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Quantifying the impacts of the modifiable areal unit problem in travel demand models

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QUANTIFYING THE IMPACTS OF THE MODIFIABLE AREAL UNIT PROBLEM IN TRAVEL DEMAND MODELS

by

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Abstract

This project introduces new analyses of the impacts of the modifiable areal unit problem (MAUP) in traffic assignment models which are not widely available in the literature, as well as to reveal how stable the effects are in diverse models. A comprehensive review of the literature is conducted to provide an overview of MAUP, including the scale and zonal effect, as well as its recent applications in travel demand modelling and other subject areas. Particular scrutiny is made towards inappropriate methods of MAUP-analysis in travel demand models. The scale effect is tested in traffic assignment models using associated zone structures of the Greater Montreal Area (GMA), a unique geographic region involving island regions and water bodies.

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1.0 Introduction

The modifiable areal unit problem (MAUP) has been a topic of interest in the field of transportation for the past few decades. Much of the transportation-related MAUP research pays particular attention to determining appropriate structure of traffic analysis zones (TAZs) for improved travel demand forecasting purposes.

As a general topic, the MAUP "has recently roared back to the forefront of spatial analysis" (Miller, 1999, p.375). Although this is a somewhat unfamiliar subject area for transportation analysts (Páez and Scott, 2004), researchers have been able to conclude effects of the MAUP on both the statistical results and other network performance measures associated with travel demand forecasts by aggregating or disaggregating zones of a particular analysis region.

For travel demand forecasting purposes, understanding the impact of the MAUP is very crucial to achieving more accurate trip forecasts. Travel demand forecasts are conducted in a spatial manner (i.e. in the form of TAZs), so investigating the MAUP impacts on various zone structures can also lead researchers to determining the most suitable zone structure for analysis purposes.

At present, two concepts of the MAUP are well known. The *scale effect* of the MAUP occurs when a set of zones are aggregated or disaggregated into a different number of zones with different sizes and shapes, thus resulting in different numerical outputs. The *zonal effect* of the MAUP is a result of zonal aggregation to the same scale, but with different sized and shaped zones.

Few publications, both on the MAUP in general and in transportation-related MAUP analysis, discuss the zonal effect of the MAUP, while many focus on the scale effect. As has been found in the general literature, transportation-related MAUP research has continued to reaffirm the presence of the scale effect as a result of various zonal aggregations and disaggregations.

Over the years, specific rules to zone delineation have been established in the literature which, for the most part, have been followed when conducting MAUP-related research. It is unfortunate that, given the extremely limited literature exists on the impacts of the MAUP on the mode split stage of the Urban Transportation Planning Process (UTPP), the one study that has focussed on this stage applied an arbitrary zone system in the analysis.

This project attempts to fill some gaps on MAUP-related travel demand forecasting research. Specifically, this project will reinforce how to test for zonal effect of the MAUP in a mode split model for the Greater Montreal Area (GMA) while taking into account appropriate rules for TAZ design. The main and unique component of this project features the performance of multiple traffic assignments using two zone systems designed for the GMA (GMA) in Quebec, Canada, testing for the scale effect of the MAUP. In both cases, the purpose of the research is to prove that there is a significant difference in statistical outputs between zone systems of different scales.

The second chapter provides a comprehensive review of the literature with an overview on:

- The evolution of the MAUP, with case studies primarily referenced from studies on jurisdictions in the United States of America (herein referred to as the U.S.);
- The impact on the MAUP as presented in research on the latter three stages of the UTTP: trip distribution, mode split and traffic assignment;
- The general rules developed over time for the delineation of TAZs;
- The presence of scale effect in traffic assignment exercises; and
- The presence of zonal effect in a mode split exercise.

The third chapter describes the results of testing the MAUP in a mode split model. The research methodology and study area will be introduced in the fourth chapter with an overview of the GMA model, along with the study results of MAUP testing in a traffic assignment exercise. A summary of conclusions and research contributions are reported in the final chapter.

2.0 Literature Review

This literature review is divided into five subsections. The first subsection describes the evolution of the MAUP as it is known under present standards. The second subsection discusses the relevant literature pertaining to rules of zone delineation, with particular respect to TAZs. The third subsection provides an overview of applicable research on scale effect, with a particular focus on travel demand models. The fourth subsection provides a review of the limited research conducted on the zonal effect. A summary of the literature review is provided in the fifth subsection.

2.1.0 The Modifiable Areal Unit Problem Defined and Applied

The Modifiable Areal Unit Problem (MAUP) has been a topic of discussion since the early 1930s. Although not formally defined as MAUP until the late 1970s, the concepts were well established in studies of geographic units and the impact of their modification. The earliest studies, however, focused on the result of changing scale.

2.1.1 The Effect of Spatial Aggregation – Pre-1970s

Prior to the 1970s, the MAUP had not been formally defined. However, much work had been conducted on the impact of spatial aggregation in spatial analysis, all of which proved their associated impacts on statistical outputs (Gehkle and Biehl, 1934; Robinson, 1950; Blalock, 1964). Over time, definitions related to the MAUP were developed and taken into consideration as more recent publications on the topic became available (Yule and Kendall, 1950; Sawicki, 1973).

The earliest publications on spatial aggregation were provided by Gehkle and Biehl (1934) and Robinson (1950). The two demonstrated the effect of aggregating geographic units in their respective analyses of *correlation coefficients* – a standard index used to measure the level of linear correlation between two different variables of analysis. In an analysis of correlation between male juvenile delinquency and median equivalent monthly rental in Cleveland, Ohio, Gehlke and Biehl (1934) aggregated 252 census tracts into seven sets of larger zones - of equal size in each case, and subsequently reported higher values for the correlation coefficients as the size of the zone increased (-0.763 at the most aggregate scale, and -0.502 at the most disaggregate scale). Similar results were concluded by Robinson (1950) in an analysis of ecological correlations between black populations and illiterate populations across the United States, where the resulting coefficient differed at each level of aggregation (0.203 at the individual level, 0.773 at U.S. state-level, and 0.946 under a structure of nine geographic divisions defined by the U.S. Census Bureau in 1930).

In the same year that Robinson (1950) added to the discoveries of Gehlke and Biehl (1934), Yule and Kendall (1950) introduced the concept of *modifiable unit* – a geographic unit that can be divided or united with another geographic unit for enhanced analysis. In their analysis of correlation between yields of wheat and potatoes in England, spatial aggregation was necessary in some cases in order to give the analysis meaning due to the physical inability or impracticality of growing two distinct crop types on the same harvesting ground. They thus aggregated 48 geographic units to 24, which ultimately affected the correlation coefficient (from 0.2189 to 0.2963). The same procedure was repeated for a grouping of 12 zones, again resulting in a higher correlation coefficient value (0.5757).

Blalock (1964) continued the trend of correlation analysis, but took a slightly different approach. In a study based in the southern U.S., the percentage of non-white population in the southern U.S. was regressed against the income difference between whites and blacks in the respective jurisdiction. In this instance, the interest was geared towards the impact of different methods of zonal aggregation. A set of 150 counties was aggregated into zonal systems with 75, 30, 15 and 10 zones respectively using four different aggregation methods – random aggregation, grouping by the independent variable (percentage of non-white population), grouping by the dependent variable (income difference between whites and blacks), and geographical proximity. While it was expected that the resulting coefficients would differ between scales (see Table 1), it was interesting to see how some variance existed between zonal structures at the exact same scale.

Sawicki (1973) introduced the concept of *aggregation bias*, noting that "one should be wary of using high correlation coefficients resulting from correlations with large units of analysis" (p.110), and that only the appropriate scale of analysis would reveal appropriate results. In a case study of social disorganization in Syracuse, New York, he was able to use individual-level data from surveys to test for heterogeneity of societal elements at three zonal levels – census tracts (most aggregate level), neighbourhoods, and "police beats" (most disaggregate level).

2.1.2 Verging on the Definition of the MAUP – Post 1970s

The most noteworthy sources on the topic of MAUP were introduced in the late 1970s and early 1980s by Openshaw (1977; 1984; 1989) and colleagues. Openshaw (1977) introduced the concept of *scale effect*, which related to the work of Yule and Kendall (1950), Blalock (1964) and Sawicki (1973), as well as the *zoning effect*, which related more towards the extended research of Blalock (1964). The impact of the scale problem was further demonstrated through an analysis of 1,219 grids at 100 square metres, which were then aggregated into grids of $200m^2$, $300m^2$, $400m^2$, $500m^2$, $600m^2$, $700m^2$, $800m^2$, $900m^2$, and $1km^2$. To demonstrate the aggregation problem, a series of alternate aggregations were used at each scale.[1] A linear correlation analysis on the number of early-Victorian homes and mid-Victorian homes within each grid was performed in each zone system. Similar to previous studies, most of the resulting values of product moment correlation (*r*) increased at each level of aggregation, which demonstrated the scale problem. To test for the aggregation problem, the mean value and standard deviation of the product moment correlation was calculated, and the reported results of these outputs differed by scale. Openshaw (1977) noted that "it has not been possible to consider the full extent of the aggregation problem, as this would involve an examination of every possible zonal configuration of boundaries for each integer of zones between 2 and 1,218" (p.460).

[1] Openshaw (1977) only made mention of the 25 different aggregations at the $500m^2$ scale.

In a separate publication, Openshaw (1984) provided detailed definitions of the *scale problem* and *aggregation problem*. The scale problem was defined as "the variation in results that can often be obtained when data for one set of areal units are progressively aggregated into fewer and larger units for analysis" (Openshaw, 1984, p.8). The aggregation problem was defined as "any variation in results due to the use of alternative units of analysis when the number of units is held constant" (Openshaw, 1984, p.8).

Openshaw (1989) further elaborated on the importance of investigating the aggregation problem as a result of the availability of Geographic Information Systems (GIS), which allows the user to go beyond defined number of areal units of investigation. It was mentioned that there was no technology available at the time to produce the most optimal aggregated zone system, particularly since the zone system is meant to react with a particular model or method of analysis being used. The example of intrazonal trips in a travel demand forecasting model – those trips that are not detected in a zone system because they do not cross zonal boundaries from one zone to another – was specifically cited to explain this theory. By changing the boundaries of the zone system, the output model and goodness of fit can be manipulated to better represent the spatial interaction of trip. However, Openshaw (1989) cautioned that randomly generated (or aggregated) zone systems can have limited application to real-life examples depending on units of analysis as well as the manner of aggregating the zone system.

2.2.0 Zone Delineation

As previously elaborated by Openshaw (1989), zones should be delineated based on a series of specified constraints, and not randomly. "The imposition of TAZ homogeneity for a specific variable (e.g. car ownership) and the number of zones established can have a deep impact in the modeling results, making the use of one specific data sample unfeasible in some studies" (Martinez et al., 2007, p.59), so constraint aggregation must be done carefully.

2.2.1 Rules for Designing TAZs

One of the original publications specific to TAZ design came from Baass (1981), who set out a series of guidelines for appropriate TAZ design.

> "These criteria are based on quantitative and qualitative data of such a multitude and diversity that the human mind alone will not be able to process. These criteria can be stated in the following way:
>
> 1. *Achieve a maximum of homogeneity inside the newly created zones, which is important for the trip generation and the modal split phase of the model sequence;*
> 2. *Retain a maximum of interaction between newly established zones or a minimum of intrazonal trips, which is an important requirement for the trip distribution and trip assignment models;*
> 3. *Limit the number of trip ends for the newly created spatial entity in order to avoid overloading of the adjacent street network in the assignment phase;*
> 4. *Respect physical, political, and historical boundaries as far as they are of importance from a planning point of view;*
> 5. *Avoid undesirable shapes of newly created zones;*
> 6. *Group only adjacent basic spatial units:*
> 7. *Generate only connected zones;*
> 8. *Avoid the formation of islands, which means zones that are completely contained in another zone:*
> 9. *Obtain a zonal system in which the number of households, population, area, or trips generated and attracted are nearly equal in each zone (the variation with respect to one of these variables should be kept as small as possible); and*
> 10. *Base the delineation of the zonal boundaries on the census boundaries."*
>
> (Baass, 1981, p.1)

In a recent study by Spurr (2005) on performing traffic assignment in a digital GIS-based model, four principle zone delineation criteria based on rules established by Bennion and O'Neill (1994), Ortuzar and Willumson (1994) and Caliper Corporation (2005) were applied, which stated that:

1. *The system must be mutually exclusive and collectively exhaustive. In other words, the zones must not overlap and must entirely cover the area under study.*

2. *The system must respect the boundaries of existing census tracts. This condition was imposed in order to facilitate linkages between model data and demographic data contained in the census.*

3. *Trips must be distributed evenly throughout zones. Zones generating or attracting exceptionally large numbers of trips will result in large assignment errors because trips whose ends are distributed throughout the zone will be aggregated to a single point.*

4. *The system must be optimally disaggregated. While the zones must be small enough to provide reasonable spatial resolution, they must not be so small that many thousands are required to cover the study area. A 10,000 zone region will generate a matrix of 100,000,000 cells. Even if this matrix were to be filled with all the valid trip records in the O-D survey (the case of a 24 hour model), at most 385,000 – only 0.4% of all cells – would be filled.*

(Spurr, 2005, p.28).

2.2.2 Other Forms of Zone Design

Contrary to random zone design, zone boundaries for certain applications can be a result of manual design in order to accommodate organizational needs, such as jurisdictional boundaries, physical boundaries such as rivers, or transportation corridors for government analysis (O'Neill, 1991; Ding, 1994; Cockings and Martin, 2004). On the other hand, grid systems are a form of arbitrary user-defined set of zones, as applied in a mode split analysis by Zhang and Kukudia (2005) (see **Chapter 5.2**).

In a non-TDM, but transportation-related study, Martinez et al. (2007) investigated the presence of scale effect between a local governmental TAZ system, an arbitrary grid system, and a new user-defined TAZ system. After developing measures for statistical precision, geographical precision, and information loss between the three systems, they found that their grids produced better results than the existing TAZs, but that the newly delineated TAZs with more natural boundaries with additional constraints performed better than the grids.

2.3.0 Scale Effect of the MAUP

Numerous publications have concluded that the adjustment of the scale of areal units will impact the resulting statistics. Of particular interest are the few publications that exist on the analysis on MAUP specific to the classic four-stage UTPP – namely the trip distribution stage (Batty and Sikdar, 1982), the mode split stage (Zhang and Kukudia, 2005), and the traffic assignment stage (Crevo, 1991; Ding, 1998; Khatib et al.; 2001, Binetti and Ciani, 2002; Chang et al., 2002). This chapter will reveal the results of these publications that studied the MAUP specifically within the realm of the UTPP.

2.3.1 Trip Distribution and Scale Effect

Batty and Sikdar (1982) reviewed the earliest study on scale effect in gravity modeling – namely in trip distribution. This study initially reviewed the distribution of trips from the Reading, England region in 1966 using 22 aggregations of a 23-zone system. The test for scale effect involved the solving for the scale and dispersion parameters developed in the unconstrained, origin-constrained, destination-constrained, and doubly constrained. The cost friction coefficient (*C*) was maintained at the level of the 23 zones for the reason "that dimensional consistency must be retained by the aggregation process, and that the twenty-three-zone level estimate of *C* is the most accurate available" (Batty and Sikdar, 1982, p.641). The observed results were graphed against the predicted results under each model, revealing a linear relationship. The observed results and predicted results were then each respectively graphed against the level of spatial aggregation, showing a downward slope – "that is, the informations increase in value as levels of greater aggregation are produced" (Batty and Sikdar, 1982, p.643). However, a goodness of fit performance (measured as r^2) was then determined for each model, and revealed that the model fit was highest at a higher level of aggregation. Furthermore, the r^2 outputs yielded acceptable results for the doubly- and origin-constrained models (0.9697 and 0.8269 respectively at the disaggregate level and 1.0 and 0.9907 respectively at the aggregate level), and poor results for the unconstrained model (0.0384 at the disaggregate level and 0.2679 at the aggregate level).

2.3.2 Traffic Assignment and Scale Effect

One of the first publications on traffic assignment performance in reconfigured TAZs came from Crevo (1991). In most cases, equilibrium assignment was used (Ding, 1994; Ding 1998; Khatib et al., 2001; Chang et al., 2002; Binneti and Ciani, 2002[2]). This simple analysis of scale effect two zone systems did not reveal much evidence of the scale effect. By the late 1990s and early 2000s, additional scale effect studies in traffic assignment were produced with more complex analyses and more than two zone systems. Ding (1998), Khatib et al. (2001), Binetti and Ciani (2002) and Chang et al. (2002) designed a test of the MAUP in their respective traffic assignment models using diverse parameters for traffic network performance. These latter authors concluded the presence of scale effect in traffic assignment, as demonstrated by the different resulting network performance criteria values at each scale.

Crevo's (1991) study involved the analysis of how to account for population and land use changes over time through the reconfiguration of TAZs. Using the 204 zone system of New Castle County provided by the Delaware Department of Transportation, "candidate zones" were identified for analysis based on growth level between 1970 and 1985 of land use and population as well as associated impact on travel compared to other TAZs. Such criteria included household and employment characteristics trip productions and attractions, the relationship of the total trip ends to the geographic area of the TAZ[3]. Once this was completed, the selected (ten) TAZs were further analyzed for geographical coverage, and one additional zone was removed from analysis since it mostly covered a land mass without any population or imposed land use. With the nine remaining TAZs, a process of zone subdivision was applied whereby 6,000-8,000 trip ends warranted a new TAZ (down from an average 11,000 trip ends in the original TAZ format). This resulted in the creation of 23 new TAZs.

Using traffic volumes from 1985 provided by the Delaware Department of Transportation, a traffic assignment exercise was performed on both the original TAZ system and the new TAZ system. Using total trips, trip hours, average trip length (in minutes), and total number of

[2] Binetti and Ciani (2002) specified that they used *Stochastic* User Equilibrium traffic assignment.
[3] This was measured by calculating the ratio of the total trip ends to the total number of acres making up the TAZ.

intrazonal trips as the travel characteristic criteria, the differences between the zone systems were very minor (Crevo, 1991). Other statistical correlation comparisons and traffic assignment comparisons concluded a similar lack of variation between TAZ systems.

Horner M. W., & Murray (2004) provided an appropriate scrutiny of this publication, stating that "one could argue that perhaps an insufficient number of tests were conducted by Crevo (1991) to conclude any general relationship, as considering a larger set of zones or choosing an alternative representation of demand could have produced alternative findings, at least in the context of traffic assignment" (p.787). However, the fact that only a portion of the entire geographic area was investigated, whereas most scale effect studies review the impacts within the full geography incorporated in a given zone system.

A unique nation-wide analysis conducted in South Korea using multiple zone systems was reported in Ding (1994) and Ding (1998). Using a TAZ design algorithm that maximised for criteria such as homogeneity, interzonal trips, and compatibility with existing census boundaries, the 130 zone TAZ system was aggregated to seven different scales of 100, 75, 50, 35, 25, 15 and 8 zones respectively. Ding (1998) reported issues not addressed by the TAZ design algorithm, such as some incompatibility between the census boundaries and the new TAZ delineations.

1991 demographic and traffic data was used in an equilibrium traffic assignment. Ding (1994) acknowledged the use of the Bureau of Public Roads (BPR) exponent for the time parameter in the equilibrium assignment, the use of 0.01 as the closure criterion for achieving equilibrium, and the application of a maximum of 25 iterations in the assignment. The network performance criteria included a ratio of interzonal trips to total trips, a congestion index output from the TRANSPLAN software (not defined in either publication), assigned and unassigned interzonal trips[4], intrazonal trips, total trips, total vehicle miles, total vehicle hours, and average speed. Ding (1998) reported that, while there was no impact on total trips between scales, the total vehicle miles travelled increased by nearly 49% from the most aggregate scale to the most disaggregate scale, while the total vehicle hours increased by 31% respectively. Oddly enough, the (undefined) congestion index yields less congested conditions in the 130 TAZ scale

[4] In all TAZ systems, there was no case of unassigned interzonal trips.

compared to the eight TAZ system, but the volume/capacity ratios for the individual links[5] suggested that congestion was more apparent in the more disaggregate TAZ system due to the level of detail. Overall, the effect of adjusting for scale in TAZ was demonstrated in traffic assignment.

A study based in the U.S. state of Idaho was published in Khatib et al. (2001) and Chang et al. (2002). In both publications, it was reported that 11 zone systems were created based on the existing census geographies of counties (44 zones), census tracts (269 zones) and census blocks (1,122 zones). While only three different scales were used, each scale was assigned a unique centroid weighted by a different parameter. Four zone systems were created for each level of census geography except for census blocks where only three zone systems were created, where the only difference was the type of centroids used in each zone system: the geometric (physical) centre within the zone, the (largest) city within a zone, centroids weighted by population, and centroids weighted by household-density[6]. Khatib et al. (2001) performed a full four-stage model using socioeconomic data from the 1990 U.S. Census for the trip generation step and traffic data from 1996 provided by the Idaho Transportation Department (ITD) for the traffic assignment.

The network performance criteria used in the traffic assignment included trip length (in minutes), number of assigned interzonal trips, a ratio of the estimated volume to the recorded average annual daily traffic count (AADT) from the ITD, and percent root-mean square error (*RMSE%*) – an index that measures the variance between the observed and forecasted traffic volumes.
Khatib et al. (2001) also tested for correlation using Pearson product moment correlation coefficient (*R*). A series of analyses of variance (ANOVA) and a Fisher test of least significant difference (LSD) were performed on each zone structure to check the variance of resulting coefficients and other mathematical results between zone systems.

[5] These particular results were not reported in great detail in either publication.
[6] The census-block level zones did not have a zone system with household-density-weighted centroids. While Chang et al. (2002) it was not explained why, the author believes that the size of the census blocks may have made it impossible to weight centroids according to household-density.

The resulting traffic assignment outputs suggested the presence of the scale effect, as they differed at each scale. Chang et al. (2002) noted specifically that trip length by type varied between zone systems by an average of +/- 16 minutes around the mean value, with the census blocks yielding many shorter trip lengths[7]. The number of interzonal trips was less on the most aggregate scale (counties) and greater on the most disaggregate scale (census blocks). The estimated volume to AADT ratios performed better at the census block-level except in the case of urban minor arterials where this variable performed better at the census tract-level. The root mean square error statistic also yielded lower results for the census blocks. The ANOVA and LSD results suggested that the root mean square error value was not the same among all 11 zone systems, and that resulting mean values at each scale of zone systems were significantly different from each other.

Binneti and Ciani's (2002) study involved the design of 10 TAZ systems for the City of Bari, Italy – with 10 zones being the most aggregate scale and 75 zones being the most disaggregate. After constructing the 1475 link street network using GIS, a Stochastic User Equilibrium (SUE) traffic assignment was performed using the results of a trip generation, trip distribution and mode split model. Using total cost (hours), average cost (seconds), average cost (seconds when the path cost vector is equal to zero), number of saturated links, and a poorly defined congestion index[8] as the network performance criteria, scale effect was demonstrated by the diverse results ranging +/- 20% around the mean value of the results.

2.4.0 Zonal Effect of the MAUP

Limited research exists demonstrating the zonal effect of MAUP. The most notable studies on zonal effect come from Blalock (1964), who authored one of the original studies on zonal effect, as well as Fotheringham and Wong (1991), Amrhein and Reynolds (1996) and Hunt and Boots (1996) who performed a test of zonal effect alongside their respective analyses of scale effect.

[7] Chang el al. (2002) also reported that the shorter trip lengths may have also been a result of the derived centroids, where many of the trips would be geographically concentrated within the zones.
[8] Binetti and Ciani (2002) produced an equation of $I_C = \sum_l [(Gs_l f_l)/\sum f_l]$ as a means of defining the so called "PCP" congestion index without ever defining the value of I_C in the publication.

To date, the only paper that deals specifically with the zonal effect in the classic four-stage UTTP comes from Zhang and Kukudia (2005).

2.4.1 Miscellaneous Studies in Zonal Effect

Fotheringham and Wong (1991) created 20 separate zone systems for each level of aggregation of the Buffalo Metropolitan Area block level zones (871): census tracts (278); and random aggregations of 800, 400, 200, 100, 50 and 25 zones. When regressing mean family income (dollars) to the respective percentages of the population that were homeowners, blue-collar workers, black, and over the age of 65, they discovered that the coefficients differed not only between scales, but approximately 121 estimates per parameter as a result of the different zonal configurations at the same scale. The same occurred in a logistic regression test correlating the proportion of owner-occupied homes to blue-collard workers, mean family income (tens of thousands of dollars) and median house value (hundreds of thousands of dollars). To further demonstrate the zonal effect, they aggregated the block level zonal system of 871 into 150 sets of a 218 zone system. The dependent variable (percentage of owners) in all 150 zone systems was significantly positive from zero, and an average range of income increasing by $1000-2000 was output for each 0.1 unit of population owning a home.

Amrhein and Reynolds (1996) also tested for zonal effect using multiple zoning systems at different scales. Their case study of Lancashire County in England contained census geography comprising of 3048 enumeration areas (EAs), 304 wards, and 14 districts. It was decided that, due to lack of appropriate data, the EA level zones would not be used. Thus, the 304 wards were aggregated to zone systems of 137, 122, 106, 91, 76, 61, 46, 30 and 14 zones respectively, each weighted according to a percentage of the population within each ward divisible by 5.[9] Each level of aggregation was given 100 alternate zone systems with different boundaries. Using 1991 census data for the region, the mean of total households with dependents, the mean ratio of female-headed households with dependents to all families with dependents, and their associated variance expected variance were calculated in each scale. While the scale effect was determined

[9] The 137 zones contained 45% of the ward population, 122 zones contained 40%, and so on.

with this method due to the differences in the output variance values at each scale, the zonal effect was inconclusive, as the mean values were the same at each scale.

Hunt and Boots (1996) tested three datasets for multicolinearity on 4 levels of aggregation each containing 30 different zone systems. Two of the datasets were arbitrary with 240 grid-style spatial units, while the third featured 231 EAs of the urban area of the Saskatoon census metropolitan area (CMA) from 1986. Using factor analysis – a means to check for variance between spatial data containing random variables, scale effect and zoning effect was examined by reviewing mean values of individual characteristics for change between scale and zone structure. It was determined that zoning effect was more predominant in this exercise than scale effect, particularly in data free of spatial autocorrelation – the correlation between a variable and its reference point in space.

Hunt and Boots (1996) also calibrated a multinomial logit model exploring the probability of a given travel mode for home-based work trips and home-based-non-work trips from each of the zone systems. Each of the output coefficients for the explanatory variables used in the logit models was diverse among the eight zone systems. With respect to zonal effect, this was also the case between the three pairs of "comparable" zone systems.

2.4.2 Zonal Effect in Mode Split Models

Zhang and Kukudia (2005) conducted one of the only analyses on zonal effect related to the classic four-stage modelling process in the Boston Metropolitan Area. The study was originally designed to test for scale effect in mode split models using U.S. census data from 1990 and Trip Diary Survey data from 1991 in eight different zone systems - five arbitrary grid systems containing block sizes of 1/16, ¼, ½, 1, and 2 square miles respectively, and three zone systems based existing census geography (census block, block group and TAZ). Zonal effect was investigated by testing the differences between the most comparable pair of zone systems based on zone size (measured in acres) – namely the ¼-mile grids with the census blocks, the 1-mile grids with block groups, and the 2-mile grids with the TAZs. Using a multimomial logit model, the probability of a given travel mode for home-based work trips and home-based-non-work trips for each of the zone systems was calibrated. From a scale effect perspective, the eight zone systems yielded diverse coefficients for the explanatory variables used in the logit models. From a zonal effect perspective, these coefficients also differed within the classified pairs of zone systems.

Zhang and Kukudia (2005) suggested that that their "grid approach to aggregating data produce(d) more tractable and stable results than the approach with statistical areal units (e.g., TAZ and [block group])" (p.78). However, this application was inappropriate as it did not conform to the topology (especially with the presence of small islands, where two islands can be covered by a single grid depending on the specified area). They were wise to test other types of zonal delineations, thus avoiding the scrutiny of Openshaw (1977), as well as ensuring that their zones were homogenous in size based on user-specifications, in conformance to rules on TAZ design. However, "the most important criteria for good aggregated zoning systems in transportation planning are the achievement of homogeneity of population inside the new zones and the conservation of the interaction between zones" (Baass, 1981, p.3). By artificially aggregating zones based on a specified area measurement, some of the new zones are subject to containing a population zero, which can have a tremendous impact on the modelling and resulting statistical outputs.

2.5.0 Summary

The MAUP is not a new concept by any means – including in travel demand models. The effect of spatial aggregation and areal unit boundary changes has been proven in various studies using statistical analysis. The concepts have been well defined over time, and have since been incorporated in subsequent studies, many of which will be reviewed in later sections of this project.

The application of zone design rules to new zone systems, such as outlined by Baass (1981), can improve the output modelling when compared to the use of arbitrary zone systems. This was demonstrated by Martinez et al. (2007) who applied specific constraints to their newly designed TAZ system and thus improved their modelling results.

The existence of the scale effect of the MAUP in travel demand forecasting has a fair amount of exposure in the research – namely in the traffic assignment stage. All of these traffic assignment publications analyzed the impact of scale effect. Ding (1994), Horner and Murray (2002), Binetti and Ciani (2002) used various goodness of fit tests and other significance tests to conclude that aggregate zone structures yield less accurate and significant results than disaggregate zone structures. The main advantage of disaggregate zone systems in traffic assignment is the reduction of intrazonal trips, with minor exceptions (Khatib et al., 2001; Chang et al., 2002). There has yet to be a publication that reviews the presence of zonal effect in traffic assignment models. It is clear that this shortcoming needs to be addressed.

Each of the studies on zonal effect also featured a scale effect analysis. The majority of the studies contained multiple zone systems at the same scale for improved analysis of zone effect. The one study that investigated the zonal effect in travel demand forecasting disregarded a key rule of TAZ design, thus deeming the analysis inappropriate. A new study on zonal effect in travel demand forecasting is needed that takes the TAZ design rules into account.

3.0 Testing the MAUP in a Mode Split Model

A procedure to test the MAUP more appropriately in a mode split model for the Greater Montreal Area (GMA) by taking into account the rules for TAZ design, as highlighted in Nix (2008). The full details of this experiment are detailed in this chapter. This procedure utilized demographic data from the 2001 census for the GMA. While census data in Canada is conducted every 5 years by Statistics Canada (Statistics Canada, 2007), there was insufficient demographic data from the 2006 census at the time of the authoring of this project.

Like many of the publications that investigated the zonal effect, this study also tested for scale effect. In both cases, the following utility model was used in the form of binary logit:

$$P_n = \frac{1}{1+e^U}$$

where:

P = the probability of choosing alternative n;

n = mode of transportation (in this case, transit);

e = exponential function (or 2.718281828)

U = utility of alternative $n = \alpha + \beta_k x_k$;

α = coefficient of the dependent variable (constant);

β = coefficient of the independent variable;

x = independent variables;

k = number of independent variables

The following independent variables were used in the initial models:

- population density [pop_dens] – defined as every 10,000 persons per square kilometre;
- renting population [rent_%] – defined as the ratio of rented dwellings to total occupied dwellings;
- household size [hshld_size] – defined as the average number of persons per household);
- households with children [hshld_child] – defined as the ratio of census families with children (including single parents) to total households;

- average income of population 15 years and over (measured in $10,000s) [inc15+avg];
- distance to Central Business District [dist_CBD] – defined as distance from the centroid (or geographic midpoint) of each analysis zone to the centroid of the zone classified as the CBD, measured in kilometres.

It was expected that more public transit commuting would take place from zones with a higher population density and proportion of renters. There is a general understanding that public transit services work best, and are thus more accessible, in higher density neighbourhoods (Cervero and Gorham, 1995; Kenworthy and Laube, 1996; Cervero and Kockelman, 1997). Renting demographic can often be correlated with the inability to afford a private automobile for commuting purposes, which results in a higher dependency on public transit (Kuby et al., 2004).

As a contrast, it was anticipated that less commuting made by public transit would occur from zones with a large proportion of multiple-member households, households with children and higher average income, and those that were located further away from the CBD. The size of the household has been found be an influential factor in auto ownership (Kockelman, as cited in Holtzclaw et al., 2002). Higher income is generally associated with a higher probability of vehicle ownership (Pucher and Renne, 2003). Trips involving children and their caregivers travelling together tend to involve trip-chains that may be too complex to accommodate by transit, such as dropping off the child(ren) to a daycare facility prior to going to the place of employment (Turner and Grieco, 2000; Jang, 2003; McGuckin et al., 2005; Lee and McNally, 2006). Due to the higher densities in a typical CBD of a major city, public transit service is usually more readily available and accessible in the CBD compared to its suburban counterparts, (Charney, 2005; Alshalalfah and Shalaby, 2007).

As per other researchers involved in MAUP research (Batty and Sikdar, 1982; Khatib et al., 2001), fit and significance of each model was explored through explanatory variables such as r^2 and adjusted r^2 (where a higher value represents a better fit), dependent and independent variables coefficients, and the student t-test (where the variable is significant when $t \leq -1.65$ or ≥ 1.65).

3.1 Testing for Scale Effect in a Mode Split Model

To establish the presence of scale effect, two predetermined census zone formats were used to contain the census data: census tracts (CTs) – the larger, more aggregate agglomerations containing 939 zones (see **Figure 1**); and dissemination areas (DAs) – smaller disaggregate agglomerations containing 5,996 zones (see **Figure 2**). A census tract is defined by Statistics Canada as a small geographical unit containing a population of 2,500-8,000 and located in an urban centre with a population of at least 50,000 (Statistics Canada [2], 2009), a smaller unit with a population of 400-700 is referred to as a dissemination area (Statistics Canada [3], 2009).

The goodness of fit tests from initial binary logit models in both the CT and DA structures can be found in **Figure 3**. As demonstrated by the output values of r^2 and adjusted r^2, by running the model with all of the variables at once, the fit of the models between the dependent and independent variables was quite good.

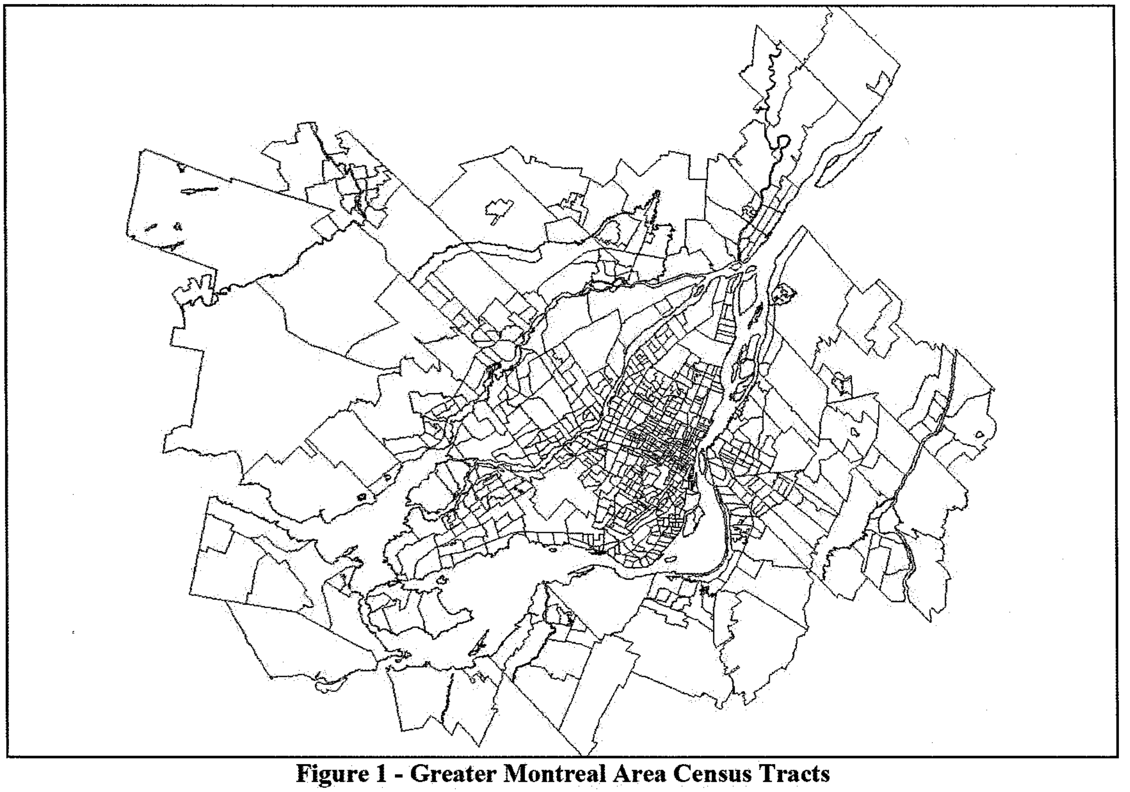

Figure 1 - Greater Montreal Area Census Tracts

Figure 2 - Greater Montreal Area Dissemination Areas

Census Tract		Dissemination Area	
r^2	Adjusted r^2	r^2	Adjusted r^2
0.951	0.950	0.899	0.898

Figure 3 - Goodness of Fit Tests in Preliminary Model

The coefficients as shown in **Figure 4** reinforced the expectation that population density and renting population would have a positive impact on transit ridership while average income and distance away from the CBD would have the opposite impact. It was surprising to see that larger households and households with children had a positive impact on transit trips, although a further review of the literature led to a study that reported similar findings (see Kim and Kim, 2004). However, almost all of the variables used in the logit model for the CT structure were insignificant as demonstrated by the t-tests, while the DA structure also had many insignificant variables.

	Census Tract		Dissemination Area	
	Coefficient	**t-test**	**Coefficient**	**t-test**
CONSTANT	-1.226	-1.027	-0.573	***-1.767***
pop_dens	0.095	0.474	0.000	-0.063
rent_%	0.848	1.084	0.631	***3.517***
Hshld_size	0.073	0.142	0.094	0.831
Hshld_child	0.980	0.619	0.419	1.388
inc15+avg	-0.131	-1.232	-0.159	***-4.467***
dist_CBD	-0.073	***-4.419***	-0.080	***-14.079***

Figure 4 - Coefficients and t-tests for Preliminary Model

From the MAUP perspective, **Figure 3** and **Figure 4** show that scale effect existed between the two census agglomeration structures. The goodness of fit differed between the two scales, as demonstrated by the respective r^2 values. There were also more insignificant variables in the CT structure compared to those in DA format, as demonstrated by the student-t tests. In order to analyze the impact of the two spatial structures on the dependent and independent variables in more detail, a correlation matrix for the CT structure (**Figure 5**) and DA structure (**Figure 6**) was created and reviewed. Significant observations included the fact that transit mode split was heavily correlated with population density and household size in the CT structure, but not in the DA structure. Similar observations were found between population density and household size, between population density and distance from the CBD, and between household size and distance from the CBD. This is a further demonstration of the scale effect, as there is more correlation in the more aggregate structure than the disaggregate structure.

	transit_MS	**pop_dens**	**rent_%**	**hshld_size**	**hshld_child**	**inc15+avg**	**dist_CBD**
transit_MS	1.000	***0.697***	***0.779***	-0.586	-0.188	-0.346	-0.776
pop_dens	***0.697***	1.000	***0.707***	-0.548	-0.232	-0.281	-0.587
rent_%	***0.779***	***0.707***	1.000	***-0.820***	-0.377	-0.449	-0.636
Hshld_size	-0.586	-0.548	***-0.820***	1.000	***0.747***	0.253	***0.550***
hshld_child	-0.188	-0.232	-0.377	***0.747***	1.000	-0.086	0.291
inc15+avg	-0.346	-0.281	-0.449	0.253	-0.086	1.000	0.066
dist_CBD	-0.776	-0.587	-0.636	***0.550***	0.291	0.066	1.000

Figure 5 - Correlation Matrix of Variables in CT Format

	transit_MS	pop_dens	rent_%	hshld_size	hshld_child	inc15+avg	dist_CBD
transit_MS	1.000	0.078	*0.616*	-0.421	-0.065	-0.322	-0.685
pop_dens	0.078	1.000	0.124	-0.118	-0.083	-0.022	-0.082
rent_%	*0.616*	0.124	1.000	-0.725	-0.208	-0.453	-0.505
hshld_size	-0.421	-0.118	-0.725	1.000	*0.592*	0.268	0.412
hshld_child	-0.065	-0.083	-0.208	*0.592*	1.000	-0.027	0.157
inc15+avg	-0.322	-0.022	-0.453	0.268	-0.027	1.000	0.063
dist_CBD	-0.685	-0.082	-0.505	0.412	0.157	0.063	1.000

Figure 6 - Correlation Matrix of Variables in DA Format

A second analysis of the two census agglomeration structures was conducted by comparing the descriptive statistics means of the each of the variables used in the binary logit model. **Figure 7**, which only reveals the respective means from each census agglomeration structure, illustrates how different the output variables can be computed as a result of the different spatial scale.

	CT Mean	DA Mean
transit_MS	0.236	0.231
pop_dens	5410.810	13481.381
rent_%	0.482	0.451
hshld_size	2.391	2.475
hshld_child	0.628	0.639
inc15+avg	29393.591	28901.210
dist_CBD	14.567	14.848

Figure 7 – Descriptive Statistics in CT and DA Structure

Due to their similarities between census agglomeration structures, it was decided that the second set of logit models would feature transit mode split as the dependent variable, and distance from CBD, households with children and average income as the independent variables. While it was recognized that $500 worth in average income is a significant difference as an output statistic when dealing with a region with a population of approximately 3.5 million as of 2001, it was anticipated that this difference would not severely impact the modeling. With less correlation between variables, the previous hypothesis tests for any remaining variables applied.

As was found in the initial models, the fit between the dependent and independent variables was quite good, despite the different values of r^2 between the two scales (see **Figure 8**). Although fewer independent variables were used in this case, the output coefficients still forced a null hypothesis acceptance on the impact of households with children on transit trips, while all other outputs supported the hypothesis (see **Figure 9**). Aside from the constant, all variables were determined significant by the t-test in both structures, with the exception of households with children which was only found to be significant at the DA level. The level of significance also differed greatly between census agglomeration structures, as suggested by the t-tests.

Census Tract		Dissemination Area	
r^2	Adjusted r^2	r^2	Adjusted r^2
0.945	0.945	0.893	0.893

Figure 8 - Goodness of Fit Tests in Revised Model

	Census Tract		Dissemination Area	
	Coefficient	t-test	Coefficient	t-test
CONSTANT	0.146	0.232	0.286	1.622
hshld_child	0.731	0.798	0.456	***1.950***
inc15+avg	-0.241	***-2.733***	-0.233	***-7.427***
dist_CBD	-0.092	***-7.334***	-0.091	***-18.681***

Figure 9 - Coefficients and t-tests for Revised Model

3.2 Testing for Zonal Effect in a Mode Split Model

Due to the limited research available on this topic, an analysis of zonal effect was also carried out. This was done by creating two aggregate zone structures that avoided arbitrary delineation (such as the application of a grid structure) with improved population homogeneity distribution between zones. Based on the 2001 GMA census population of 3.42 million, 850 zones were aggregated from the DA level for both zone systems in order to comply with the average population distribution in the census tract form of 4,031. The expectation was that aggregation bias would remain the same, as would be supported by two unique spatial delineations, thus leading to the discovery of how different spatial delineations result in different statistical representation.

A regional portioning feature was used to create the two new zone structures. Horn (1995) describes the process of generating seed-zones randomly though the specified number of clusters per structure (in this case 850) with a uniform distribution across the land-mass of the analysis region (the GMA). This process also allowed the exclusion of water bodies, which would not contain population. The results of this process were two zone structures herein referred to as *Alternative Zone System 1* (**Figure 10**) and *Alternative Zone System 2* (see **Figure 11**).

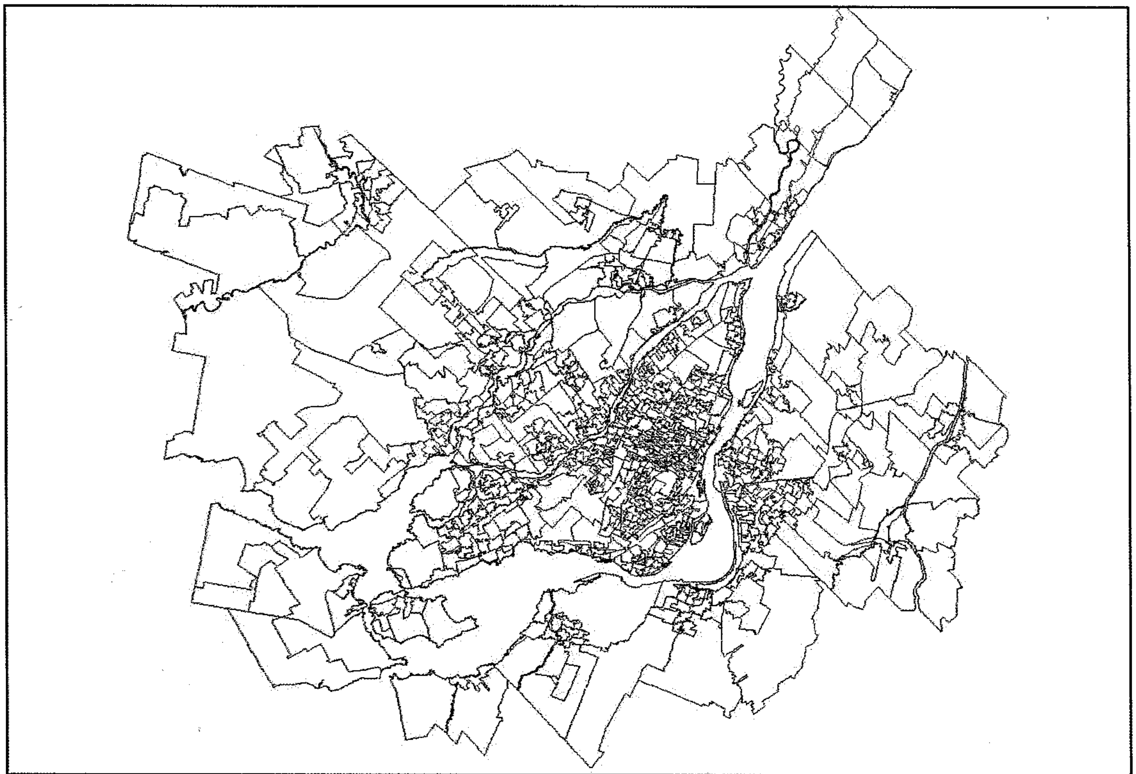

Figure 10 - Greater Montreal Area Alternative Zone System 1

Using the same dependent and independent variables with associated hypoproject tests from the revised scale effect models, a binary logit model was run in each of the two new zone structures. Many of the resulting outputs were similar to the revised model of the CT structure. As expected, the two new aggregate zone structures yielded higher goodness of fit results (see **Figure 12**), with a difference in r^2 value between the two zone structures by 0.01.

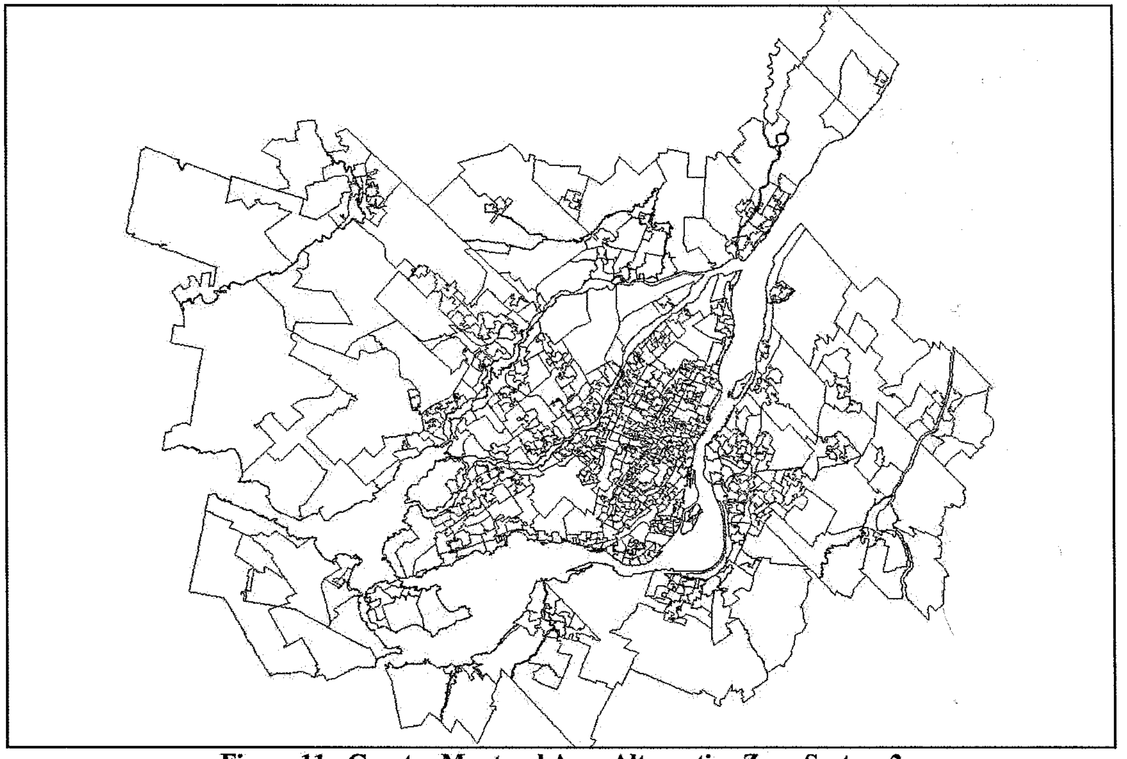

Figure 11 - Greater Montreal Area Alternative Zone System 2

Structure 1		Structure 2	
r^2	Adjusted r^2	r^2	Adjusted r^2
0.955	0.955	0.954	0.954

Figure 12 - Goodness of Fit Tests of New Zone Structures

The output model supported the hypothesis that all independent variables (except for households with children) impact transit trip production. Both zone structures yielded significant student-t tests for the independent variables of average income and distance to CBD only, as was the case for the revised CT model (see **Figure 9**). Minor differences in coefficient values and student-t outputs resulted for all variables in both models (see **Figure 13**). Like in the scale effect analysis, the coefficients as well as the student t-tests for the constant were also diverse among the two zone structures.

	Structure 1		Structure 2	
	Coefficient	t-Test	Coefficient	t-Test
CONSTANT	0.203	0.275	0.239	0.326
hshld_child	0.734	0.690	0.694	0.662
inc15+avg	-0.256	***-2.482***	-0.258	***-2.525***
dist_CBD	-0.093	***-6.957***	-0.093	***-6.970***

Figure 13 - Coefficients and t-Tests of New Zone Structures

3.3 Summary

This section revealed the results of MAUP-related analysis that determined the presence of scale effect and zonal effect between two zonal structures in a stage of the travel demand forecasting process that is rarely covered in the literature. In the case of scale effect, the more aggregate the scale, the better the fit of the model, as has been previously demonstrated by Batty and Sikdar (1982). However, aggregate structures tend to yield less significant and therefore less accurate independent variable coefficients compared to disaggregate scales (Ding, 1994; Ding, 1998; Horner and Murray, 2002; Binetti and Ciani, 2002).

4.0 Project Methodology

For this project, a comparison of traffic assignment outputs was conducted between two TAZ systems – an aggregate model developed for analysis purposes in a previous study (Spurr, 2005), and a disaggregate model currently in use for a local jurisdiction. The goal of this comparison was to reinforce previous findings from other MAUP-related studies on traffic assignment:

1. That traffic assignment outputs change between TAZ-level aggregations;
2. That the number of intrazonal trips reduces in an disaggregate TAZ system; and
3. That disaggregate TAZ systems yield more statistically significant results that those of aggregate TAZ systems.

None of the authors cited in the literature review describe which form equilibrium assignment is used in their traffic assignment model (Crevo, 1991; Ding, 1994; Ding, 1998; Khatib et al., 2001; Chang et al., 2002), except for Binetti and Ciani (2002) who performed a SUE assignment model. It is safe to assume that "equilibrium assignment" is a looser term representing User Equilibrium (UE) assignment, and is thus the popular choice algorithm for use in a traffic assignment exercise. However, it is important to distinguish between the two forms of equilibrium traffic assignments.

UE assignment achieves convergence through a series of iterations, and adopts Wardrop's first principle that one cannot save time by using an alternate route, assuming that there is perfect knowledge of the traffic network (Caliper Corporation, 2005). SUE assignment, on the other hand assumes imperfect knowledge by the travellers of the attributes of the traffic networks, and that they may have a different perceptions of travel costs, and has the ability to produce more accurate results since it has the ability to assign limited flow on less attractive routes, unlike UE assignment which assigns zero flow on such links (Caliper Corporation, 2005).

4.0.1 The Study Area

The study area chosen for this research is the Greater Montreal Area (GMA). Located in the southwest part of the Province of Quebec, the GMA serves as an opportune area to research based on its physical and census geography – an area consisting of two large islands and many small islands, as well as a population of 3.6 million as of the 2006 census (Statistics Canada, 2009 [1]). A thorough review of the literature suggested that the use of such geography for a MAUP-related analysis has not previously been used, as previous studies generally used a single-island or mainland region without a series of water bodies dividing the census geography.

4.0.2 The Network

Much of the work on the traffic network used for this study came from Spurr (2005), who conducted an analysis of performing traffic assignment in a traffic network created in GIS. Using a street network file developed by DMTI Spatial Ltd., as well as a skeletal EMME/2 network provided by the Ministère des transports de Québec (MTQ) for cross-comparison where appropriate, a total of 133,998 one- or two-way links were coded in TransCAD, the GIS software with a travel demand forecasting interface.

A series of specifications based on observations of true characteristics and patterns in the field, such as lane configuration, posted travel speed or turn bans (particularly for u-turns), were used to allow the network to represent true capacity and other existing conditions (or network segment costs) on the real traffic network as much as possible, contrary to a typical skeleton network featuring only freeways and major arterial roads. For modelling purposes, the links were all coded to Bureau of Public Roads (BPR) volume-delay function standards, meaning that the corresponding values of alpha (α) and beta (β) parameters were 0.6 and 2 respectively. Routes not associated with the traffic network, such as pedestrian and bicycle trails, as well as ferry routes, were specially coded so as not to be included when running the shortest-path algorithm. Two centroid connectors per zone were delineated and specially designed to not connect with inappropriate links, such as freeways and freeway ramps, or any of the links previously mentioned that were to be discarded from the shortest path analysis, and were further refined after the connection to the network to ensure logical delineation.

4.0.3 The Origin-Destination Matrices

Three origin-destination matrices were created from the origin-destination survey data provided by the AMT – the regional transportation authority for the GMA. Each of the three matrices was created to reflect the three hours within the morning peak-period – 6:00-6:59 AM, 7:00-7:59 AM, and 8:00-8:59 AM.

4.1.0 Zone System 1 - Spurr

Spurr (2005) created a zonal system using the census metropolitan area (CMA) census geographies of Montreal, Saint-Jean-Iberville and Salaberry-de-Valleyfield for 1996 using the four principle zone delineation criteria based on rules established by Bennion and O'Neill (1994), Ortuzar and Willumson (1994) and Caliper Corporation (2005). The application of the first criterion explains the addition of the two non-Montreal CMAs to the study area. These were included due to an abundance of trips originating and destined outside of the Montreal CMA as per the origin-destination survey provided by the Agence Métropolitaine de Transport (AMT), the local regional transportation authority. This process resulted in the creation of 873 zones.

Spurr (2005) expressed problems with the original TAZ delineation with regards to the number of trip attractions. 8,935 was the mean number of trip attractions per zone yielded under the 873 zone configuration, with a standard deviation of 7,039 trip attractions. Meanwhile, one zone yielded 55,718 trip attractions, which was recorded as being greater than six standard deviations from the average, yielding problematic issues for a traffic assignment representing real conditions. With the TAZ representative of the Central Business District (CBD) containing an area of 0.82 square kilometers due to the lack of residential distribution, causing all CBD bound trips to be attracted to a single centroid. This was also problematic for zones with major shopping malls, office towers and other large institutions such as universities and colleges. Spurr (2005) thus applied a clustering method to account for these problems. By converting the x-y coordinates of the trip destinations into a point file, these trip destinations could be clustered into groupings based on their spatial distribution, and new zones were created based on the user-specification of 939 zones.

4.1.1 Traffic Assignment 1 - Spurr

Using the User-Equilibrium traffic assignment algorithm, specifying a 1% convergence criterion, three traffic assignments were run based on the three peak periods. As Spurr (2005) notes, the peak hour with the lowest demand did not require the least number of iterations to converge compared to the peak hour with higher interzonal demand, which suggests the impact of intrazonal trips. The maximum number of iterations required for convergence was 12 (see **Figure 14**).

OD DEMAND	600-659	700-759	800-859
OD Pairs	962361	962361	962361
Non zero OD Pairs	36427	45214	43515
Demand	193559.5	378600.1	352773
Intranodal Demand	14997.57	33307.3	40085.82
PARAMETERS	**600-659**	**700-759**	**800-859**
Iterations	8	12	5
RUNNING RESULTS	**600-659**	**700-759**	**800-859**
Relative Gap	0.01	0.01	0.01
Max Flow Change	830.99	583.83	680.24
Equilibrium reached	Yes	Yes	Yes
Total V-Time-T	4007418	6925071	4432141
Total V-Dist-T	3762435	5733014	4226269

Figure 14 - Summary of TransCAD Output for the 3 Traffic Assignment Models (Source: Spurr, 2005)

To validate the output from the traffic assignment model, Spurr (2005) used field observations provided by the MTQ for 197 observation points. The field flows were cross-referenced against the output flows from the traffic assignments using the following equation:

$$\%RMSE_n = \frac{\sum_j \frac{(x_j - y_j)^2}{\sqrt{n-1}}}{\frac{\sum_j y_j}{n}} * 100$$

where:

x_j = the forecast flow at j

y_j = the observed flow at j

n = the number of observations

For optimal performance of this equation, the resulting output should less than 30 according to the U.S. Department of Transportation (Transportation Model Improvement Program, 2001, in Spurr, 2005). In addition, the correlation between the field flows and the forecasted flows was measured using a linear regression model, where an overall output r^2 of 0.88 was recommended by the U.S. Department of Transportation (Transportation Model Improvement Program, 2001, in Spurr, 2005). The results of this exercise are shown in **Figure 14, Figure 15** and **Figure 16**.

Hour	R^2	*%RMSE*	*% Error*	Bridge Links Within Target Range*	Autoroute Links Within Target Range**
0600-0700	0.8788	37.79538	-14.5924	2	27
0700-0800	0.8536	37.85626	5.879487	6	30
0800-0900	0.8414	41.14094	-4.39898	7	27
AM Peak (all 3 hours)	0.8891	31.6287	-3.33842	8	29

* = out of 42 bridge links
** = out of 66 Autoroute links

Figure 15 - Performance of AM Peak Hour Models Including Fitted Points (Source: Spurr, 2005)

Trial	R^2	*%RMSE*	*% Error*	Bridge Links Within Target Range*	Autoroute Links Within Target Range**
0600-0659					
1	0.8178	49.45086	-13.3378	3	
2	0.8187	49.56457	-13.3948	3	
3	0.8239	49.09624	-13.4738	5	14
4	0.8094	52.07972	-13.5019	6	9
5	0.8724	40.03511	-6.16172	6	21
6	0.8728	38.5982	-8.76252	2	19
7	0.8719	44.67398	-10.9542	3	27
8	0.8753	37.85573	-9.28506	4	24
9	0.8751	37.87904	-11.425	4	25
10	0.8755	38.52175	-11.1218	5	24
11	0.871	38.82136	-13.6829	4	25
12	0.8788	37.79538	-14.5924	2	27
0700-0759					
7	0.822	49.65747	16.38989	4	25
10	0.8443	43.18217	9.815516	4	23
11	0.855	38.8192	7.193456	6	25
12	0.8536	37.85626	5.879487	6	30
0800-0859					
7	0.8241	46.9167	4.79822	6	25
10	0.8323	38.70149	-2.27728	9	27
11	0.8313	43.25576	-3.24569	8	27
12	0.8414	41.14094	-4.39898	7	27
AMPeak					
7	0.8689	38.22392	5.262295	5	25
10	0.8813	35.2268	1.391054	13	23
11	0.8855	32.79659	-2.19849	11	28
12	0.8891	31.6287	-3.33842	8	29

Figure 16 - Changes in Model Performance Over Successive Trials (Source: Spurr, 2005)

4.2.0 Zone System 2 - MTQ

A dissagregate TAZ system provided by the MTQ was used to as the comparison TAZ system to that of Spurr. The MTQ system contained 1,496 zones, of which the majority of the smaller zones located on the Island of Montreal, and on the fringes of the shoreline suburbs off the coast of the Island of Montreal.

4.2.1 Traffic Assignment 2 - Nix

A UE assignment was performed twice per peak hour to check for the different outputs between equilibrium assignments – one using the default alpha and beta parameters provided in TransCAD of 0.15 and 4 respectively, and the other using the alpha and beta parameters of 0.6 and 2 respectively as defined by Spurr (2005). As in both Spurr (2005) and in Ding (1994 and 1998), a convergence criterion of 1% was applied, with a maximum of 25 iterations.

For this exercise, the traffic assignment results provided by Spurr (2005) were compared with results from a different zone system of 1,496 zones provided by the MTQ using the same traffic demand and street file. Since similar problems with the automated centroid connector feature arose as outlined in Spurr (2005), each zone was reviewed to ensure that the centroid connectors did not cross zonal boundaries, or did not connect an island centroid to a mainland street.

In the case of centroid connectors crossing zonal boundaries, 32 zonal centroid connectors were modified to maintain them within their respective zone, ensuring that they did not connect to endpoints that were also connected to freeways, pedestrian-only paths, transit-only corridors, ferry routes, ferry ramps and highway ramps. In addition, modifications were made in larger suburban zones using enhanced point of interest (EPOI) file provided by DMTI Spatial Inc., in order to allow for major trip generators such as large shopping malls, hospitals and post secondary institutions to serve as the appropriate centroid for the zone where activity was not so diverse, such as the CBD. To summarize, any EPOI representing a large hospital, a *collège d'enseignement général et professionnel* (College of General and Vocational Education – **CEGEP**), a university, or a department store such as Holt Renfrew, La Baie, Les Ailes de la Mode, Sears, Simons, Wal-Mart or Zellers was considered the major trip generator in most zones. In a unique case where a combination of these establishments existed in the same zone, the retail store would be considered the more valid major trip generator of the zone since the traffic assignment outputs were exclusively for auto-oriented traffic, followed by a post-secondary institution. In certain cases, the author's previous knowledge of the area would override the EPOI data (for example: in Sallabery-de-Valleyfield, there was no EPOI data for a

Wal-Mart on Boulevard Monseigneur Langlois). In total, 52 zones' centroid connectors were relocated to reflect true traffic conditions.

4.3.0 Traffic Assignment Results Comparison

A quick comparison of the various outputs between simulations can reveal the impact of the MAUP in the Montreal traffic assignment. Compared to the model performed by Spurr (2005), the traffic assignments required more iterations to converge (see **Figure 17**, **Figure 18** and **Figure 19**), however the maximum flow change in all simulations with the MTQ zone system was lower than that of Spurr (2005).

	Alpha = 0.15, Beta = 4		Alpha = 0.6, Beta = 2		
OD DEMAND	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto**	**Nix-Adj2**
OD Pairs	2238016	2238016	962361	2238016	2238016
Non zero OD Pairs	7639	7639	36427	7639	7639
Demand	181983.06	181983.06	193559.47	181983.06	181983.06
Intranodal Demand	19529.99	19529.99	14997.57	19529.99	19529.99
% Intranodal	10.73%	10.73%	7.75%	10.73%	10.73%
Trip Speed (km/h)	43.595829	43.5959301	56.33	43.6086657	43.6086644
Trip Length (km)	20.198604	20.1983704	21.07	20.3244656	20.3244864
Trip Time (min)	17.14444	17.144393	22.44	17.2347612	17.2347638

PARAMETERS	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto**	**Nix-Adj2**
Iterations	14	12	9	14	12

Running Results	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto**	**Nix-Adj2**
Relative Gap	0.01	0.01	0.01	0.01	0.01
RMSE	8.31	10.24	13.65	8.32	10.24
% RMSE	13.57	16.81	21.29	13.59	16.81
Max Flow Change	270.22	394.51	830.99	272.31	394.51
Equilibrium reached	Yes	Yes	Yes	Yes	Yes
Total V-Time-T	58695.73	60463.75	4007417.57	58696.1	60464.04
Total V-Dist-T	3320398.7	3374740.35	3762434.89	3320463.54	3374740.51

Figure 17 - Traffic Assignment Outputs - 0600-0659

	Alpha = 0.15, Beta = 4		Alpha = 0.6, Beta = 2		
OD DEMAND	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto2**	**Nix-Adj2**
OD Pairs	2238016	2238016	962361	2238016	2238016
Non zero OD Pairs	14167	13739	45214	14167	13739
Demand	370964.42	361345.91	378600.05	370964.42	361345.91
Intranodal Demand	44090.2	44019.63	33307.3	44090.2	44019.63
% Intranodal	11.89%	12.18%	8.80%	11.89%	12.18%
Trip Speed (km/h)	42.96837582	42.96838806	49.67	43.08957231	43.08957231
Trip Length (km)	31.77708656	31.77707977	16.6	30.52780085	30.52780085
Trip Time (min)	17.34810695	17.34810513	20.06	17.38963709	17.38963709

PARAMETERS	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto2**	**Nix-Adj2**
Iterations	20	18	13	20	18

Running Results	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto2**	**Nix-Adj2**
Relative Gap	0.01	0.01	0.01	0.01	0.01
RMSE	9.97	10.1	13.31	9.96	10.1
% RMSE	9.21	9.99	12.49	9.2	9.99
Max Flow Change	321.62	310.47	583.83	321.52	310.49
Equilibrium reached	No	Yes	Yes	No	Yes
Total V-Time-T	110101.59	102545.31	6925070.75	110101.67	102545.89
Total V-Dist-T	5373416.04	5199125.97	5733013.81	5373406.44	5199125.99

Figure 18 - Traffic Assignment Outputs - 0700-759

	Alpha = 0.15, Beta = 4		Alpha = 0.6, Beta = 2		
OD DEMAND	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto2**	**Nix-Adj2**
OD Pairs	2238016	2238016	962361	2238016	2238016
Non zero OD Pairs	12466	12466	43515	12466	12466
Demand	342087.98	342087.98	352772.96	342087.98	342087.98
Intranodal Demand	50173.53	50173.53	40085.82	50173.53	50173.53
% Intranodal	14.67%	14.67%	11.36%	14.67%	14.67%
Trip Speed (km/h)	43.4519032	43.451901	57.21	43.47231	43.4723113
Trip Length (km)	22.1859111	22.185911	13.52	22.227695	22.227695
Trip Time (min)	17.163379	17.16338	14.17	17.248816	17.2488139

PARAMETERS	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto2**	**Nix-Adj2**
Iterations	8	8	6	8	8

Running Results	**Nix-Auto**	**Nix-Adj**	**Spurr**	**Nix-Auto2**	**Nix-Adj2**
Relative Gap	0.01	0.01	0.01	0.01	0.01
RMSE	10.62	12.27	15.78	10.62	12.27
% RMSE	13.94	16.23	19.77	13.94	16.23
Max Flow Change	414.01	470.62	680.24	414.01	470.61
Equilibrium reached	Yes	Yes	Yes	Yes	Yes
Total V-Time-T	65528.48	66953.58	4432140.69	65528.53	66953.8
Total V-Dist-T	3697994.68	3775048.2	4226269.4	3697994.7	3775048.22

Figure 19 - Traffic Assignment Outputs - 0800-0859

The intrazonal demand was also approximately 3% higher in each of the disaggregate models compared to Spurr's model. Other noticeable differences in values were trip speeds and trip time in minutes, while trip lengths showed marginal differences. This contradicted the hypothesis, as supported by Ding (1998), Khatib et al. (2001) and Chang et al. (2002), particularly with respect to the intrazonal demand. Although differences occurred between TAZ outputs, they yielded opposite results than what was predicted.

A key assumption that can be made regarding the results from these simulations is the detailed delineation difference between TAZ systems. Since the boundaries of the aggregate zones are not necessarily pure amalgamations of the smaller zones found in the MTQ TAZ system, intrazonal demand can increase from the aggregate TAZ system to the disaggregate system purely based upon the location of the geocoded trips used in the model. For example, it was found that the Sallabery-de-Valleyfield zone was delineated differently in the MTQ system than that of Spurr (2005) - Spurr's TAZ system had this region delineated as three zones. A series of follow-up simulations were performed to investigate a possible modelling error. As the results in the follow-up simulations were the same, a thorough investigation of the origin-destination matrices was conducted. It was found that demand was inflated in the Sallabery-de-Valleyfield zone, which may have led to the overall increase in trip parameters in the disaggregate zone system. However, time did not permit to rectify the problem, as it was unknown how to do so in a timely manner.

4.3.1 Model Performance by Link

As was done by Spurr (2005), a comparison of model forecasts to actual flows recorded in the field was conducted based on available count-station data from the MTQ. Since Spurr (2005) only provided detail for the 21 bridges, the freeways were not included in this analysis so as to conduct a comparative analysis for model performance between the aggregate and disaggregate models.

Figure 20 shows the results of the network performance analysis for the 6:00-6:59 peak hour. The first peak hour yielded an approximate 7 percent over-forecast for one-directional flow inbound to Montreal, and an approximate 35% under-forecast in outbound flows from the island, both of which are higher than the results reported in Spurr (2005). The number of bridge links that fell within the acceptable target forecast range was found to be the same in both models. One noticeable change between models was the regional forecasts, where close-to-accurate forecasting reduced for inbound flows and increased for outbound flows in the MTQ model.

The results of the network performance analysis for the 7:00-7:59 peak hour can be found in **Figure 21**. As was found in Spurr (2005), the network performance changed significantly – in this case to an approximate 7% under-forecast for inbound flows and an approximate The first peak hour yielded an approximate 3 percent over-forecast for one-directional flow inbound to Montreal, and an approximate 20% under-forecast in outbound flows from the island. These results are also quite different from the results of Spurr (2005), who reported over-forecasts for both directions. The number of regional forecasts falling within the acceptable target range was

Bridge	0600-0659							
	Forecasts		Counts		Errors (%)		Convergence	
	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound
Champlain	5536	783	5072	2335	9.15	-66.45	0	0
Victoria	1743	53	1623	1538	7.38	-96.58	0	0
Jacques Cartier	7196	1653	7761	1587	-7.27	4.18	0	1
Mercier	4699	692	3971	1488	18.34	-53.48	0	0
Lafontaine Tunnel	4263	1784	5257	3233	-18.91	-44.81	0	0
Galipeault	2679	234	3122	473	-14.18	-50.63	0	0
Ile aux Tourtes	2080	339	1810	440	14.87	-23.06	0	0
Louis-Bisson	6991	826	6528	1577	7.10	-47.62	0	0
Lachapelle	2920	179	4077	339	-28.38	-47.21	0	0
Mederic-Martin	5952	1447	5835	2231	2.00	-35.14	1	0
Viau	2055	138	2559	382	-19.68	-63.77	0	0
Papineau-Leblanc	4567	628	4031	2025	13.30	-68.98	0	0
PieIX	4284	1365	5080	1688	-15.67	-19.16	0	0
Charles-de-Gaulle	461	5857	1338	4509	-65.55	29.90	0	0
Le Gardeur	1771	52	3105	249	-42.97	-79.04	0	0
Arthur Sauvé	1343	265	1266	275	6.07	-3.65	0	1
Vachon	4474	1052	4593	1233	-2.60	-14.65	1	0
Gédéon-Ouimet	4899	1110	5941	2112	-17.54	-47.44	0	0
Marius Dufresne	1195	170	1473	222	-18.85	-23.39	0	0
David	960	211	1198	320	-19.83	-33.96	0	0
Mathieu	4006	369	3790	1059	5.70	-65.13	0	0
TOTALS	74075	19208	79430	29315	-6.74	-34.48	2	2

Regional Aggregations								
Fleuve St-Laurent	23438	4966	23684	10181	-1.04	-51.22	0	1
West Island	4759	572	4932	913	-3.52	-37.35	0	0
Riviere-des-Prairies	26769	4583	28110	8242	-4.77	-44.40	1	0
East Island	2232	5909	4443	4758	-49.77	24.19	0	0
Riviere-des-Mille-Iles	16878	3178	18261	5221	-7.58	-39.13	1	1
TOTALS	74075	19208	79430	29315	-6.74	-34.48	2	2

Figure 20 - Bridge Performance for the First Hour of the AM peak (0600-0659)

Bridge	0700-0759							
	Forecasts		Counts		Errors (%)		Convergence	
	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound
Champlain	5811	1664	4305	3027	34.99	-45.04	0	0
Victoria	2174	464	1538	1468	41.37	-68.41	0	0
Jacques Cartier	8377	3302	7838	2442	6.87	35.21	0	0
Mercier	4313	1211	3732	1486	15.58	-18.53	0	0
Lafontaine Tunnel	4507	3191	10198	6614	-55.80	-51.75	0	0
Galipeault	3170	658	3020	718	4.96	-8.34	1	0
Ile aux Tourtes	2980	523	3967	939	-24.88	-44.28	0	0
Louis-Bisson	6869	1753	6631	2226	3.58	-21.23	1	0
Lachapelle	4042	707	3046	787	32.71	-10.17	0	0
Mederic-Martin	6507	2980	6809	3258	-4.43	-8.54	1	0
Viau	3341	613	2510	709	33.12	-13.50	0	0
Papineau-Leblanc	5721	1380	3070	1262	86.35	9.32	0	0
PielX	5287	2524	4993	2252	5.89	12.08	0	0
Charles-de-Gaulle	5859	971	4654	1518	25.89	-36.04	0	0
Le Gardeur	1773	119	1558	373	13.82	-67.99	0	0
Arthur Sauvé	1059	586	1069	468	-0.93	25.14	1	0
Vachon	4131	1921	3538	1629	16.77	17.94	0	0
Gédéon-Ouimet	4993	2554	5639	2863	-11.46	-10.78	0	0
Marius Dufresne	1445	617	1256	361	15.06	71.00	0	0
David	1049	256	880	439	19.25	-41.79	0	0
Mathieu	4087	1224	4231	1821	-3.39	-32.80	1	0
TOTALS	87497	29218	84482	36660	3.57	-20.30	5	0

Regional Aggregations								
Fleuve St-Laurent	25183	9831	27611	15037	-8.80	-34.62	0	0
West Island	6150	1181	6987	1657	-11.98	-28.71	1	0
Riviere-des-Prairies	31768	9957	27059	10494	17.40	-5.12	2	0
East Island	7632	1090	6212	1891	22.86	-42.34	0	0
Riviere-des-Mille-Iles	16765	7158	16613	7581	0.92	-5.58	2	0
TOTALS	87497	29218	84482	36660	3.57	-20.30	5	0

Figure 21 - Bridge performance for the second hour of the AM peak (0700-0759)

also different between the two models, with the MTQ model yielding five inbound flows within an acceptable range, and the Spurr model yielding four acceptable inbound forecasts and two acceptable outbound forecasts.

The 8:00-8:59 peak hour results can be found in **Figure 22**. Whereas the network performance in Spurr (2005) was near accurate for both inbound and outbound flows, the MTQ model under-forecasted flows in both directions by as much as 25% on average. However, the number of links that fell within the acceptable range was greater in the MTQ model – with eight links in the

Bridge	0800-0859							
	Forecasts		Counts		Errors (%)		Convergence	
	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound
Champlain	4394	1257	3572	2361	23.00	-46.74	0	0
Victoria	1253	175	1295	244	-3.22	-28.08	1	0
Jacques Cartier	5380	2558	5610	1876	-4.09	36.34	1	0
Mercier	2539	1141	2711	1202	-6.36	-5.11	0	0
Lafontaine Tunnel	2580	2220	7569	5230	-65.91	-57.54	0	0
Galipeault	2017	428	1562	726	29.15	-41.03	0	0
Ile aux Tourtes	1938	431	3545	1202	-45.33	-64.14	0	0
Louis-Bisson	4650	1578	4458	1924	4.30	-17.96	1	0
Lachapelle	1464	995	2058	1036	-28.88	-4.00	0	1
Mederic-Martin	4869	2601	5410	2752	-10.00	-5.48	0	0
Viau	1446	667	1438	589	0.58	13.31	1	0
Papineau-Leblanc	3164	1159	2430	911	30.20	27.22	0	0
PieIX	2574	1345	2946	1626	-12.63	-17.26	0	0
Charles-de-Gaulle	3369	604	3467	1335	-2.83	-54.74	1	0
Le Gardeur	310	180	540	290	-42.51	-37.91	0	0
Arthur Sauvé	585	301	610	463	-4.11	-35.08	1	0
Vachon	2392	1485	2947	1122	-18.84	32.38	0	0
Gédéon-Ouimet	3613	1489	4463	2080	-19.04	-28.41	0	0
Marius Dufresne	877	342	708	423	23.89	-19.18	0	0
David	578	124	595	341	-2.87	-63.61	1	0
Mathieu	2873	891	2767	1407	3.84	-36.67	1	0
TOTALS	52866	21973	60701	29140	-12.91	-24.59	8	1
Regional Aggregations								
Fleuve St-Laurent	16146	7352	20757	10913	-22.21	-32.63	2	0
West Island	3955	859	5107	1928	-22.55	-55.44	0	0
Riviere-des-Prairies	18166	8346	18740	8838	-3.06	-5.57	2	1
East Island	3679	784	4007	1625	-8.18	-51.74	1	0
Riviere-des-Mille-Iles	10918	4632	12090	5836	-9.69	-20.63	3	0
TOTALS	52866	21973	60701	29140	-12.91	-24.59	8	1

Figure 22 - Bridge performance for the third hour of the AM peak (0800-0859)

inbound direction and one link in the outbound direction, compared to the three inbound and four outbound links in the Spurr model. The MTQ model also yielded the same acceptable links in the same respective directions at the regional level, while the Spurr model yielded four acceptable inbound forecasts and three acceptable outbound forecasts.

Figure 23 presents the overall three-hour peak period network performance results. Overall, the MTQ model under-forecast flows in both directions – by approximately 5% in the inbound direction and by approximately 26% in the outbound direction, compared to the Spurr (2005)

Bridge	0600-0859							
	Forecasts		Counts		Errors (%)		Convergence	
	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound
Champlain	15741	3704	12949	7723	21.56	-52.03	0	0
Victoria	5170	692	4456	3250	16.03	-78.71	0	0
Jacques Cartier	20953	7513	21209	5905	-1.20	27.23	1	0
Mercier	11551	3043	10414	4176	10.92	-27.12	0	0
Lafontaine Tunnel	11350	7196	23024	15077	-50.70	-52.27	0	0
Galipeault	7866	1320	7704	1917	2.11	-31.16	1	0
Ile aux Tourtes	6998	1293	9322	2581	-24.94	-49.91	0	0
Louis-Bisson	18510	4158	17617	5727	5.07	-27.40	0	0
Lachapelle	8426	1881	9181	2162	-8.22	-13.02	0	0
Mederic-Martin	17328	7028	18054	8241	-4.02	-14.72	1	0
Viau	6843	1419	6507	1680	5.16	-15.53	0	0
Papineau-Leblanc	13452	3167	9531	4198	41.14	-24.57	0	0
PieIX	12145	5234	13019	5566	-6.71	-5.97	0	0
Charles-de-Gaulle	9689	7432	9459	7362	2.43	0.95	1	1
Le Gardeur	3855	352	5203	912	-25.92	-61.44	0	0
Arthur Sauvé	2987	1151	2945	1206	1.42	-4.55	1	1
Vachon	10997	4459	11078	3984	-0.73	11.92	1	0
Gédéon-Ouimet	13505	5154	16043	7055	-15.82	-26.95	0	0
Marius Dufresne	3518	1129	3437	1006	2.35	12.25	1	0
David	2588	591	2673	1100	-3.19	-46.28	1	0
Mathieu	10967	2484	10788	4287	1.66	-42.05	1	0
TOTALS	214438	70399	224613	95115	-4.53	-25.99	9	2

Regional Aggregations								
Fleuve St-Laurent	64767	22148	72052	36131	-10.11	-38.70	1	0
West Island	14864	2612	17026	4498	-12.70	-41.92	1	0
Riviere-des-Prairies	76703	22886	73909	27574	3.78	-17.00	1	0
East Island	13543	7784	14662	8274	-7.63	-5.93	1	1
Riviere-des-Mille-Iles	44561	14968	46964	18638	-5.12	-19.69	5	1
TOTALS	214438	70399	224613	95115	-4.53	-25.99	9	2

Figure 23 - Bridge performance for the Entire AM peak (0600-0859)

model which over-forecast inbound flows and under-forecast outbound flows by approximately 7% respectively. The number of acceptable forecasted link flows between models is quite comparable at the individual link level, with nine acceptable inbound link flows in the MTQ model and six acceptable inbound link flows in the Spurr model, with two acceptable outbound link flows in both models. However, at the regional level, the number of acceptable links in the MTQ model remains the same, while the number of acceptable inbound link flows in the Spurr model drops to only one.

As was found in Section 4.3.0, there were significant differences in outputs between the two models. This, unfortunately, may still be skewed by the modelling error found through the inflated demand in the western suburban region of the GMA. Nevertheless, there are reportable differences between the two sets of outputs, which support the general understanding of the MAUP.

4.3.2 Statistical Significance of Different Model Outputs by Link

As was done by Khatib et al. (2001), Chang et al. (2002), the impact of the MAUP in traffic assignment was further explored by investigating statistical significance of the model output differences – in this case through the application of a t-test. To perform this analysis, the mean values of one-way flows on the 21 bridges in the GMA were calculated for the Spurr model and the disaggregate model using the Spurr Alpha-Beta parameters with new centroid connectors, which was the selected as the most appropriate comparison model to that of Spurr given the similar parameters and centroid connectors.

The results in **Figure 24** shows that the average one-directional flows were higher in the aggregate Spurr model compared to the disaggregate model created in this study. In this case, the t-test suggested that the difference in output for average travel speed between the Spurr and disaggregate model for the three peak hours was significant. As was reported in previous sections, the significant difference may be skewed by the modeling error discussed in Section 4.3.0. However, based on the general understanding of the impact of the MAUP, these significant differences are noteworthy to report.

	600-659		700-759		800-859	
	F_Nix Flow	F_Spurr Flow	F_Nix Flow	F_Spurr Flow	F_Nix Flow	F_Nix Flow
Mean	2444	2221	3083	2779	2027	1782
Variance	4877774	4465173	4989223	4418804	2253782	1901339
Observations	42	42	42	42	42	42
Pearson Correlation	0.993		0.985		0.975	
Hypothesized Mean Difference	0		0		0	
df	41.000		41.000		41.000	
t Stat	5.230		4.955		4.637	
P(T<=t) one-tail	0.0000027		0.0000065		0.0000179	
t Critical one-tail	1.683		1.683		1.683	
P(T<=t) two-tail	0.0000053		0.0000130		0.0000358	
t Critical two-tail	2.020		2.020		2.020	

Figure 24 - Statistical Significance Testing for One-Directional Flows

4.4.0 Summary

The results in this study did not completely support the research hypotheses. While traffic assignment outputs between TAZ-level aggregations were noticeably different, as evidenced in the outputs for speed, v/c ratios and distance travelled, these outputs increased through TAZ disaggregation, rather than increased as has been previously found in the literature. The number of intrazonal trips increased in the disaggregate TAZ system rather than decreased. All of this was the result of a modelling error caused by inflated demand in the origin-destination matrix, which time did not allow for rectification.

There were significant differences found when one-directional flows were compared between the aggregate and disaggregate models. This was further supported by a t-test to suggest that there was a statistically significant difference in one-directional flows between the disaggregate MTQ TAZ system and that the aggregate Spurr TAZ system, despite the potential modelling error.

5 Conclusions

With the increasing attention on the MAUP in spatial analysis research, its impact on travel demand forecasts is equally important to understand, especially when attempting to develop the ideal TAZ structure for a transportation planning region, whether in a metropolitan region as was investigated in this study and many others, or a larger regional scale such as an island nation.

While the impact of scale effect was the primary focus of this research, limited research on the zonal effect was also highlighted in this study. This study reaffirmed previous findings on scale effect impact, while enhancing findings on zonal effect by using appropriate rules for TAZ delineation.

The results of this study contribute to the literature in various ways. Firstly, it thoroughly links the available literature on the MAUP and its impact on travel demand models. Secondly, it fills a major gap in the literature on zonal effect in travel demand models by introducing a more appropriate method of conducting such in the mode split stage by taking into account the rules of zone delineation. Finally, it introduces a test of the scale effect in a traffic assignment model in a Canadian jurisdiction – one with island regions and water bodies, creating a complex environment for traffic zones and their respective delineations.

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