving license entered at the end with a positive effect on work production.

For suburban area 1, employment density was the most important variable to explain variation in work production, then entered the ratio of self containment (jobs per labor) which had a negative effect on work production, as did employment density. Then entered all the following variables with positive effect on work production: car ownership followed by employment participation rate, percentage of children and distance to the nearest employment node.

For suburban area 2, the order of the explanatory variables was different than the other locations. Accessibility to the nearest employment node was the first entered variable which explained 24.2% of the variation in work production, then entered employment participation rate followed by Transit use percentage which had a negative effect on

vehicular work production. Then followed the ratio of self containment (jobs per labor) which had also a negative effect on work production. Then entered the percentage of part time worker which had a negative effect on work production as well.

	Metro		Hamilton		Suburban 1		Suburban 2	
R ²	.372		.587		.380		.407	
	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff
constant	-5.014	-2.442	.434	.203	2.345	1.026	-.392	-.15
Ln distCBD	6.395	.258	NO	NO	NO	NO	NO	NO
Ln employment density	NO	NO	-2.674	-.071	-3.305	-.051	NO	NO
Ln dist nearest emp node	2.123	.086	NO	No	2.075	.075	6.616	.228
Ln job5kmbuffer/labor	NO	NO	NO	NO	-4.118	-.067	-3.432	-.055
HHL2+veh	4.820	.629	1.878	.490	2.903	.429	NO	NO
Emp. Participation	4.866	1.497	4.036	1.858	6.188	1.45	7.261	1.506
% Children	4.469	1.995	3.218	2.242	5.789	1.946	NO	NO
% work at home	-2.124	-1.896	NO	NO	NO	NO	NO	NO
% part time employee	NO	NO	-1.867	-1.027	NO	NO	-2.906	-.749
% adult with driving	NO	NO	2.662	1.445	NO	NO	NO	NO
% Transit use	NO	NO	NO	NO	NO	NO	-2.861	-

5.4.2 Attracted Work VKT/ Employee

For the attracted work VKT per employee, the following explanatory variables were chosen based on the correlation analyses performed in chapter 4. Only the following variables that were significantly correlated at the 5% level with travel demand were included in the stepwise regression runs:

- Density: employment density
- Sprawl: distance to Toronto CBD, distance to Hamilton CBD
- Accessibility or attractiveness of the site: distance to the nearest employment nodes
- Self containment: jobs within 5 km buffer / labor force
- Transit use: % of trips made by transit

The obtained results are summarized in the following table in the order in which they entered the regression run and the magnitude of the explanatory power is shown by the R-square value after each entry.

Metro		Hamilton		Suburban 1		Suburban 2	
Variables	R ²	Variables	R ²	Variables	R ²	Variables	R ²
% Transit use	.165	Ln emp density	.286	Ln emp density	.275	Ln emp density	.271
Ln emp density	.187			Ln job/labor	.330	Ln distCBD	.338
				Ln DistHamilton	.358	Ln job/labor	.348

A summary of the “t” statistic and the coefficient of the combination of explanatory variables that remain in the final run are included in the next table. The term “NO” means that this variable was not significant at the 5% level.

	Metro		Hamilton		Suburban 1		Suburban 2	
R ²	.187		.286		.358		.348	
	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff
constant	25.287	3.552	20.76	3.443	.642	.644	6.654	10.39
Ln distCBD	NO	NO	NO	NO	NO	NO	-4.131	-.59
Ln dist HamiltonCBD	NA	NA	NO	NO	3.351	.316	NA	NA
Ln employ density	-3.317	-.077	-6.996	-.184	-11.038	-.274	-11.752	-.262
Ln job5kmbuffer/labor	NO	NO	NO	NO	5.038	.146	2.054	.057
% Transit use	-5.513	-	NO	NO	NO	NO	NO	NO

Employment density was a key variable that entered first in the regression analysis at all locations except Metro. This variable explained around 28% of the variation in the attracted work trips at the three locations other than Metro. However, for the four location consistently it had a negative effect on work trip attraction demand which supported the view that locations of high employment concentration were served better by transit which in return reduce the vehicular attraction demand to those locations.

In Metro, the use of transit system was the most important variable to explain work trip attraction, followed by employment density where both variables explained 18.7% of the attracted VKT per employee.

Both variables of degree of sprawl and self containment ratio (job/labor) entered the regression runs following the employment density for both suburban area 1 and 2. However, self containment ratio was more important in suburban area 1 than in area 2.

Meanwhile for suburban area 1, the distance to Hamilton CBD was significant to explain variation in the attracted work demand, however, the distance to Toronto CBD was not significant at 5% level. The further the distance from Hamilton CBD, the higher the expected attracted work VKT per employee where employment locations were not served by transit as was the case for locations closer to Hamilton CBD.

For suburban area 2, the degree of sprawl had a negative effect on the attracted VKT per employee. The further the distance from Toronto CBD, the less attracted vehicular demand since that the employment locations in the suburbs would be expected to attract employees who live close to these locations.

5.4.3 Produced Non-Work VKT/ Adult

The following explanatory variables were chosen to explain variation in the produced non-work trips. That was based on the performed correlation analyses in Chapter 4 and the understanding of the nature of the non-work trips. Only the tested variables that were significantly correlated at the 5% level with travel demand were included in the stepwise regression runs:

- Density: population and employment density
- Sprawl: distance to Toronto CBD, distance to Hamilton CBD
- Accessibility: distance to the nearest employment nodes
- Self containment: jobs within 5 km buffer / labor force
- Demographic variables: % children, % full time workers, % part time workers, % work at home, % adult with driving license, employment participation rate
- Car ownership: % house holds with no vehicles, % house holds with 2 or more vehicles

- Transit use: % of trips made by transit

The stepwise regression analyses were conducted for the produced non-work VKT and all the explanatory variables in one run. The obtained results are summarized in the following tables.

Metro		Hamilton		Suburban 1		Suburban 2	
Variable	R ²	Variable	R ²	Variable	R ²	Variable	R ²
Ln pop	.567	Ln pop	.245	Ln pop	.279	Ln pop	.178
Ln emp. density	.847	Ln emp. density	.757	Ln emp. density	.663	Ln emp. density	.573
HHL0veh	.856	% adult with license	.781	HHL0veh	.674	% Children	.591
% adult with license	.859	%Wk at home	.793	HHL2+veh	.686	% Transit use	.604
% Children	.862	Emp. Partic	.802			Ln distCBD	.612
		HHL2+veh	.810			HHL0veh	.618
						Emp. Partic	.626

“NO” means that this variable was not significant at the 5% level.

	Metro		Hamilton		Suburban 1		Suburban 2	
R ²	.862		.810		.686		.626	
	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff
constant	15.561	4.178	4.661	2.225	16.290	3.229	5.655	5.627
Ln distCBD	NO	NO	NO	NO	NO	NO	-2.441	-.219
Ln population density	-38.812	-.790	-17.314	-.643	-21.679	-.478	-17.787	-.452
Ln employment density	27.786	.504	15.171	.513	16.335	.360	14.194	.304
HHL0veh	-2.787	-.531	NO	NO	4.140	1.583	2.745	.973
HHL2+veh	NO	NO	2.336	.723	3.181	.597	NO	NO
Emp. Participation	NO	NO	2.373	1.381	NO	NO	2.436	.591
% Children	3.102	1.634	NO	NO	NO	NO	3.292	1.072
% work at home	NO	NO	3.549	3.042	NO	NO	NO	NO
% adult with driving license	3.838	.904	1.523	.829	NO	NO	NO	NO
% Transit use	NO	NO	NO	NO	NO	NO	-3.877	-2.632

It was generally observed that the produced non-work VKT per adult was longer than the produced work VKT per adult, as shown in Chapter 3. For instance in Metro, the mean of produced non-work trips was 50 km per adult compared to 6.8 km produced work VKT per adult. That may be caused by the observations with more than 200 VKT/adult which were observed at zones with low population and comparatively high employment densities as shown in the discussion in Chapter 3.

However, the explanatory power of the selected spatial structure variables for the variation in produced non-work trips was higher than the case for the produced work trips. For instance in Metro Toronto, the value of fit (R-square) for the produced non-work trips was .862 compared to .372 for the produced work trips.

The investigation for the produced non-work VKT/adult shows similarities in the variables entered to explain travel demand at different locations. For instance, both population density and employment density entered at the beginning of the regression runs at the four locations explaining a great percentage of the variation in the produced non-work demand. The explanatory power of these variables varied from 57.3% in suburban area 2 to 84.7% in Metro.

Population density consistently had a negative relationship with the produced non-work demand at the four locations. Meanwhile, employment density consistently had a positive effect on the produced non-work demand at the four locations, showing the importance of non-home-based trips in this category.

The rest of the explanatory variables entered the regression with a different order at each location. Generally similarities were observed in the type of the significant explanatory variables at the four locations. For instance in Metro, the car ownership, percentage of children and adult with driving license were significant explanatory variables for the non-work trips. While in Hamilton, in addition to all the above mentioned significant variables, there were other variables explaining the variation in travel demand such as percentage of workers who work at home and employment participation rate. Also, for the suburbs, similar explanatory variables were significant except for the degree of sprawl and Transit use that came to be significant and had a negative relationship with the produced non-work trips in suburban area 2.

5.4.4 Attracted Non-Work VKT/ Adult

The following variables were chosen to explain variation in the attracted non-work trips. This was based on the performed correlation analyses in Chapter 4 and the understanding of the nature of non-work travel. Only the tested variables that were significantly correlated at the 5% level with travel demand were included in the stepwise regression runs:

- Density: population and employment density

- Sprawl: distance to Toronto CBD, distance to Hamilton CBD
- Accessibility: distance to the nearest employment nodes
- Self containment: jobs within 5 km buffer / labor force
- Transit use: % of trips made by transit

It was generally observed that the attracted non-work VKT per adult was longer than the attracted work VKT per employee as discussed earlier in Chapter 3. For instance in Metro, the mean of attracted non-work trips was 45.6 km per adult compared to 17 km of attracted work VKT per employee. Again, this may be caused by the observations with more than 200 VKT/adult which were observed at zones with low population and comparatively high employment densities, as shown in the discussion in Chapter 3.

However, the explanatory power of the selected spatial structure variables for the variation in attracted non-work trips was higher than the case for the attracted work trips. For instance in Metro Toronto, the value of fit (R-square) for the attracted non-work trips was .835 compared to .187 for the attracted work trips.

The investigation for the attracted non-work VKT/adult shows similarities in the variables entered to explain travel demand at different locations. For instance, only population density and employment density entered the regression runs at the four locations except at suburban area 2. These two variables explained a great percentage of variation in the attracted non-work demand. Their explanatory power varied from 55.9 % in suburban area 2 to 83.5% in Metro.

Population density consistently had a negative relationship with the attracted non-work trips at the four locations. Meanwhile, employment density consistently had a positive effect on the attracted non-work demand at the four locations, showing the attraction of the employment locations to non-work trips.

In suburban area 2, similar to the produced non-work trips, Transit use and the degree of sprawl were significant at the 5% level in explaining the variation of the attracted non-work trips as well. These two variables had negative relationships with the attracted non-work trips reflecting the lower attractiveness of locations located at further distance from the CBD.

Metro		Hamilton		Suburban 1		Suburban 2	
Variable	R ²	Variable	R ²	Variable	R ²	Variable	R ²
Ln pop	.558	Ln pop	.253	Ln pop	.300	Ln pop	.186
Ln emp. Density	.835	Ln emp. density	.744	Ln emp. density	.658	Ln emp. Density	.534
						% Transit use	.547
						Ln distCBD	.559

“NO” means that this variable was not significant at the 5% level

	Metro		Hamilton		Suburban 1		Suburban 2	
R-square	.835		.744		.658		.559	
	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff	t- stat.	Coeff
constant	26.603	5.089	21.032	4.535	38.6	3.805	6.426	6.485
Ln population density	-39.546	-.773	-18.326	-.685	-22.326	-.474	-16.038	-.405
Ln employment density	26.445	.444	15.376	.441	16.503	.336	13.316	.275
Ln distCBD	NO	NO	NO	NO	NO	NO	-2.678	-.251
Transit use	NO	NO	NO	NO	NO	NO	-3.782	-2.932

Chapter 6

SUMMARY AND CONCLUSIONS

6.1 Introduction

This chapter summarizes findings of the spatial distribution investigation, testing several urban form hypotheses and stepwise regression analyses performed to test the explanatory power of combinations of spatial structure variables to variation in travel demand. It also includes the general conclusion and issues that need to be resolved in future work.

6.2 Summary and Conclusions

Recently, the relationship between urban form and transportation energy efficiency has become a matter of considerable concern among planners and policy-makers who are concerned with issues of sustainable urban development. The energy consumed by the transportation sector depends directly on the level and spatial distribution of activities within the urban area and the "behavioural interconnections" between these activities.

Many empirical studies involve data analysis from different cities to identify variations in energy efficiency as a function of urban form defined at an aggregate. While undoubtedly useful, such analyses raise at least two potential problems. First, it is not easy to characterize entire urban areas in few variables that are susceptible to statistical analysis. The results would be based on the use of overly aggregate variables which may or may not be "representative" of a given urban area or consistently computed among 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 the 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 an 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 combinations of factors more conducive to achieving energy efficiency improvements through density increases than others? Questions such as these presumably require more detailed, intra-urban area analysis.

In response to the arguments presented above, the focus of this thesis was to explore empirically the cross-sectional relationship between the physical dimensions of urban form and auto travel as a surrogate for energy use within the Greater Toronto Area, with particular emphasis on identifying variations in VKT as a function of variations in the urban form attributes.

Attempts were made to define combination of the physical distribution of activities over space to reflect the urban form of the GTA. Dimensions like density, degree of sprawl or decentralization, accessibility to employment, self containment ratio, demographic characteristics, and transit use were explored.

Prior to undertaking any rigorous statistical analyses, the spatial distribution of the explanatory variables were investigated using spatial maps generated by "MapInfo". Several issues were explored about the urban form of the GTA such as distribution of activities, spatial match between the distribution of jobs and labour across the GTA, and travel demand across the GTA. The following general conclusions can be drawn:

1. The spatial distribution of population and employment in the GTA shows that the urban form of the GTA is not a single Centre form with concentration of activities in the CBD. Rather, the form of the GTA has become a multi-nodal form which combines both

concentration and dispersion. A decline in population and employment density was observed in the peripheral suburban areas.

2. Evidence of sprawl or decentralisation in employment locations across the GTA was observed with an outward expansion of the metropolitan boundary and additional employment locations at long distance from Toronto CBD. Meanwhile, several employment nodes with densities greater than 5000 employee per square km have developed across the GTA.
3. There is a spatial mismatch between the distribution of employment opportunities at most of the employment nodes and people residing at these locations. The mismatch between jobs and labour was highly observed in zones in the peripheral suburban areas.
4. The population sprawl and employment relocation outside of the Metro boundary has resulted in an increase in cross boundary travel. The travel demand outside of Metro boundary shows both sprawl and vehicle dependency in suburban areas.
5. Car ownership was quite high in suburban areas where more than 50% of the households have more than two vehicles.
6. Transit system use: more than 50% of both produced or attracted (work and non-work) trips to the core of Metropolitan Toronto were generated by public transit, reflecting the effect of availability of intensive transportation system in Metro. However, an obvious decline in transit use was observed for both produced and attracted trips at zones outside of the Metro boundary.

A similar pattern for transit use was observed in Hamilton-Wentworth region where 25% to 50% of produced or attracted trips were generated by public transit in the core of Hamilton (CBD) and then a decline of transit use occurred in the surrounding suburban areas.

Also, availability of local public transit system and the GO rail in Peel region affected transit use in Mississauga and Brampton where 10% to 25% of produced and attracted trips were generated by transit.

6.2.1 Travel Demand Across the GTA:

The average produced VKT per adult for work trips from most Metropolitan Toronto zones was around 10 km/adult. Longer produced work VKT per adult were observed in the suburban zones out side of both Metro and Hamilton-Wentworth boundaries.

The attracted VKT per employee to the majority of Metropolitan Toronto zones had a maximum value of 30 km with very few observations of more than 30 km per employee. Longer attracted VKT per employee for work trips were observed at suburban zones out side of both the Metro and Hamilton-Wentworth boundaries.

The majority of produced non-work trips in the GTA varied from 0 to 30 km per adult. In Metro Toronto, the majority were less than 30 km per adult which reflected the effect of self containment and accessibility to transit system. A very similar pattern was observed for attracted non-work trips where 88% of the observations in the GTA varied from 0 to 30 km/adult.

6.2.2 Summary of Testing the Hypotheses

The literature review shows that many researchers concluded that travel demand in cities is a function of population density, job density, and city center dominance. Other researchers focused on accessibility as a major factor affecting travel behavior. This study, analyses were performed to test several hypothesis of the relationship between travel demand and spatial structure characteristics in the GTA such as density, degree of sprawl, accessibility, and level of self containment.

To test these hypotheses, correlation analyses were conducted between travel demand measures and spatial structure measures that correspond to each of these hypotheses for each of four locations: Metropolitan Toronto, Hamilton-Wentworth, and Suburban areas 1 (Peel and Halton) and Suburban areas 2 (York and Durham), to test differences and similarities between the four geographical locations.

Testing for the density hypothesis revealed that:

- Population density explained a range of 4.4% to 14.6% of variation in produced work VKT per adult. It also explained 2.1% to 9.5% of variation in produced non-work trips.
- Employment density explained 1% to 4.1% of variation in produced and attracted work trips. It was also positively and significantly correlated at the 5% level with non-work VKT per adult explaining more variation (1.3% to 58%) in non-work trips than the case for work trips in Metro and Hamilton regions. This reflects the non-home based activities associated with work trips at employment locations.

The direct conclusion drawn from these results is that under the assumption of controlling for the geographical location but not for other spatial structure variables, density is an influential factor in determining travel demand in the GTA.

Testing for the degree of sprawl, results showed that:

- Degree of sprawl explained to a great extent variation in vehicular travel demand in the GTA, and influenced travel demand in locations which were not well served by transit. For example, it explained high percentages of variation in produced work VKT per adult varying from 6.6% in suburban areas to 14.4% in Metro Toronto.
- Degree of sprawl explained variation in attracted work VKT per employee in Metro and Hamilton. However, for suburban areas where there were lot of variations in travel demand, the degree of sprawl did not explain these variations.

- There was a negative correlation between produced non-work trips and degree of sprawl where distance from the CBD explained .36% to 3% of the variation.
- There was a positive correlation between attracted non-work trips and distance from the CBD, with more vehicular demand observed at locations further from the CBD reflecting the influence of transit system in serving non-work trips in Metro but not in suburban areas.
- Considering distance from Hamilton CBD as a measure of dispersion for both Halton, Peel and Hamilton-Wentworth regions, it was found that degree of sprawl from Hamilton CBD was positively correlated with produced and attracted work trips in Hamilton and produced VKT per adult in suburban area 1.

Testing the relationship between travel demand and accessibility showed that:

- The explanatory power of accessibility to opportunities of work within the 5 km buffer was not significant to explain variation in travel demand in the GTA.
- Distance to the nearest employment node was significantly correlated with produced work VKT per adult. The longer this distance, the higher observed produced work VKT per adult. This measure explained around 23% to 29% of variation in travel demand for suburban area 2 and Hamilton, respectively. In Metro, non-work VKT per adult was negatively correlated with distance to the nearest employment node. The further distance from the employment node, the less attractive the site became for non-work trips, which reflects the generated non-work activities at the sites of employment nodes.

Testing for the self containment ratio as a spatial match between employment opportunities and labour force, showed that this ratio significantly influenced travel demand in the GTA. However, selecting a measure for testing the self containment hypothesis and the proper value of this ratio for a good match is open for discussion and further studies. In the current study, this ratio was also tested in combination with other potential spatial structure

measures to explain variation in travel demand in the GTA using stepwise regression technique.

However, since there was evidence of correlation between some of the explanatory variables for spatial structure characteristics, it should be noted that no strong conclusions can be drawn from these analyses until a control is established for the other possible influential factors such as socio-economic factors, accessibility or access to transit, etc.

Attempts to maintain control for some of the explanatory variables and test for others were conducted, and a comparison was made between results of testing the hypothesis controlling only for geographical locations, and the new results obtained under the control for location and other explanatory variables. There were some differences between the two scenarios; however, it was very difficult to slice the data in numerous ways to control for all the possible influential variables other than the one tested at a time. That process would be very complicated since there were many variables involved in the analysis, and the size of the final data set would have become very small by the time control was forced for a number of variables.

6.2.3 Summary of the Multivariate Analysis

The stepwise regression technique was used to test the explanatory power of combinations of spatial structure variables for variation in travel demand. The potential explanatory variables were defined for each type of trip (produced and attracted work and non-work trip) based on results from the correlation analysis, and logical expectations. Then the screening procedure of the stepwise regression was used to identify the most influential spatial structure variables to variation in travel demand for each of the four locations: Metro Toronto, Hamilton-Wentworth, suburban area 1 west of Toronto (Halton and Peel), and suburban area 2 north and east of Toronto (York and Durham).

For produced work VKT per adult, results differed from one location to another where different combination of explanatory variables were significant in explaining variation in

travel demand. Also, the ranking of the explanatory power of the significant variables differed from one location to another. For instance, the degree of sprawl in Metro was the most powerful explanatory variable to explain variation in produced VKT per adult. Meanwhile, car ownership was the most powerful explanatory variable in Hamilton, employment density in Suburban area 1 (Peel and Halton), and accessibility to employment in Suburban area 2 (York and Durham).

- In Metro, more than one third of variation in produced work VKT per adult was explained by the combination of distance from the CBD, car ownership, employment participation rate, % of children, % of work at home and accessibility to the nearest employment node.
- In Hamilton 60% of variation in produced work VKT per adult was explained by car ownership, employment participation, employment density and percentage of part time people, % children and adults with driving license.
- In suburban area 1, more than one third of variation in produced work VKT per adult was explained by employment density, self containment ratio (jobs per labor), car ownership, employment participation rate, percentage of children and distance to the nearest employment node.
- In suburban area 2, around 40% of variation in produced work VKT per adult was explained by accessibility to the nearest employment node, employment participation rate, transit use percentage, self containment ratio (jobs per labourer, and percentage of part time workers).

Employment density was a key variable that explained around one third of variation in attracted work VKT per employee at all locations except in Metro Toronto. In Metro, the transit system usage was the most important variable to explain attracted work trips, followed by employment density where both variables explained 18.7% of variations in the attracted VKT per employee.

In addition, degree of sprawl and self containment ratio (job/labor) entered the regression analysis following the employment density for both suburban area 1 and 2. However, this ratio was more important in suburban area 1 than in suburban area 2.

It was generally observed in the GTA that produced non-work VKT per adult was longer than produced work VKT per adult. Moreover, the explanatory power of the selected spatial structure variables for variation in produced non-work trips was higher than the case for produced work trips. In Metro Toronto for example, 86.2% of variation in produced non-work trips was explained by the selected variables, compared to only 37.2% for produced work trips.

Both population and employment density were the most powerful explanatory variables at the four locations explaining a great percentage of variation in produced non-work demand. Population density had consistently a negative influence on produced non-work demand at the four locations, while, employment density had consistently a positive effect on produced non-work demand at the four locations, showing the associated non-home-based trips in this category.

Other variables such as car ownership, percentage of children and adults with driving license were significant in explaining non-work trips in Metro. In Hamilton, in addition to all the mentioned variables, percentage of workers who work at home and employment participation rate were also significant in explaining the variation in non-work travel demand. In addition, the degree of sprawl and transit use were significant in suburban area 2.

Similarly, it was observed that attracted non-work VKT per adult was longer than attracted work VKT per employee. Also, the explanatory power of the selected spatial structure variables for variation in attracted non-work trips was higher than the case for attracted work trips. In Metro Toronto for example, 83.5% of variation in attracted non-work trips was explained compared to only 18.7% for work trips.

At the four locations, the analysis for attracted non-work VKT/adult showed similarities of the significant variables entered into the regression analysis to explain variation in travel demand. Population and employment density were the first two significant variables at the four locations. These two variables explained a great percentage of variation in attracted non-work demand which varied from 55.9 % in suburban area 2 to 83.5% in Metro. In suburban area 2, transit use and degree of sprawl were also significant in explaining variation in attracted non-work trips.

6.3 A General Conclusion and Future Work

The interrelationship between urban form and travel demand is a complex issue is affected by many factors such as density, degree of sprawl, accessibility, self containment, demographic characteristics, transit system, etc.

Other factors were excluded from the current study for two reasons, first the difficulty in obtaining representative data, and second some factors are non- quantitative. These include culture-related factors such as the age and stage of the city's development and it's historical growth: the economic environment such as the city's functional character, prevailing mode of production, and economic base: property rights: developers' activities: planning controls and concepts: and technological aspects. All of these factors are expected to influence travel demand.

Activity and, eventually, travel behaviour are indirectly affected by public policy. Provision of transportation infrastructure and services can directly affect behaviour, as can various "transportation demand management" policies. A wide variety of other policies such as taxation, monetary policy affecting interest can have a variety of effects. Ultimately, the final outcome is the result of the complex location, activity, and travel choices which people make over time in response to all these 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 work such as in Anderson, *et al.*, 1994.

Another issue that needs to be investigated and resolved is spatial autocorrelation. Since observations in the data set are area zones which make up regions, there is a tendency for adjacent areas to have correlated values. That means it is likely to find close or similar values (high or low) in areas that are near each other, an effect known as spatial autocorrelation. Spatial autocorrelation can be interpreted as a descriptive index measuring the degree of influence exerted by something over its neighbor.

Spatial autocorrelation for zones can be measured by the Moran index which is defined so that its extremes match the intuitive notions of positive and negative correlation. This index is positive when nearby areas tend to be similar in attributes, negative when they tend to be dissimilar, and approximately zero in large samples when the attributes values are randomly arranged independently in space.

Evidence of spatial autocorrelation was found between observations in the GTA. An attempt was made to investigate spatial autocorrelation for employment density in the GTA. The Moran Index value was found to be equal 0.6148. For spatial autocorrelation between employment nodes, the Moran Index value was 1.0178 showing high autocorrelation between these locations showing a tendency of clustering of employment opportunities in these zones in the GTA.

Due to time limitations of the current research, no further analyses were conducted to investigate this matter. However, it is recommended for consideration in future work. Resolving this issue involves statistical estimation of parameters for models of spatial data series and the conceptualization of spatial process. Spatial autocorrelation provides a type of information that is not available by any statistical analysis and can be vital for correct interpretation of results. Also, it provides information of causes for a particular spatial distribution or pattern and it is necessary for correct forecasting.

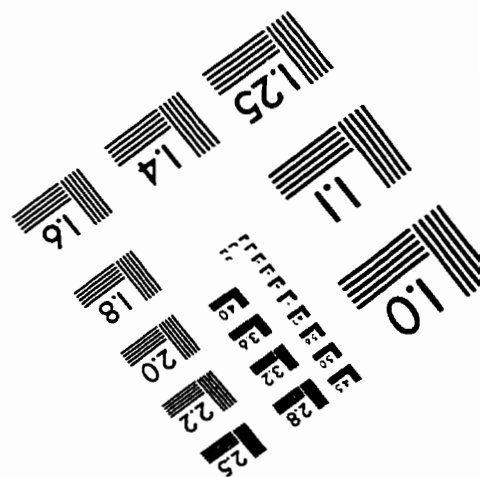
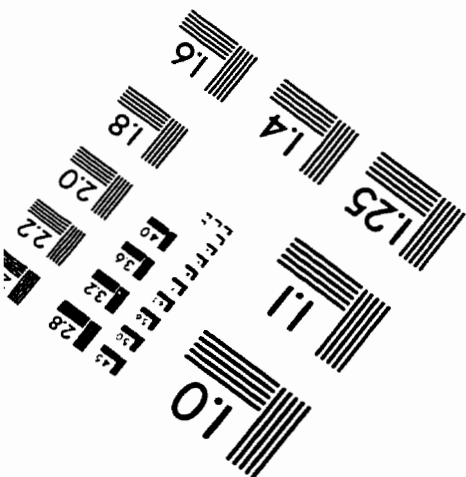
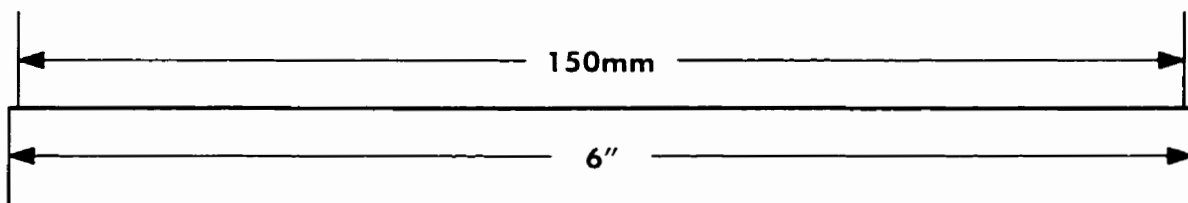
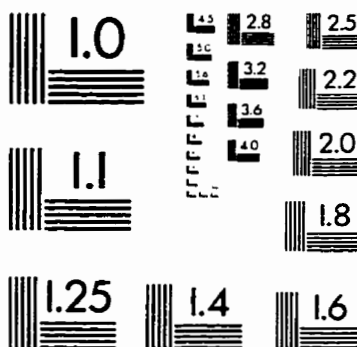
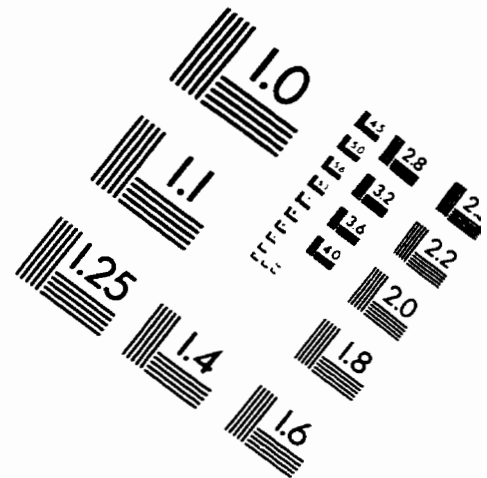
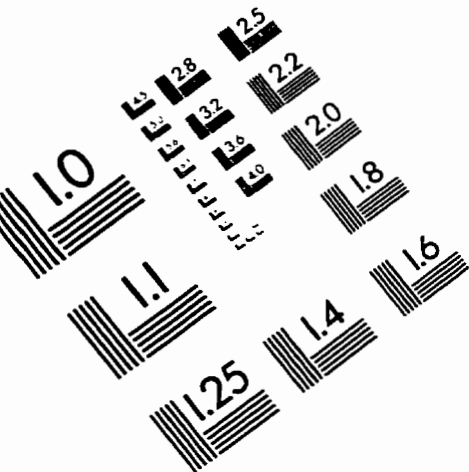
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IMAGE EVALUATION TEST TARGET (QA-3)



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