A COMPARATIVE ANALYSIS OF TRAVEL SPEEDS BETWEEN SUBURBS AND THE DOWNTOWN CORE IN THE GREATER TORONTO AREA

by

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ABSTRACT

Traffic congestion is a major problem in urban areas and poses numerous environmental, economical, and health-related challenges. It is, therefore, important that congestion is understood, measured, and spatially identified. A large body of research on traffic congestion exists, with studies increasingly focusing on comparing congestion between suburbs and the downtown core. Suburbs are typically more dependent on automobiles. It is assumed that suburbs in the Greater Toronto Area (GTA) are getting more congested than the downtown core, though research to substantiate this assumption is not readily available. This paper attempts to fill the research gap by employing spatial analysis to compare average travel speeds between the GTA's suburbs and its downtown core. Interzonal automobile travel time and distance data are combined to estimate average speeds between GTA traffic analysis zones (TAZs). These speeds act as a proxy for traffic congestion, to determine whether suburban or downtown zones are more congested.

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TABLE OF CONTENTS

List of Tables vi
List of Figures vii
List of Appendices viii
1. Introduction 1
  Context 1
  Research Objectives 1
2. Research Context 3
  2.1 Defining Traffic Congestion 3
  2.2 Urban-Suburban Comparisons 4
  2.3 Existing Studies of Spatial Analysis of Traffic Congestion – City of Toronto 5
  2.4 Existing Studies of Spatial Analysis of Traffic Congestion – Other Cities 5
  2.5 Origin-Destination Matrices & Travel Times 6
3. Methodology 7
4. Data 8
  4.1. Data Collection 8
  4.2. Data Preparation 12
5. Analysis 13
  5.1. Point to Point Analysis 13
  5.2. Distance/Time Matrix Calculation 13
  5.3. Average Distance/Time Matrix Segmentation 14
  5.4. Average Speeds by TAZ Estimation & Data Visualization 15
6. Results & Interpretation 17
  6.1. Visualized Results of Average Origin Speed Estimations by Destination TAZ 17
  6.2. Discussion of Visualized Results 20
  6.3. Results of O-D Matrix Trip Type Segmentation 21
  6.4. Discussion of O-D Matrix Trip Type Segment Results 21
  6.5. Interpretation of Results 22
  6.6. Limitations 23
    6.6.1. Modifiable Areal Unit Problem 23
    6.6.2. Study Area Limitations 23
    6.6.3. Other Data Limitations 24
    6.6.4. Methodological Limitations 24
  6.7. Summary 25
7. Conclusion 26
Appendix A 27
Appendix B 28
Appendix C 29
References 30

LIST OF TABLES

Table 1 – Traffic Congestion Measures and their Definitions..3

Table 2 – TAZ Trip Type Segments..7

Table 3 – Traffic Analysis Zone Shapefile Municipalities and their Unique IDs 8

Table 4 – List of Datasets and their Sources...12

Table 5 – Sample Dataview of O-D Distance-Time Matrix Data 14

Table 6 – Sample Table of Summary Statistics for Dt-Dt Trip Type Segment............................15

Table 7 – Summary of O-D Matrix Metrics by Trip Type Segment 21

LIST OF FIGURES

Figure 1 – Study Area – Greater Toronto Area by Municipality..9

Figure 2 – Study Area – Greater Toronto Area with Highlighted Downtown TAZs....................11

Figure 3 – Average Speed to Destination TAZ Per GTA TAZ 17

Figure 4 – Average Downtown Speed to Destination TAZ in the GTA 18

Figure 5 – Average Suburban Speed to Destination TAZ in the GTA..19

Figure 6 – Average Toronto Suburban Speed to Destination TAZ in the GTA............................20

LIST OF APPENDICES

Appendix A – Study Area – Greater Toronto Area Traffic Analysis Zones (TAZs) 27

Appendix B – Study Area – Greater Toronto Area TAZ Centroids and Road Network with Close-Up View...28

Appendix C – TransCAD 8.0 Software Window as Used for Routing, Shortest Path Analysis, and Matrix Calculation 29

1. INTRODUCTION

1.1. Context

Road-based traffic congestion is generally increasing in metropolitan areas, which poses several challenges (Bull & Thomson, 2002). Higher congestion imposes costs due to increases in travel times and the need for resources to support additional traffic, as well as decrease in productivity due to delays. It also creates numerous environmental issues, such as increased air and noise pollution (Hatzopoulou & Miller, 2010; Bull & Thomson, 2002). Additionally, these impacts further affect the health of trip makers, and this does not even account for the stress that is experienced when driving in traffic (Bull & Thomson, 2002). There is no shortage of studies focused on traffic congestion and how it can be mitigated. Congestion has been defined and measured using a variety of methods (Bertini, 2005). However, the majority of related studies do not employ a network or spatial approach. This results in an absence of spatial and temporal analysis of congestion, which has impeded further opportunities for analysis, such as travel cost integration and travel time comparisons (Sweet et al, 2015; Yiannakoulias et al., 2013).

The "travel time" metric refers to the time it takes to travel from an origin to a destination. It is a fundamental measurement in transportation planning, design, operations, and evaluation (Wu et al., 2004). It has also been adopted as a critical measurement for any traveller, as the goal soon becomes to reduce one's travel time as much as possible. An assumption is made that the time spent travelling is essentially wasted. While this perspective has been challenged (Lyons & Urry, 2005), it solidifies the basis for why travel times continue to be used as a credible measurement of transportation efficiency, and by extension, traffic congestion (Calfee & Winston, 1998). It is also helpful that travel times can be easily integrated as data points in a spatial approach to map congestion patterns (Yiannakoulias et al., 2013, Stathopoulos & Karlaftis, 2001). Additionally, they can be combined with travel distances to estimate travel speeds, which have been shown to act as a reasonable proxy for traffic congestion (Allie, 2016; Salonen & Toivonen, 2013).

1.2. Research Objectives

A wide scan of research on traffic congestion revealed no existing research that specifically compares traffic congestion between suburban areas of the Greater Toronto Area (GTA) and its downtown core. Therefore, the spatial distribution of congestion in the GTA is not well understood beyond anecdotal accounts. Low density development is prevalent in suburban areas, which poses multiple problems associated with higher reliance on automobiles, leading to greater motorized traffic (Downs, 1988). In contrast, high density means that land is tightly packed, potentially leading to more friction during automobile traffic movement and slower speeds. Interestingly, promoting high density urban development is also viewed as a strategy for decreasing automobile usage and, by extension, emissions, though studies in recent decades both support and disprove this perspective (Hong et al., 2014). This suggests that congestion patterns should be examined at a local level. Therefore, the objective of this research is to explore the spatial heterogeneity in traffic congestion by means of a comparative analysis of travel speeds in the GTA. Comparisons will be made between suburban areas and the downtown core. These objectives are summarized in the following research questions:

1. Is the average travel speed faster for suburban trips than for downtown trips by automobile in the Greater Toronto Area?
2. Is the average travel speed for automobile trips originating from and destined to suburban zones faster than trips originating from and destined to the downtown core in the Greater Toronto Area?

This research hypothesizes that travel speeds will differ between suburban areas and the downtown core in the GTA.

2. RESEARCH CONTEXT

2.1. Defining Traffic Congestion

Traffic congestion has been identified as a major problem in urban areas, one example being the City of Toronto (Sweet et al., 2015a; Sweet et al., 2015b; Mekky, 2004). However, a singular definition of traffic congestion has not been universally agreed upon. In a critical review of primary literature related to measuring traffic congestion on roads, Aftabuzzaman (2007) identified thirteen different definitions of congestion. The definitions are categorized into three groups: i) demand capacity related, ii) delay-travel time related, and iii) cost related. They also, by extension, determine the chosen methods of measuring traffic congestion, which are equally as different. The review categorizes traffic congestion measures into four groups: i) basic measures, ii) ratio measures, iii) level of service, and iv) indices. It also provides a list of criteria to consider when selecting and evaluating a specific measure, and when it is appropriate to use within the research context. Using these criteria, Aftabuzzaman (2007) concludes that fifteen traffic congestion measures used in previous studies vary in their suitability, but notably fail to account for the congestion-relieving effects of public transport. This adds yet another dimension to the problem, and whether separate definitions should exist based on travel mode. A summary of these congestion measures is provided below in Table 1 (Aftabuzzaman, 2007; Lomax et al., 1997).

Table 1 – Traffic Congestion Measures and their Definitions

Measure Name	Definition	Units
Total delay	Sum of time lost due to congestion for a roadway	Vehicle hours
Congested travel	Amount of travel that occurs in congestion	Vehicle miles
Congested roadway	Summed extent of congestion on a roadway	Miles
Travel rate	Rate of motion for a roadway	Minutes/mile
Delay rate	Rate of time loss for vehicles operating in congestion conditions	Minutes/mile
Relative delay rate	Delay rate divided by acceptable travel rate	N/A
Level of service	Qualitative measure that categorizes traffic flow using measures like speed, density, etc.	N/A
Congestion index	Ratio of link delay (actual – acceptable travel time) to acceptable travel time	N/A
Travel rate index	Comparison of travel rates to freeflow conditions on a roadway	N/A
Roadway congestion index	Measure of daily vehicles-miles of travel (VMT) per lane-mile of roadways	Hours/mile
Congestion severity index	Measure of roadway delay per million VMT	Hours/mile
Corridor mobility index	Speed of person movement divided by a standard value (e.g. roadway occupancy rate)	N/A
Lane mile duration index	Measure of extent and duration of roadway congestion	Miles × hours

Consequently, the question of how studies should handle the multimodal nature of congestion needs to be asked. Congestion on networks for different traffic modes can be measured separately or together, and that decision could, again, be made based on the review's set of criteria, as well as the study's scope, area, and objectives.

A separate paper on road congestion using data from the Canadian Vehicle Use Study (CVUS) provides a definition of congestion, but also acknowledges that it has four dimensions: spatial, temporal, stochastic, and predictable (Allie, 2016). It then identifies four groups of measures as used by Weisbrod et al. (2001): time-related, volume, delay, and level of service. It was decided that six measures would be employed based on the available information from the CVUS dataset. In contrast to Aftabuzzaman's (2007) recommended process for determining the appropriate congestion measures, the selection process for this study was determined by the availability of interzonal travel time data.

Clearly, there is no standardized definition or measure of traffic congestion, nor is there a clear process of how those two pieces should be determined. Therefore, it becomes difficult to draw upon existing literature when conducting one's own congestion study, as any previous analysis, methodologies, and results are circumstantial. Ideally, an appropriate definition and set of measures are chosen using a process and with reference to previous studies, but it is likely that those will be determined more by the study's scope, as similarly stated before (Allie, 2016). The spatial nature of traffic congestion demands that an appropriate spatial approach be taken at the very least (Sweet et al., 2015) and combined with other methods if necessary.

2.2. Urban-Suburban Comparisons

Unlike in the GTA, the spatial distribution of traffic congestion has been studied in many cities (Bertini, 2005), and there is no consensus on where it definitively exists in cities. The discourse around its spatial nature is also varied. Depending on the measures and areal units used, it could be alluded that congestion is higher in the urban core than in the suburbs, or vice versa. Sweet et al. (2015) suggests that this current discourse mischaracterizes the geography of congestion and, depending on the metric that is used, either neighbourhood type could be more congested.

Another factor to consider is the urban form of the city that is being examined. The term "urban form" refers to the size, shape, and configuration of an urban area (Živković, 2019), and whether it has one central urban core (monocentric) or is comprised of multiple economic cores (polycentric). Urban form and its influence on congestion has also been studied (Chowdhury et al., 2013; Maat & Timmermans, 2009; Milakis et al., 2008), producing varying results and conclusions regarding the spatial distribution of congestion. Toronto has been described as a polycentric city, with numerous subcenters of jobs being identified beyond the central business district located in the City's downtown core (Sweet et al., 2017). It has also been described as a largely monocentric city surrounded by suburban growth in the past (Miller & Soberman, 2003), though recent development strategies in those suburbs have established what can be considered "downtown" cores (Die, 2015; Luqman, 2014).

2.3. Existing Studies of Spatial Analysis of Traffic Congestion – City of Toronto

Notable studies of traffic congestion in Toronto using a spatial approach do exist. However, they typically focus only on the City of Toronto and fail to account for the surrounding municipalities in the Greater Toronto Area (GTA). Additionally, they do not intentionally draw comparisons of traffic congestion between the GTA's downtown core and its suburbs. Nevertheless, a brief summary of existing research is provided.

Referring back to the report issued by Statistics Canada (Allie, 2016), a congestion index was constructed using 2014 data from the Canadian Vehicle Use Study (CVUS). The report linked congestion to the City of Toronto road network, concluding that the network in the urban core is one of the most congested in the city. Save for a graphical comparison of congestion by province, the report did not spatially examine congestion in Toronto, let alone draw comparisons between the city's urban core and suburbs.

Day et al. (2010) also studied congestion in the Greater Toronto Area (GTA) by sourcing an "EMME/2" traffic assignment model, which included origin-to-destination travel times for automobiles. The study used data from the Transportation Tomorrow Survey (TTS) to analyze work trip timing and travel mode preferences in the GTA. The study found that the automobile mode of travel is preferred over public transit modes when accessing suburban workplaces. In comparison, residents preferred accessing workplaces in the urban core using public transit modes (Day et al., 2010). Travel time data with origin-destination matrices were not collected as a part of the TTS, only trip start times and not even end times (Day et al., 2010). If necessary, travel times can be constructed or obtained from other sources. Unfortunately, this study does not measure or compare traffic congestion between the urban core and the city's suburbs.

Perhaps the most comprehensive body of research on traffic congestion trends in the City of Toronto exists in a study by Sweet et al. (2015). The study used numerous metrics to visualize traffic congestion intensity and its temporal and spatial patterns for three separate years (2011, 2013, and 2014). It measured congestion changes and drew comparisons between downtown and city-wide segments. However, the study opted to only use arterial roads and highways for congestion measurement and routing, which means that trends were not associated with specific areal units within the City (Sweet et al., 2015). Additionally, its analysis was specific to the City of Toronto, and did not consider data or trends from the neighbouring municipalities in the Greater Toronto Area.

2.4. Existing Studies of Spatial Analysis of Traffic Congestion – Other Cities

Beyond the City of Toronto, comparative studies of traffic congestion between a city's downtown core and its suburbs do exist, though are limited. The majority of studies focus on analyzing congestion in individual districts, therefore comparisons between different areas, let alone between downtown and suburban areas (Zhao & Hu, 2019). Nevertheless, notable studies are summarized below to highlight once again the circumstantial nature of traffic congestion research, along with its varied standardizations and definitions.

A study by Soltani & Allan (2006) examined the effects of four suburban residential neighbourhoods in Adelaide, Australia, on travel measures. While comparisons between these neighbourhoods and the urban core were not made, the study concluded that residents in denser neighbourhoods were less likely to use a private automobile as their travel mode due to concerns for congestion. Travelling by automobile was favoured more by residents who lived in neighbourhoods that were further away from Adelaide's urban core (Soltani & Allan, 2006).

Zhao & Hu (2019) found that new towns and job centres in the suburbs of Beijing exhibited higher congestion in relation to other areas. The study also found that congestion tended to decrease when moving from the urban core to the suburbs. This is one of the few studies that uses a spatial approach to examine and compare congestion in both the urban core and suburbs of a major city (Zhao & Hu, 2019).

Çolak et al. (2016) used a dimensionless traffic measure, named the demand to supply ratio, to understand congestion in five cities: Boston, USA; San Francisco Bay Area, USA; Lisbon, Portugal; Porto, Portugal; and Rio de Janeiro, Brazil. The demand to supply ratio was estimated as the total distance travelled by all vehicles to the upper bound of the total vehicle kilometres the road network can support per hour (Çolak et al, 2016). The study showed that higher population densities result in increasing traffic congestion. It was also observed that traffic congestion increased as the demand to supply ratio increased, leading to the conclusion that it is influenced by the spatial distribution and gradient of population density. However, while accounting for population densities, the study did not explicitly compare suburban areas with the urban cores of these cities. It acknowledges a gap in the research and the need for analysis of how travel times, and by extension, congestion, are spatially distributed with a city (Çolak et al, 2016).

The above-mentioned studies employ different methodologies and definitions in order to analyze traffic congestion, but clearly there is a gap in the research related to specific comparisons of congestion between urban and suburban areas of cities. Based on the literature, the question of which area type is more congested has not been frequently posed and answered using a spatial approach. Therefore, this provides an opportunity for this study to fill a gap in the research, especially for the GTA.

2.5. Origin-Destination Matrices & Travel Times

While traffic congestion studies are quite varied in their methodologies and approaches, the metrics, while also varied, are similar across multiple studies, especially when analyzing traffic congestion using travel patterns within a network (Allie, 2016). The spatial nature of travel patterns has been traditionally captured in transportation research using origin-destination (O-D) matrices (Yiannakoulias et al., 2013; Liu & Zhu, 2004; Wu et al., 2001; Yang et al., 1992). These matrices can be combined with other matrices to analyze congestion. Other matrices can old data in the form of locations, times, trip counts, distances, and travel times (Çolak et al., 2016; Louail et al., 2015). The measure of "travel time" refers to the time it takes to travel from an origin to a destination. It is a fundamental measurement in transportation planning, design, operations, and evaluation (Wu et al., 2004). As previously stated, travel times have been adopted as a transportation efficiency measurement, which is directly related to traffic congestion. (Calfee & Winston, 1998).

Travel times, when combined with distance information, have been shown to generate a reasonable assessment of the spatial distribution of traffic congestion within a city (Allie, 2016; Salonen & Toivonen, 2013). These matrices can then be used to calculate measures of traffic congestion, such as distance travelled per unit of time (travel speed) or vice versa, depending on whether the intent is to minimize distance or time (Allie, 2016; Hall, 1996).

3. METHODOLOGY

It was decided that traffic congestion analysis and comparisons would be conducted using an origin-destination (O-D) matrix approach involving travel time and distance data. O-D matrices have been used in numerous studies to identify and measure congestion, along with travel times (Liu & Zhu, 2004; Wu et al., 2001; Yang et al., 1992). Additionally, the travel time data were available upon request from the University of Toronto's Data Management Group (Data Management Group, 2020). The study uses traffic analysis zones (TAZs) as the areal units for analysis. TAZs are designated analysis zones for the Transportation Tomorrow Survey (TTS), and are accepted as standard areal units for traffic and congestion research (Hasnine et al., 2020; Kloostra & Roorda, 2019; Kasraian et al., 2018).

Two shortest distance matrices between TAZ centroids, one for Euclidean distances and one for road network-based distances, were estimated using the shortest path tool in Caliper Corporation's TransCAD 8.0. This was accomplished by specifying all centroids as both origins and destinations to create an O-D distance matrix between each zone. The network-based matrix was then collated with an average travel time matrix obtained from the Data Management Group (Data Management Group, 2020). The travel time matrix was constructed similar to the distance matrices in that TAZ centroids were specified as both origins and destinations.

An average travel speeds matrix was then estimated from the existing matrices to obtain the average travel speed from zone i to zone j for each centroid pair. The values of this matrix were then segmented using nine identifiable trip type segments. These segments are identified below in Table 2.

Table 2 – TAZ Trip Type Segments

Trip Type Segment Name	Abbreviation
Downtown to Downtown	Dt-Dt
Suburbs to Suburbs	Sb-Sb
Toronto Suburbs to Toronto Suburbs	SbT-SbT
Downtown to Suburbs	Dt-Sb
Downtown to Toronto Suburbs	Dt-SbT
Suburbs to Downtown	Sb-Dt
Suburbs to Toronto Suburbs	Sb-SbT
Toronto Suburbs to Downtown	SbT-Dt
Toronto Suburbs to Suburbs	SbT-Sb

Metrics were calculated for each segment, with the key metric being the average travel speed. This final metric was then compared across all segments as a proxy for traffic congestion measurement. Slower metric values would seem to suggest that trips between TAZs for the respective trip type covered less distance per unit of time, suggesting higher traffic congestion. Faster metric values would then suggest the opposite, that average trips between TAZs would cover more distance over time, suggesting lower traffic congestion.

To visualize the results of the study, average travel speeds to each TAZ as a destination were calculated in TransCAD. These values were segmented by origin TAZ type, and whether they were downtown, suburban, or Toronto suburban TAZs. The values were visualized by TAZ using a thematic mapping and natural breaks classification approach. Once again, lower metric values correspond to lower average travel speeds, suggesting higher traffic congestion per TAZ, while higher metric values correspond to higher average travel speeds and lower traffic congestion per TAZ.

4. DATA

4.1. Data Collection

A polygon shapefile of traffic analysis zones (TAZs) was obtained from the Data Management Group website's survey boundary files page (Data Management Group, 2014). The shapefile contained polygons representing 3,764 TAZs used in the 2006 Transportation Tomorrow Survey (TTS). While the survey has been updated since 2006, the TAZ polygons remain unchanged and continue to be used in traffic analysis studies as areal units. A summary of the shapefile municipalities and their TAZ unique IDs is provided in Table 3.

The study's methodology and analysis were first attempted using all municipalities. However, network analysis tools were unable to run properly in TransCAD due to the nature of some of the TAZs. The centroids of the TAZs representing rural areas were difficult to connect to the road network. They were typically sparse in road connectivity or drawn around bodies of water and islands without any bridges. Therefore, the study area was modified to only include TAZs within the official municipalities of the Greater Toronto Area. These municipalities include: The City of Toronto, the Region of Durham, the Region of York, the Region of Peel, and the Region of Halton. Thus, instead of using all 3,764 TAZs in the study, 2,038 TAZs representing these municipalities were used. The final study area by municipality is presented in Figure 1.

Table 3 – Traffic Analysis Zone Shapefile Municipalities and their Unique IDs

Municipality	TAZ Unique IDs
City of Toronto	1-625
Region of Durham	1001-1334
Region of York	2001-2877
Region of Peel	3001-3879
Region of Halton	4001-4197
City of Hamilton	5001-5252
Region of Niagara	6001-6366
Region of Waterloo	7001-7576
City of Guelph	8001-8207
County of Wellington	8301-8380
Town of Orangeville	8401-8405
County of Dufferin	8411-8417
City of Barrie	8501-8532
County of Simcoe	8551-8667
City of Orillia	8681-8685
City of Kawartha Lakes	8701-8717
City of Peterborough	8801-8825
County of Peterborough	8851-8855
City of Brantford	8901-8949
County of Brant	8950-8960

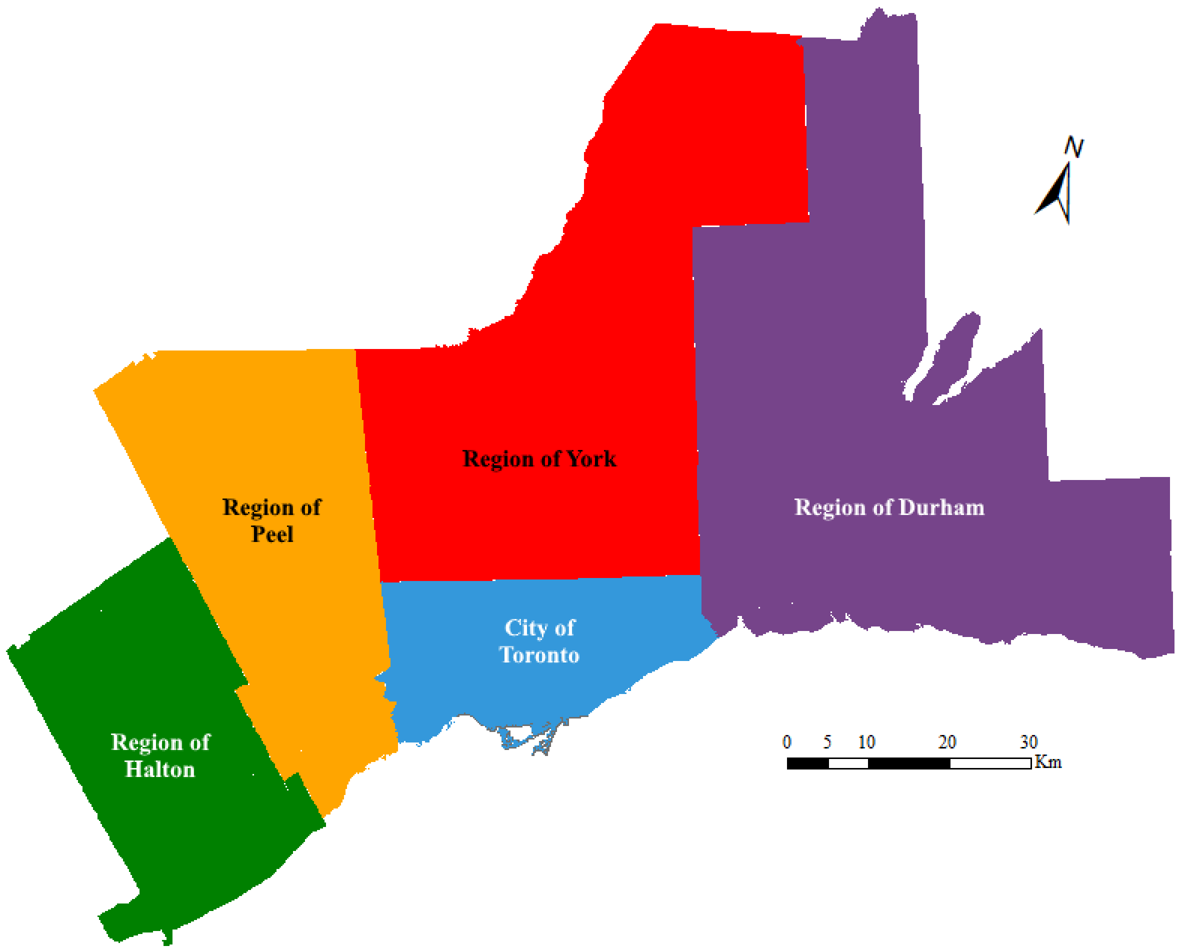


Figure 1 – Study Area – Greater Toronto Area by Municipality

It should be noted that there is a clear difference between the Greater Toronto Area and the City of Toronto. The City of Toronto, as represented by the blue polygon in Figure 1, is one of the five municipalities that makes up the Greater Toronto Area, or the study area for this research. The City of Toronto's boundaries were used to distinguish between the three classifications of TAZs used in this study. The classification groups are: downtown (Dt) TAZs, suburban (Sb) TAZs, and Toronto suburban (SbT) TAZs. The study areas TAZs were classified into one of these groups using the planning districts.

A polygon shapefile of planning districts (PDs) was also obtained from the Data Management Group's website's survey boundary files page (Data Management Group, 2014). As mentioned, these planning districts were not used in the analysis, but rather for TAZ classification. In order to draw comparisons between suburban TAZs within the City of Toronto, suburban TAZs not within the City of Toronto, and downtown TAZs, the zones had to be classified into these three groups. PDs are larger areal units but their boundaries do overlap with TAZs. Therefore, both PDs and TAZs were visualized in ESRI ArcMap 10.7.1. It was decided that all TAZs within PDs 1, 2, and 6 would be classified as "downtown" TAZs. These three PDs represent approximately

87.51Km^2 of area. This corresponds to approximately 13.78 per cent of the City of Toronto's total area (634.96Km^2), while also accounting for approximately 45.9 per cent of the City's total jobs based on employment data from the Data Management Group (Data Management Group, 2016). This indicates employment centricity within the three PDs, which is characteristic of downtown cores (Anas & Xu, 1999). Additionally, 50 per cent of the Toronto Transit Commission's subway stations are located within the area represented by these three PDs. This indicates a concentration of transit destinations, which is also characteristic of downtown cores (Barnes, 2005).

When compared to the area of the Borough of Toronto before the City's amalgamation, there is an approximate area overlap of 65 per cent (City of Toronto, 2016). This indicates that the area represented by PDs 1,2 and 6 adequately represents the location of the City's downtown core. Therefore, the chosen PDs were deemed acceptable in classifying TAZs as "downtown" zones. All other TAZs outside of these PDs but within the City of Toronto's boundaries would be classified as "Toronto suburban". Finally, all other unclassified TAZs within the study area would then be classified as "suburban". While Toronto has been identified as both a monocentric and polycentric city in the literature, this study assumed a monocentric urban form and focused specifically on the City's downtown core.

To identify the downtown TAZs, the TAZs shapefile's built-in PD data field was used. All polygons with a PD value of 1,2, or 6 were selected and their TAZ unique IDs were identified. A total of 165 TAZs were identified and classified as "downtown" zones, and had unique IDs within the following ranges: 1-128, 248-284. Next, a total of 460 unclassified TAZs within the 1-625 ID range were classified as "Toronto suburban" zones, as per the City of Toronto's TAZs ID ranges when referring back to Table 3. Finally, all other unclassified TAZs were classified as "suburban" TAZs. The downtown TAZs are identified in grey in Figure 2. The Toronto suburban TAZs are then, by extension, represented by the blue polygon. Suburban TAZs not within the City of Toronto are represented by the Regions of Halton (green), Peel (yellow), York (red), and Durham (purple).

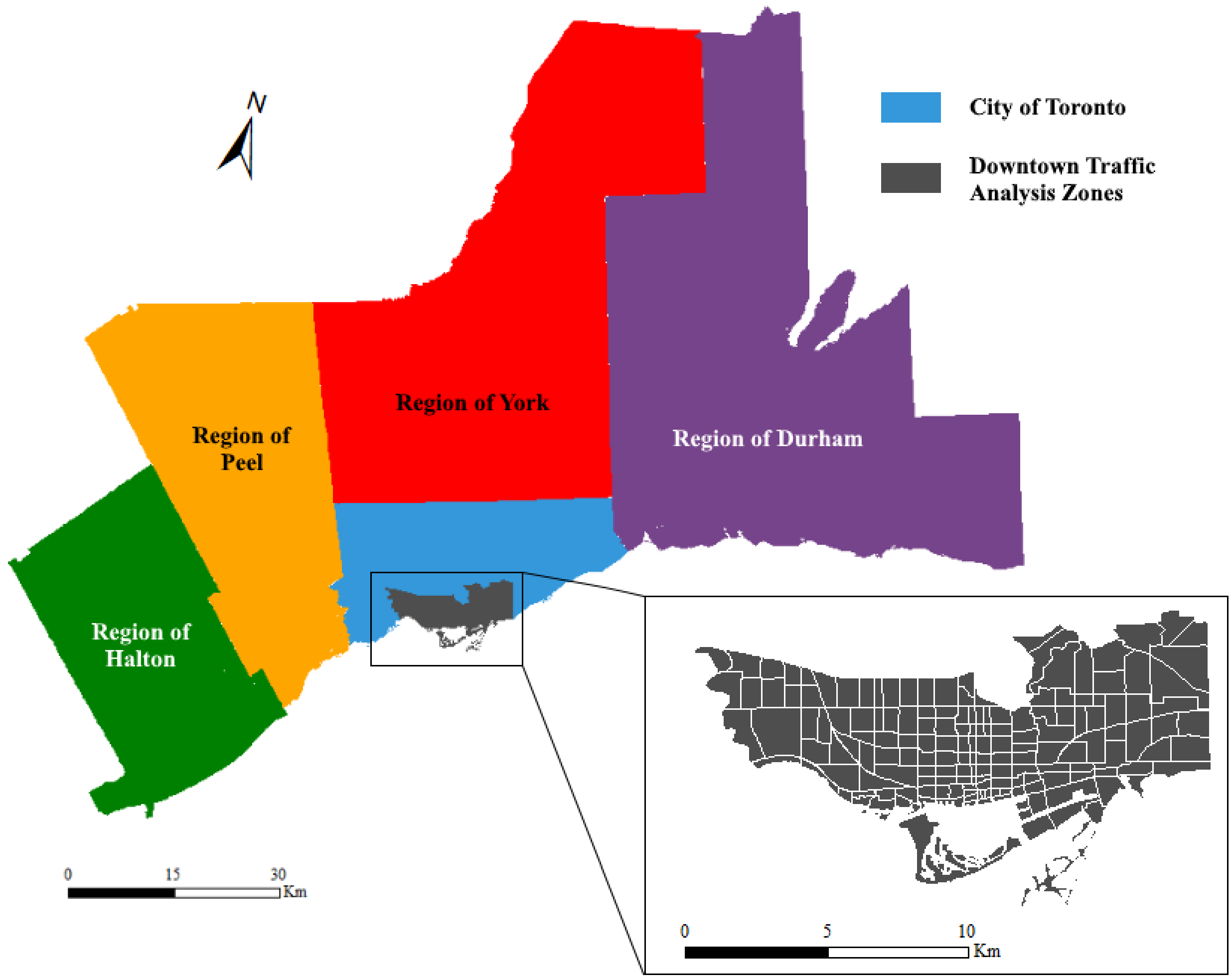


Figure 2 – Study Area – Greater Toronto Area with Highlighted Downtown TAZs

A matrix of average interzonal morning peak period travel times between TAZs for automobiles was obtained from the Data Management Group (Data Management Group, 2020). These average automobile travel times were calculated by the Group using their own methods and models.

The x and y axes of the matrix corresponded to the unique IDs of the TAZs from the zonal shapefile.

Finally, the most recent version of the official Ontario road network polyline shapefile was obtained from Statistics Canada, which was last updated on November 1, 2019 (Statistics Canada, 2019). A summary of all data sets and their sources is provided in Table 4.

Table 4 – List of Datasets and their Sources

Name	Description	Scale/Geometry	Format	Year	Source
Traffic Analysis Zones (TAZs)	Zonal boundary file representing all traffic analysis zones (TAZs) in the Greater Toronto Area	Traffic analysis zone (TAZ)	ESRI Shapefile (.shp)	2006	Data Management Group Survey Boundary Files, University of Toronto
City of Toronto Planning Districts (PDs)	Zonal boundary file representing all planning districts (PDs) in the City of Toronto	Planning districts (PDs)	ESRI Shapefile (.shp)	2006	Data Management Group Survey Boundary Files, University of Toronto
Average Interzonal AM Peak Travel Times	Matrix of average interzonal morning peak travel times between TAZs in minutes for automobiles	Traffic analysis zone (TAZ)	Comma Separate Variable File (.csv)	2020	Data Management Group, University of Toronto
Ontario Road Network	Ontario's provincial road network file	Road network	ESRI Shapefile (.shp)	2019	Census of Population – Statistics Canada

4.2. Data Preparation

The TAZs shapefile was imported into ESRI ArcMap 10.7.1. To determine the centroids for each TAZ, two fields were added to the shapefile and called "CENTX" and "CENTY". The "Calculate Geometry" tool was used to calculate the X and Y coordinates of the centroid for each TAZ in the shapefile. The coordinates were then displayed as points and saved as a separate centroids point shapefile layer. A new field was added to the centroids shapefile and populated with the corresponding unique IDs of the TAZs that each centroid represented. This would make it easier to identify the centroids in TransCAD. The 2019 road network layer was added, clipped within the TAZs shapefile layer using the "Clip" tool, and saved as a new shapefile layer.

The TAZs shapefile was imported into TransCAD, projected using the UTM Zone 17N coordinate reference system, and converted to a standard geographic file (.dbd) so that it could be used in the software for analysis. The same was done for the centroids shapefile and clipped road network. Breaks in the lines around the edges of the road network were observed, likely due to the clipping that was conducted in ArcMap. These breaks were reconnected using the "Layer Editing" tool by comparing the clipped network to the unclipped network in ArcMap and manually drawing straight lines between endpoints.

The centroids file was then connected to the road network using the "Centroid Connectors" tool. It was specified that centroids could be connected by straight lines to the nearest segment of the road network within a tolerance of 25 miles. To account for centroids that were located in bodies of water or on islands, a maximum of four connectors were allowed. Once connected, the road network file was split into two layers, representing line and nodes, respectively. When the node file was checked in Table View, the corresponding TAZ ID field for all centroids had been added, making it easy to distinguish between the centroids and all other nodes in the layer.

With the road network standard geographic file built, it was necessary to then build a network file (.net). The "Create Network" tool was used to build the network file using the line layer of the road network file as an input. No additional fields were added. Once the network file was built, it was loaded into TransCAD to use as the reference network for analysis.

5. ANALYSIS

5.1. Point to Point Analysis

To ensure that the network had been prepared properly, the "Point to Point" tool was used to calculate Euclidean (straight line) distance values (in miles) between all centroids using the "Straight Lines" method. It was specified that the length field should be minimized, and the "Node to Node" distance method was chosen. The tool was run and a distance matrix was generated and displayed, with the first row and column populated with the unique IDs of the centroids. The entire matrix was then copied, pasted into Microsoft Excel, and saved as an Excel spreadsheet (.xlsx). To confirm that the tool had successfully calculated correct O-D distances, a random selection of five centroid pairs and their O-D distances was chosen for cross-verification. The "Measure Distance" tool was used in ArcMap to draw straight lines between these centroids pairs and calculate distances. The calculated distances in ArcMap matched with the TransCAD O-D distances for all five centroid pairs. Therefore, it was concluded that TransCAD had successfully calculated the Euclidean O-D distance matrix for all centroids.

Now that the "Point to Point" tool was confirmed to be working, it was run again using the "Network Based" method. The final road network file was already loaded to be used as the reference network for routing. Length was once again minimized and the "Node to Node" distance method was chosen. The tool was run and another O-D distance matrix similar to the previous matrix was generated, displayed, copied, and pasted as a separate Excel spreadsheet.

5.2. Distance/Time Matrix Calculation

In Excel, the network-based O-D distance matrix values were still in miles. All values were converted from miles to kilometres using the "CONVERT" function and the spreadsheet tab was labelled "Distances". A second tab was opened in the spreadsheet and labelled "Travel Times". The average interzonal travel times matrix was then opened in Excel and pasted into the second tab. The travel times and distances were structured similarly in their respective tabs, with the first row and column being populated with the unique IDs of each TAZ in the same order. A third tab was opened in the spreadsheet to calculate distance over time measures, therefore it was labelled "Distance-Time" and its first row and column were similarly populated with the TAZ unique IDs. The values in this tab were calculated by dividing the values from the "Distance" tab by the corresponding cell values in the "Travel Times" tab, as represented by the following equation:

Average Distance Travelled Per Unit Time$_i$ (Km/min) = Distance$_i$ / Travel Time$_i$

The travel time and distance-time matrices were then added as two separate matrix layers to the shortest distance matrix in TransCAD. The result was a matrix file with three different matrix layers of data: shortest distance, travel time, and the calculated average distance travelled per unit of time (average travel speed).

5.3. Average Distance/Time Matrix Segmentation

The matrix file was exported to a new dataview in TransCAD. The dataview was structured as a table with one record for each matrix cell, with a field for each matrix. Thus, the table was comprised of 4,153,444 records. Two fields, called "O-Type" (origin type) and "D-Type" (destination type), were added to assist in labelling each record's trip type. This would then simplify the segmentation and final analysis of results. Using the "select by condition" tool, all records with "downtown" origin TAZ IDs my were selected, and the "O-Type" field was populated with the label "Urban". The same was done for all other records with "suburban" and "Toronto suburban" origin TAZ IDs, except the "O-Type" field was populated with the labels "Suburban" and "Toronto Suburban", respectively. The same procedure was conducted on all records using the destination TAZ IDs, except the "D-Type" field was populated with the corresponding "Urban", "Suburban", and "Toronto Suburban" labels. While it is not possible to show this table in its entirety, a sample is provided in Table 5, showing records representing different trip types.

Table 5 – Sample Dataview of O-D Distance-Time Matrix Data

Origin-TAZ ID	Destination-TAZ ID	Distance (km)	Time (min)	Distance-Time (Km/min)	O-Type	D-Type
1	1	0	0	0	Urban	Urban
1	129	16.523958	25.70997	0.642706	Urban	Toronto Suburban
1001	1	40.392159	72.73645	0.555322	Suburban	Urban
1001	285	54.675724	77.283188	0.707472	Suburban	Suburban Toronto
4197	4197	0	0	0	Suburban	Suburban

Now that a master table of matrix data was available for analysis, its records were segmented by trip type using the O-Type and D-Type fields. Using the "select by condition" tool, records with O-Type and D-Type fields set to "Urban" were selected and saved as a new dataview. This dataview represented all O-D pair records for the downtown to downtown (Dt-Dt) trip type segment. Then, the "summary statistics" tool was run on the table's records, producing the following univariate computed statistics for each field: count, sum, minimum, maximum, mean, and standard deviation. A sample table of the results is presented below in Table 6.

Table 6 – Sample Table of Summary Statistics for Dt-Dt Trip Type Segment

Field	Count	Sum	Min TAZ ID	Max TAZ ID	Mean	Std. Dev.
Origin	27,225	2,986,170	1	284	109.685	90.265
Destination	27,225	2,986,170	1	284	109.685	90.265
Distance	27,225	161,787.035	0	19.265	5.943	3.462
Time	27,225	294,840.960	0	42.081	10.830	7.276
Avg Speed	27,060	16,158.954	0.079	2.232	0.597	0.167

The same procedure of creating a separate dataview and computing statistics was completed for the remaining eight trip types. Additionally, statistics were computed for all records in the original dataview. The "count" and "mean" metrics for the distance-time field from the statistical summaries were compiled for each trip type into a table of results. The "mean" field represented the average travel speeds (Km/min) for each trip type. These values were multiplied by 60 to express them in units of kilometres/hour. They were then added as a separate column.

The final distance-time records table and computed statistical results produced in TransCAD were also verified in Microsoft Excel. The records table was exported to Excel and segmented into trip type ranges of cells based on the O-Type and D-Type field values. Using these new ranges, the total trip counts and average travel speed values were calculated using the SUM and AVERAGE functions, respectively. The calculated total trip counts and average travel speed values corresponded to those calculated in TransCAD for the entire records table and the nine trip type segments.

5.4. Average Speeds by TAZ Estimation & Data Visualization

The results of the previous analysis step would not translate well to a map visualization as they were segmented by trip type, not by TAZ. Therefore, further analysis was conducted to obtain statistics that could be represented in a map by TAZ. In TransCAD, the average speed to each TAZ as a destination from every other TAZ was calculated. These values were then added in a new field to the TAZ layer. The "thematic mapping" option was chosen to represent these average speeds by TAZ, specifying colour as the representative symbol. An optimal breaks classification was chosen to segment the TAZs into six classes. A gradient colour scheme from red to green was specified, with red representing the lowest class of average speeds and green representing the highest class. A thematic map was produced, and its appearance was improved using ArcMap, as seen in Figure 3. Next, the average speeds to each TAZ as a destination were segmented by TAZ origin type, producing three additional maps. The first segment consisted of average speeds from downtown origin TAZs to each TAZ as a destination. The second segment consisted of average speeds from suburban origin TAZs to each TAZ as a destination. Finally, the third segment consisted of average speeds from Toronto suburban origin TAZs to each TAZ as a destination. These three segments were once again visualized using the same classification method and colour scheme by TAZ. Thematic maps representing the three segments are presented in Figures 4, 5, and 6.

6. RESULTS & INTERPRETATION

6.1. Visualized Results of Average Origin Speed Estimations by Destination TAZ

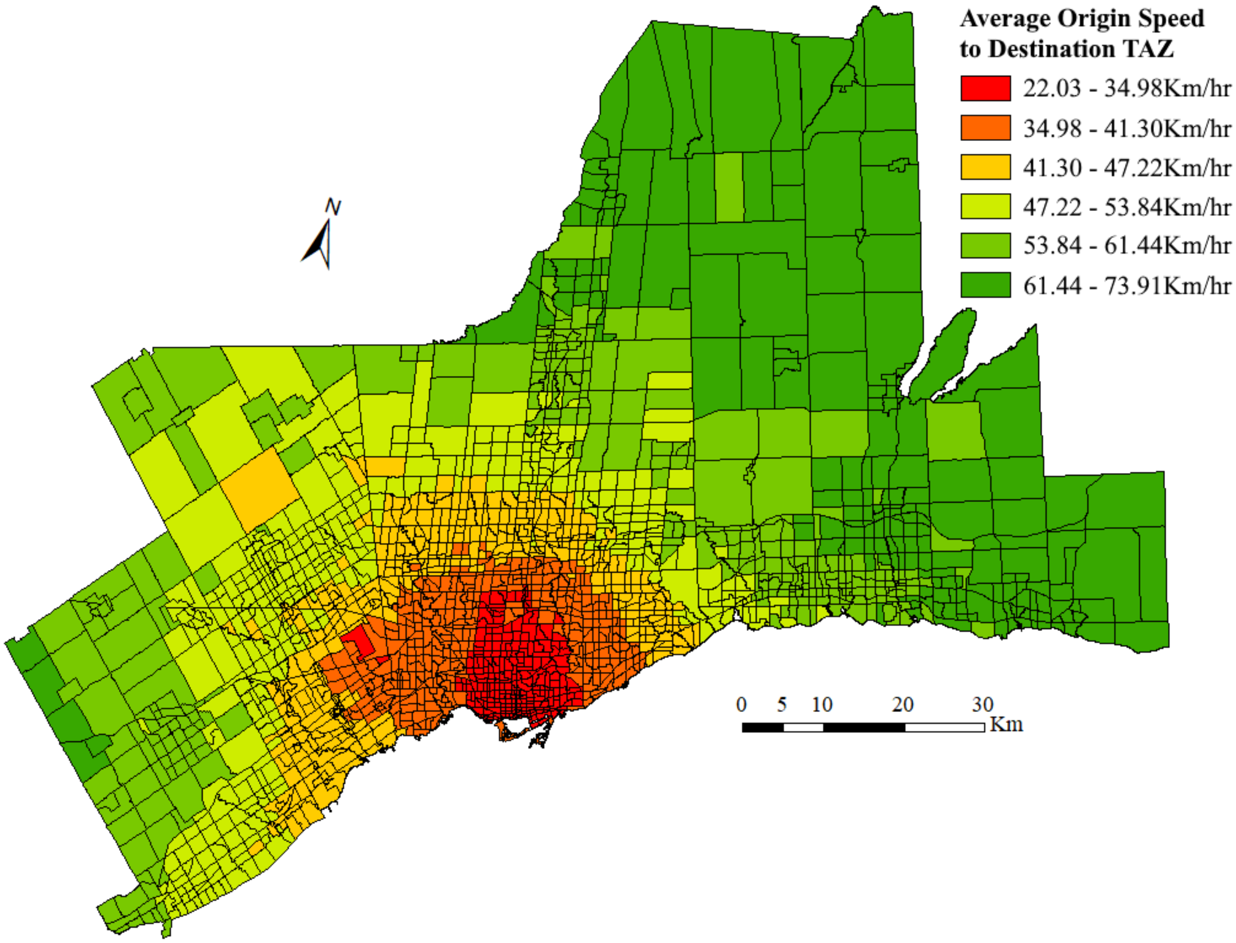


Figure 3 – Average Speed to Destination TAZ in the Greater Toronto Area

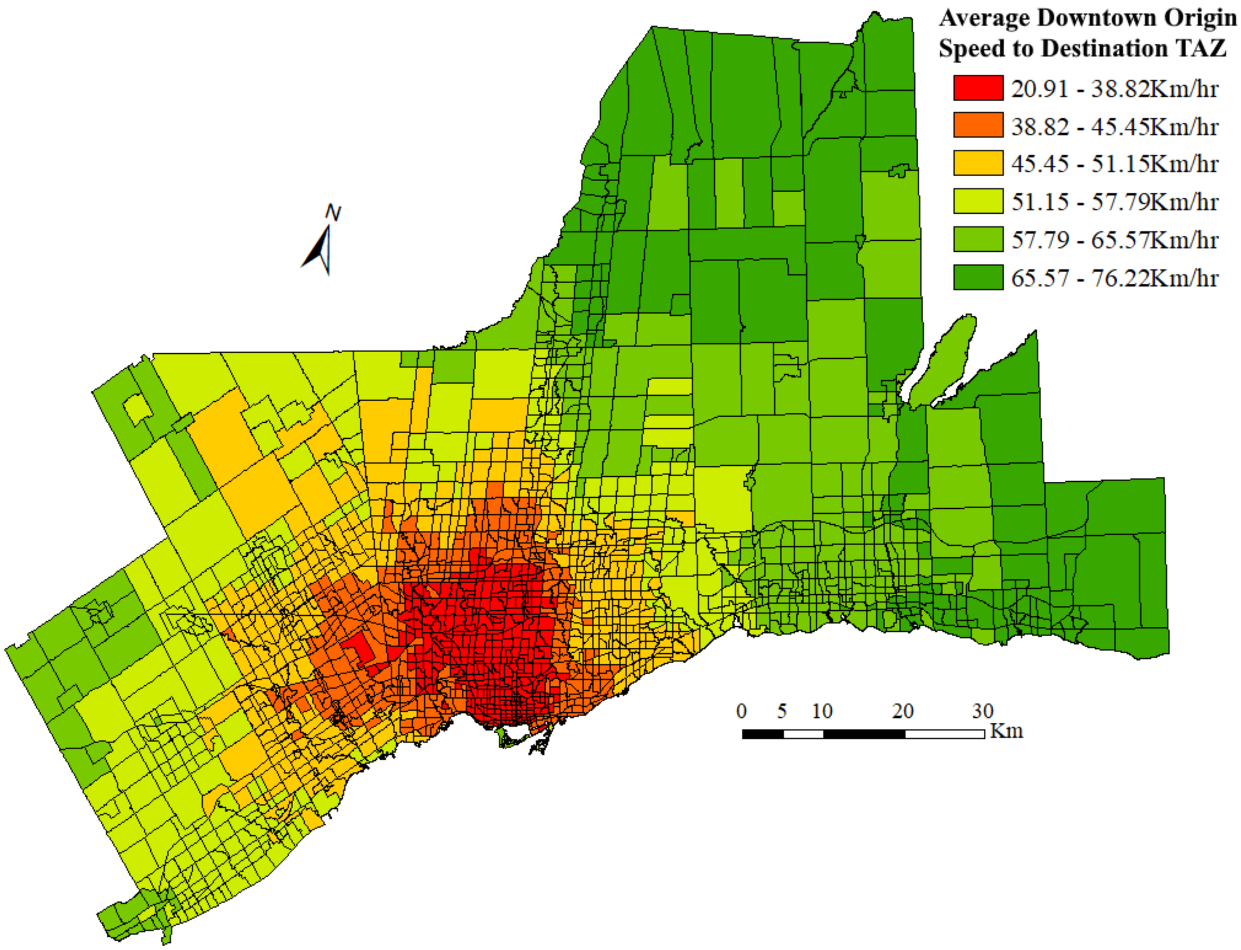


Figure 4 – Average Downtown Speed to Destination TAZ in the Greater Toronto Area

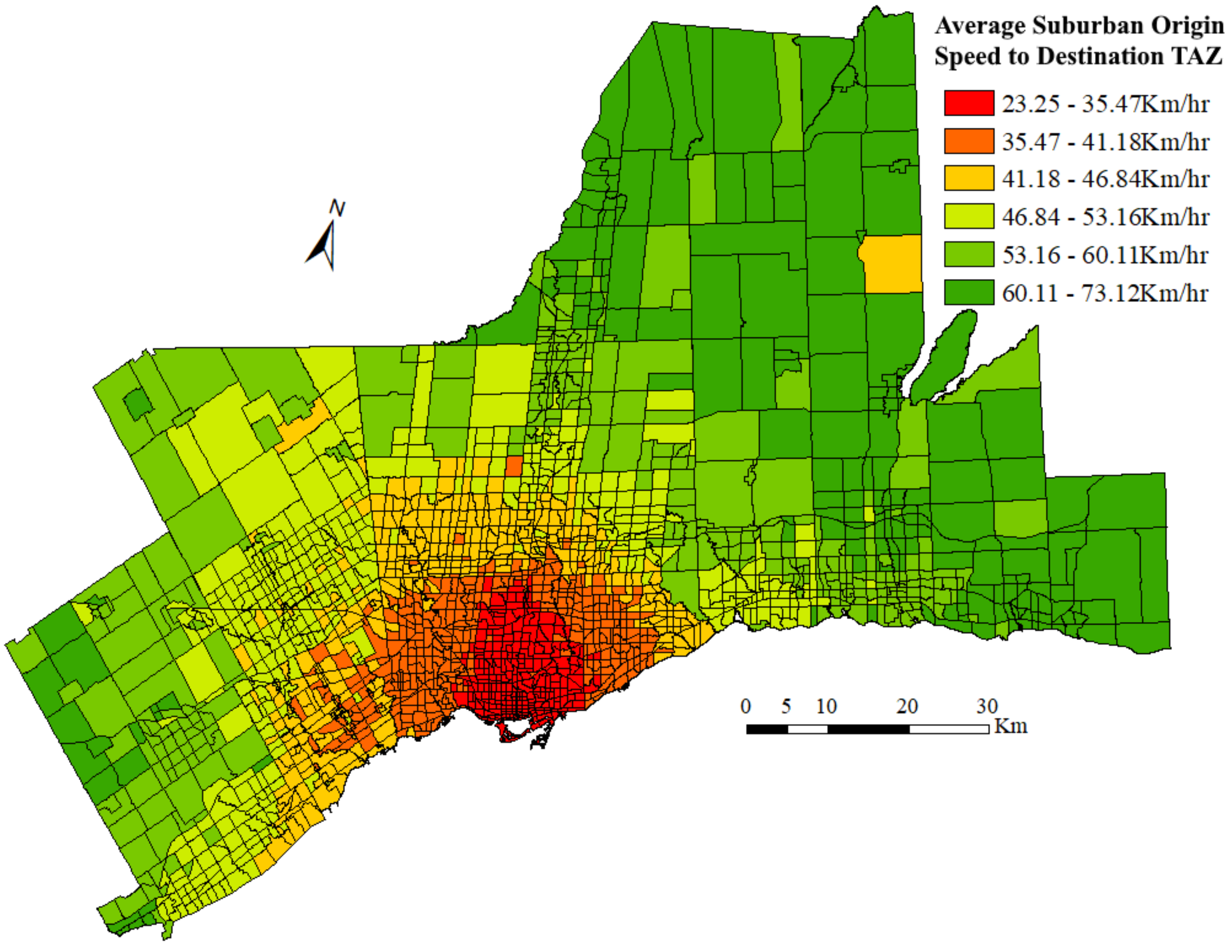


Figure 5 – Average Suburban Speed to Destination TAZ in the Greater Toronto Area

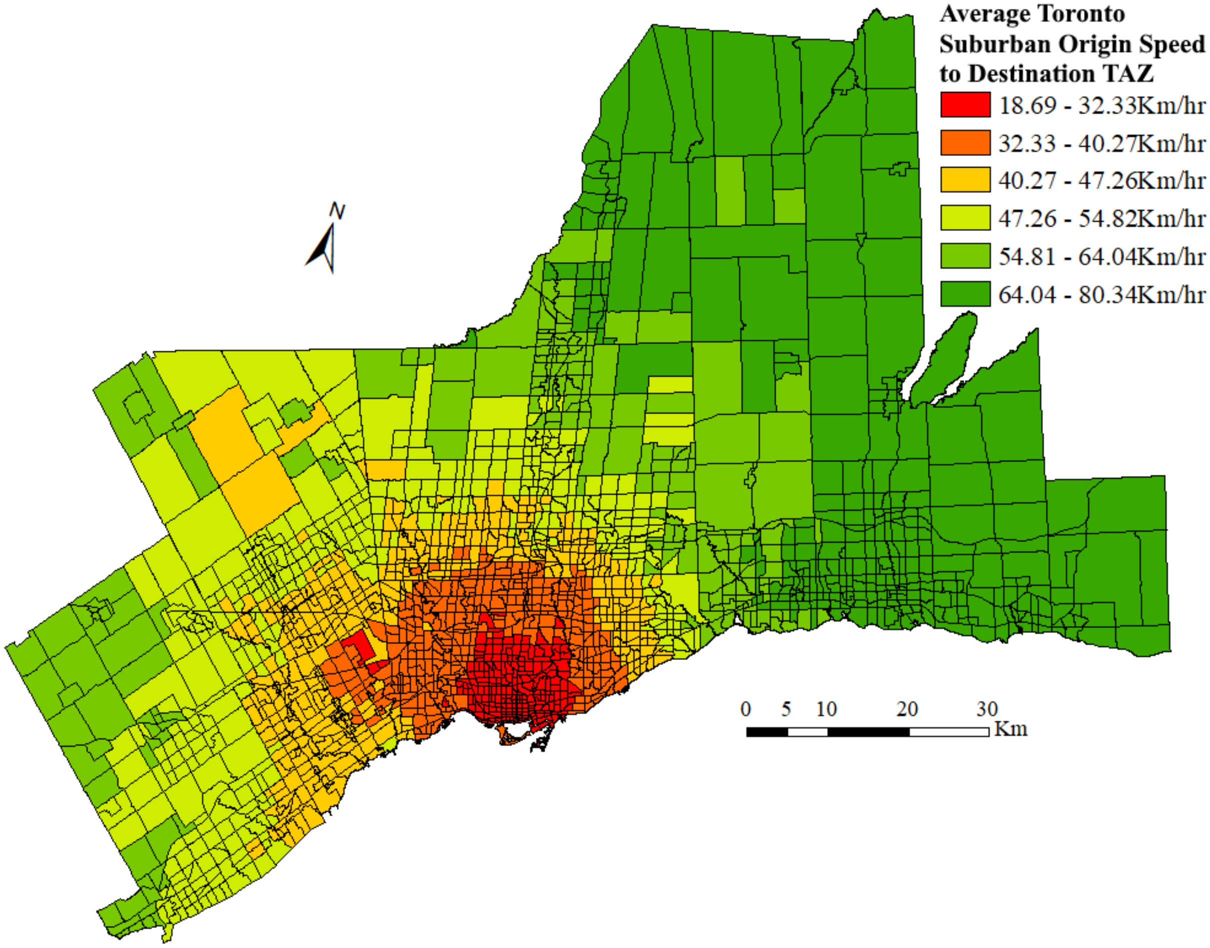


Figure 6 – Average Toronto Suburban Speed to Destination TAZ in the Greater Toronto Area

6.2. Discussion of Visualized Average Speed Results

Figures 3, 4, 5, and 6 serve to visualize the average speeds to each TAZ as a destination. Figure 3 represents average speeds from all TAZs, Figure 4 represents average speeds from downtown TAZs as origins, Figure 5 represents average speeds from non-Toronto suburban TAZs as origins, and Figure 6 represents average speeds from Toronto suburban TAZs as origins. They all appear to present similar visualizations based on the shading of TAZs by class. Downtown TAZs typically exhibit the lowest average speeds between 18 and 40 Km/hour, as indicated by their dark red shading. Suburban TAZs vary in their average speeds, though their values seem to decrease as they move further away from the downtown core. The TAZs that are furthest in distance from downtown typically exhibit the highest average speeds between 60 and 81Km/hour, as indicated by their green shading. While there are variations in the classes that the TAZs are a part of between each trip segment, the trend of average speeds by TAZ decreasing as they approach the downtown core appears to hold true for all four figures.

6.3. Results of O-D Matrix Trip Type Segmentation

The results of the analysis and matrix calculations by trip type segment, as carried out in Section 5.3, are summarized below in Table 7. These results do not include the average speeds to destination TAZ calculations and visualizations conducted in Section 5.4.

Table 7 – Summary of O-D Matrix Metrics by Trip Type Segment

Matrix Trip Type Segment	Number of O-D Pairs	Average Speed (Km/Min)	Average Speed (Km/Hour)
Downtown to Downtown (Dt-Dt)	27,060	0.5972	35.83
Suburb to Suburb (Sb-Sb)	1,995,156	0.8578	51.47
Toronto Suburb to Toronto Suburb (SbT-SbT)	211,140	0.6222	37.33
Downtown to Suburb (Dt-Sb)	233,145	0.8958	53.75
Downtown to Toronto Suburb (Dt-SbT)	75,900	0.6824	40.94
Suburb to Downtown (Sb-Dt)	233,145	0.5336	32.02
Suburb to Toronto Suburb (Sb-SbT)	649,980	0.6266	37.59
Toronto Suburb to Downtown (SbT-Dt)	75,900	0.4663	27.98
Toronto Suburb to Suburb (SbT-Sb)	649,980	0.8949	53.69
All Trip Types	4,151,406	0.7873	47.24

6.4. Discussion of O-D Matrix Trip Type Segment Results

The average distances travelled per unit of time for the nine trip type segments were compared. The total average travel speed for the entire matrix was calculated to be 47.24Km/hour. The segment representing downtown to non-Toronto suburb trips (Dt-Sb) yielded the highest segment average travel speed of 53.75Km/hour. The Toronto suburb to downtown (Sb-Dt) trip segment yielded the lowest average travel speed of 27.98Km/hour.

Based on the average travel speeds for all nine segments, it appears that suburban trip makers travel faster than downtown trip makers. Suburban trip makers travelling to other suburban zones (Sb-Sb) travel approximately 43.65 per cent faster on average compared to downtown trip makers travelling to other downtown zones (51.47Km/hour compared to 35.83Km/hour). These trip makers also travel approximately 60.74 per cent faster on average than suburban trip makers commuting to downtown zones (32.02Km/hour). Toronto suburban trip makers travelling to other Toronto suburban zones (SbT-SbT) travel approximately 4.19 per cent faster than downtown to downtown trip makers (37.33Km/hour compared to 35.83Km/hour). These trip makers also travel approximately 33.42 per cent faster than Toronto suburban trip makers commuting to downtown zones (37.33Km/hour compared to 27.98Km/hour).

Interestingly, downtown trip makers travelling to suburban zones both in and outside of the City of Toronto exhibit the fastest and third fastest average speeds, specifically 53.75Km/hour to suburban zones and 40.94Km/hour to Toronto suburban zones. Additionally, trip makers with suburban and Toronto suburban destination zones travel faster on average than trip makers with downtown destination zones. An interesting trip segment to highlight is the suburbs to Toronto suburbs trip segment (Sb-SbT), which has the second fastest average travel speed of 53.69Km/hour. Clearly, trips with suburban and Toronto suburban destination zones exhibit faster average travel speeds than trips with downtown zones. By extension, trips with suburban destination zones exhibit faster average travel speeds than trips with Toronto suburban destination zones.

6.5. Interpretation of Results

The results of the matrix trip type segmentation and average speed visualizations can be used to answer this study's two research questions. To answer question 1, the average travel speed is faster for suburban trips than for downtown trips by automobile in the Greater Toronto Area. To answer question 2, the average travel speed is faster for automobile trips originating from and destined to suburban zones than for trips originating from and destined to the downtown core in the Greater Toronto Area. This appears to hold true for both suburb to suburb trips (Sb-Sb) and Toronto suburb to Toronto suburb trips (SbT-SbT).

Referring back to the study's methodology, it was stated that the average travel speed between TAZs would likely decrease due to traffic congestion. Therefore, based on the results of both the trip type segmentation and average speed visualizations, it can be inferred that suburban trip makers experience less road congestion on average than downtown trip makers, especially when they are travelling between suburban zones.

By extension, suburban zones in the Greater Toronto Area appear to be less congested than the downtown core. This is especially apparent when referring to Figures 3, 4, 5, and 6. Additionally, the average travel speed can be faster or slower for suburban and Toronto suburban trip makers by automobile when compared to downtown trip makers. This variation is dependent on the trip type segment. Average speeds are slower when suburban and Toronto suburban trip makers are travelling to the downtown area. They are then faster on average when they are travelling to other suburban areas. It appears that if a trip is destined for a downtown TAZ, irrespective of its origin type, average speeds are slower than trips with suburban or Toronto suburban destination zones.

While the results have been used to address the research questions and objectives of this paper, there are numerous limitations that should be addressed.

6.6. Limitations

6.6.1. Modifiable Areal Unit Problem

The Modifiable Areal Unit Problem (MAUP) should always be addressed in any spatial analysis research. This limitation exists because of how spatial data is aggregated by areal unit, and how areal units can be artificially demarcated (Wong, 2004). For example, traffic analysis zones (TAZs) are the main areal unit used in this study. Shortest path analysis and subsequent matrix calculations were directly based on the spatial geometry and number of TAZs (2,038). The results of the analysis would have been different had other areal units been used. While TAZs are widely accepted as adequate units for traffic analysis, the results would have likely been more refined had smaller units been used. For example, downtown TAZs are typically smaller in size than suburban TAZs. Therefore, the travel distances between the centroids of downtown TAZs are relatively shorter than distances between suburban TAZs. This systematic difference is a result of MAUP. This also means that average travel times between TAZs will be greater if the TAZs are larger in size, as is seen with the larger suburban TAZs in the GTA, especially outside of the City of Toronto's boundaries.

It should be noted, however, that dataset availability should also be considered when choosing the appropriate areal units. TAZs were used in this study because it was known that a travel time matrix aggregated to those particular areal units would be provided by the Data Management Group for analysis. Additionally, the TAZ shapefile was readily available for download from the Data Management Group's website (Data Management Group, 2014).

Population density within TAZs should also be included in relation to this limitation, as it was not included as a variable in the analysis. Population density is not evenly spread across a TAZ's area. As a result, TAZ centroids likely do not accurately represent the average point where commuter trips begin and end. One solution would be to include a population density layer aggregated to each TAZ and factor that into determining the most appropriate location for a central point to be used in constructing O-D distance and travel time matrices.

6.6.2. Study Area Limitations

While on the topic of areal units, the study area poses a limitation. While it did incorporate all municipalities within the Greater Toronto Area, it omitted the surrounding municipalities which are also grouped into what is referred to as the Golden Horseshoe, a core region around Lake Ontario that is high in population (Luqman, 2014). Ideally, these other municipalities would have also been included in the analysis, thereby increasing the size of the calculated matrices, and affecting the final average speeds. Trip types involving suburban trip makers would be affected in particular as these other municipalities would be classified as “suburban” zones. However, if these other municipalities were incorporated, the previous problems that the research faced with sparse networks and route optimization would have to be addressed.

6.6.3. Other Data Limitations

While the 2019 road network from Statistics Canada is comprehensive in its areal coverage, it poses a limitation because it lacks certain data fields that could have improved route optimization when calculating the shortest network paths between centroids. Specifically, the road network shapefile does not contain street directions for one-way streets, dead ends, and other street obstacles (Statistics Canada, 2019).

Additionally, roadway design and speed limits were not factored into the routing analysis. On average, trip makers may choose to commute between zones using major thoroughfares and highways, as these road types typically have higher posted speed limits. This variable was intentionally left out as the intention was to minimize distance, not travel time. However, this variable could be considered in future studies, especially since speed limits are also dependent on geography-based municipal policies. One solution would be to use Caliper Corporation’s HERE data layers, which are robust in their coverage, include numerous useful data fields, and are specifically created for use within the TransCAD software (Caliper Corporation, 2020).

Other travel mode data could also be considered, such as public transit and bicycle trips. For example, Google provides access to a variety of transit data, feeds, and APIs that would likely assist in estimating trip routes and average travel speeds (Google, 2020). Downtown trip makers could likely travel at faster average speeds by public transit or bicycle. However, this multimodal approach would have to be defined within the research scope, and in this study that approach was deemed out of scope, with the focus being solely on automobile trips.

Finally, the reliability and methodology of the average morning peak period travel time matrix data for automobiles provided by the Data Management Group should be considered. The assumption is made that these travel times were calculated correctly using a methodology that is compatible with this study. Ideally, all datasets would be generated by and provided from one source.

6.6.4. Methodological Limitations

There are inherent limitations based on the study’s methodology and approach. These are related back to the reasons for choosing to focus on using travel times and specifically average travel speeds as the key metrics for drawing congestion comparisons between different areas. Other metrics could perhaps have been included in the methodology, and may have refined the final results. This is also related to a limitation concerning the definition of congestion. As presented in the research context, there are multiple definitions and accompanying measures of traffic congestion. Perhaps another starting definition of congestion would have better served as the basis for answering this study’s objectives. The solution would be to expand the methodology and scope to include additional analysis and metrics. Additionally, this research was based on minimizing distance paths between TAZs. As a result, it was specified in TransCAD that the point to point analysis tool was to be run with the intention of minimizing distance. Perhaps minimizing time between TAZs, instead, could be more effective and potentially show even greater variation between average speeds. This approach could be employed if a better road network with speed limits was used in TransCAD. These methodological changes can be accomplished in future studies that may build upon this research.

Additionally, the study's methodology did not attempt to distinguish between congestion effects and the effects of roadway design on average travel speeds. This is especially important when comparing the large design capacity and faster speed limits of highways to smaller capacity arterial roads with slower speed limits. Further analysis could be conducted to address this limitation. For example, subsets of O-D trip pairs whose shortest paths do not rely on highways could be segmented in both the downtown core and the suburbs. This segmentation would attempt to isolate the effect of highways and roadway design on the speeds. The speeds of these O-D pair subsets could then be compared once again to see if suburb to suburb trips are faster or slower on average than downtown to downtown trips.

The urban form of the Greater Toronto Area could have also factored more into the methodology. In this study, it was assumed that the GTA was monocentric, with the City of Toronto's downtown area delineated in the methodology by planning districts 1,2, and 6. While this assumption was made so that the analysis could focus on drawing comparisons between the downtown area and the surrounding suburbs, it may have been more appropriate to classify the GTA as a polycentric urban area. This is because notable job sub-centres besides the City of Toronto's downtown core do exist in other parts of the study area, such as in Mississauga and Richmond Hill (Luqman, 2014). One solution would be to also classify these areas as suburban cores. The methodology, analysis, and subsequent results would then be based on a polycentric approach to comparing traffic congestion.

However, the results of the study seem to suggest that the City of Toronto is monocentric. Since trips with downtown destination TAZs exhibited slower average speeds, and trips with suburban and Toronto suburban destination TAZs exhibited faster average speeds, there does seem to be a dominant concentration of jobs within the downtown core.

6.7. Summary

This study attempted to estimate average travel speeds between suburban zones and the downtown core in the Greater Toronto Area. Average travel speeds were used as a proxy for traffic congestion. The objective of the study was summarized in two research questions: 1) is the average travel speed faster for suburban trips than for downtown trips by automobile in the Greater Toronto Area, and 2) is the average travel speed for automobile trips originating from and destined to suburban zones faster than trips originating from and destined to the downtown core in the Greater Toronto Area?

Shortest path analysis using a point to point tool was conducted to measure shortest distances and estimate an origin-destination distance matrix between traffic analysis zones in the study area. The distance matrix was then combined with an average travel time matrix provided by the Data Management Group. The final calculated matrix consisted of values between TAZs, representing the average travel speeds in Km/hour. The matrix was then split into nine segments by trip type to draw comparisons. Based on the results, it appeared that average travel speeds were faster for suburban and Toronto suburban automobile trips when compared to the downtown core. Additionally, the average travel speeds were faster for trips originating from and destined to both suburban and Toronto suburban zones when compared to trips originating from and destined to downtown zones.

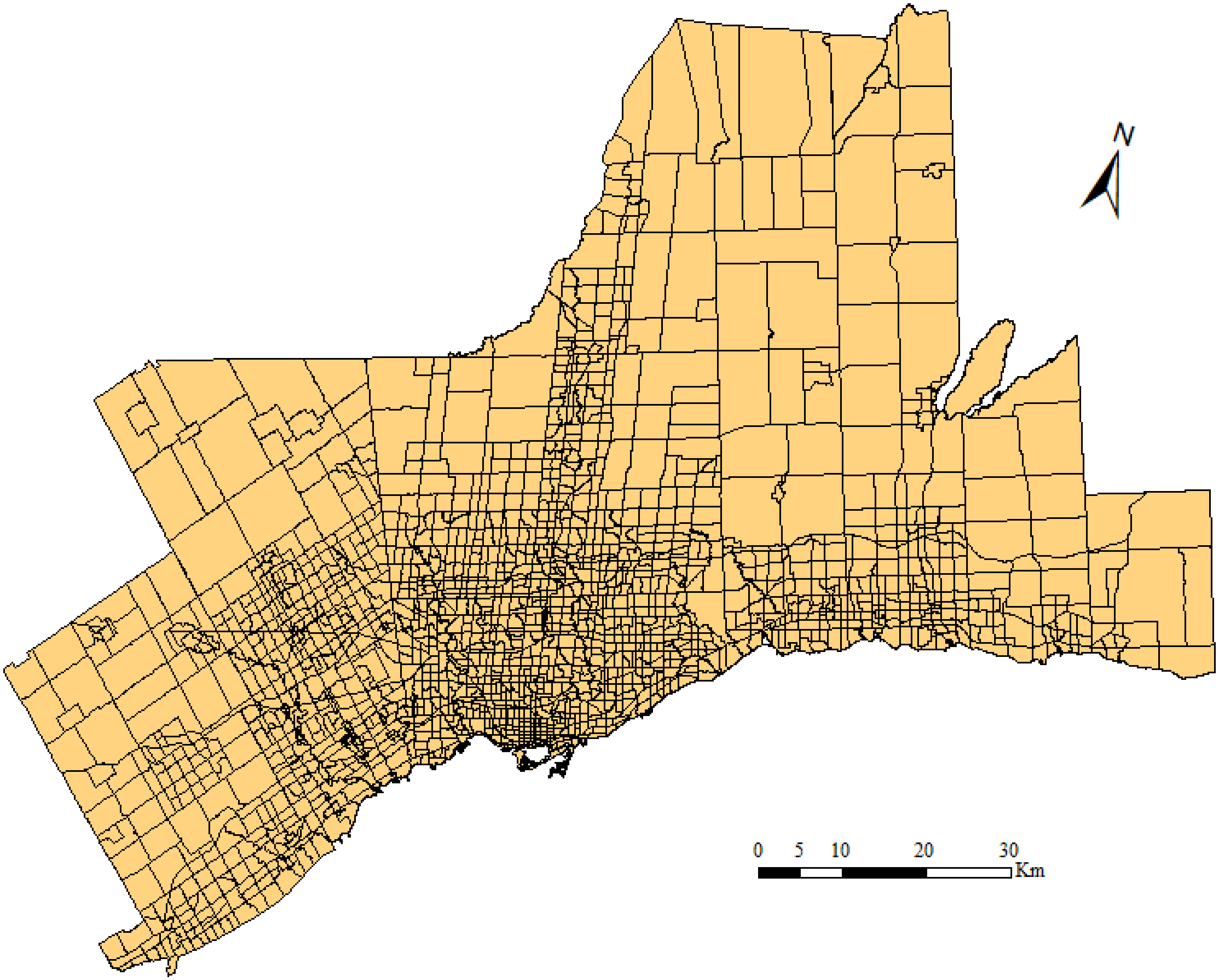
To aid in visualizing the results, average speeds to TAZs as destinations were also calculated and mapped by TAZ. Four thematic maps corresponding to different origin segments were produced: all TAZs as origins, only downtown TAZs as origins, only non-Toronto suburban TAZs as origins, and only Toronto suburban TAZs as origins. Based on these maps, it appeared that average travel speeds were slower for downtown TAZs as destinations when compared to suburban and Toronto suburban TAZs. This further supports the results and interpretation of the matrix trip type segmentation analysis. Additionally, the average travel speed for automobile trips originating from and destined to suburban zones was faster than trips originating from and destined to the downtown core. Based on the results, it can be inferred that suburban zones both within and outside of the City of Toronto are less congested than the downtown core. Thus, it can be concluded that the study answered its research questions and achieved its objective.

7. CONCLUSION

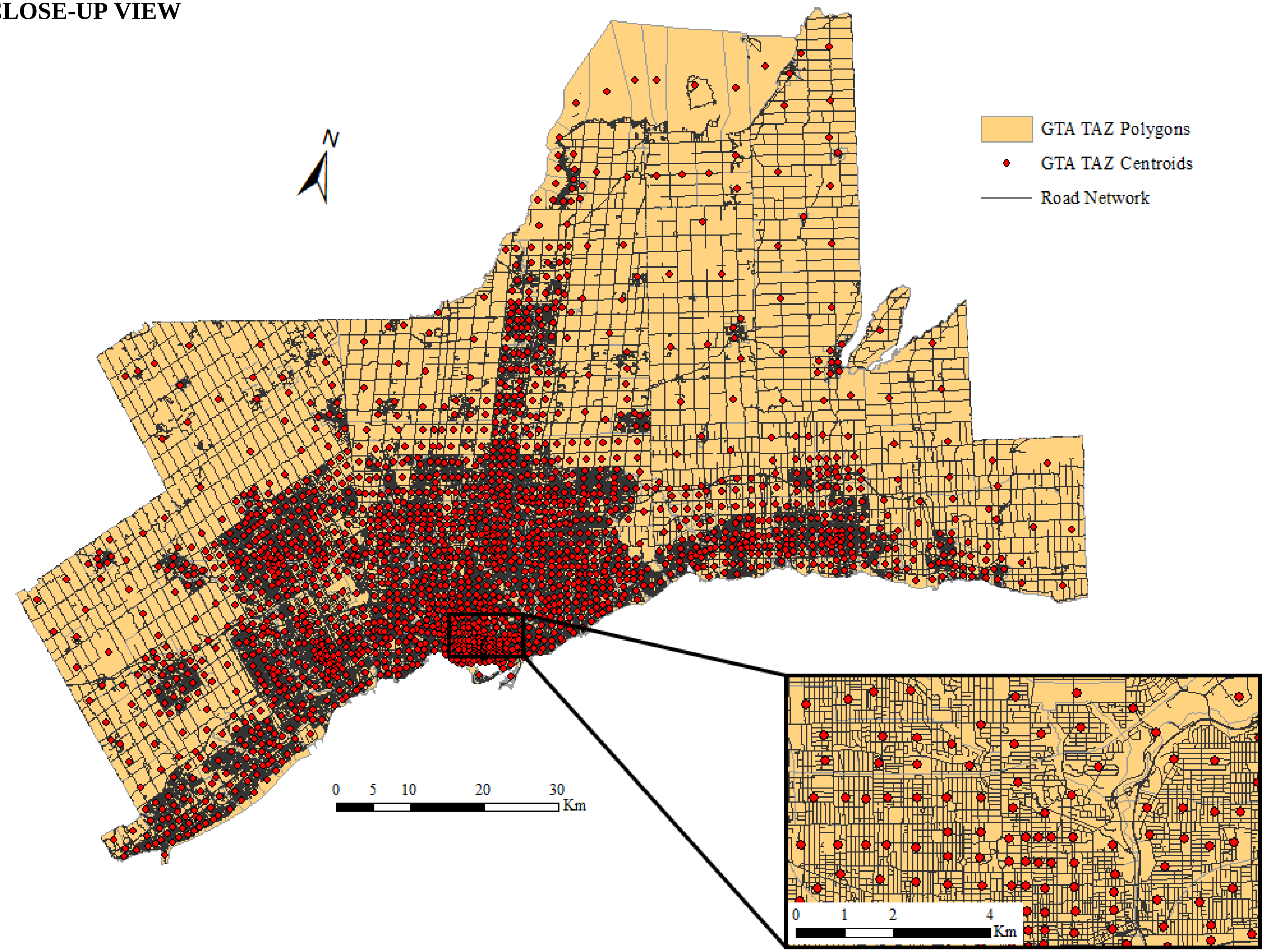
This research forms the basis for future research into comparisons of average travel speeds and traffic congestion within the Greater Toronto Area. Other methodologies and metrics can be incorporated into the analysis if necessary. For example, it would be interesting to integrate public transit networks into the methodology. Additionally, only average morning peak period travel times were used in the analysis. Other travel time data, such as evening peak periods times, could be included to establish temporal comparisons, and potentially improve the scope of the methodology. As mentioned, Google data on travel times could be obtained for different travel modes and at different times of the day. These data would certainly aid in building upon the results of this study, especially if a multimodal scope and methodology are employed.

In any case, the need for future research into traffic congestion in the Greater Toronto Area is paramount. As the region continues to grow in population, congestion will likely worsen. This research will ideally aid those in charge of monitoring and managing traffic congestion. Results and conclusions from this research could be incorporated by stakeholders into municipal decision-making, creation of policy, and future project planning. They could also contribute to the discourse around traffic congestion in the fields of urban and transportation planning.

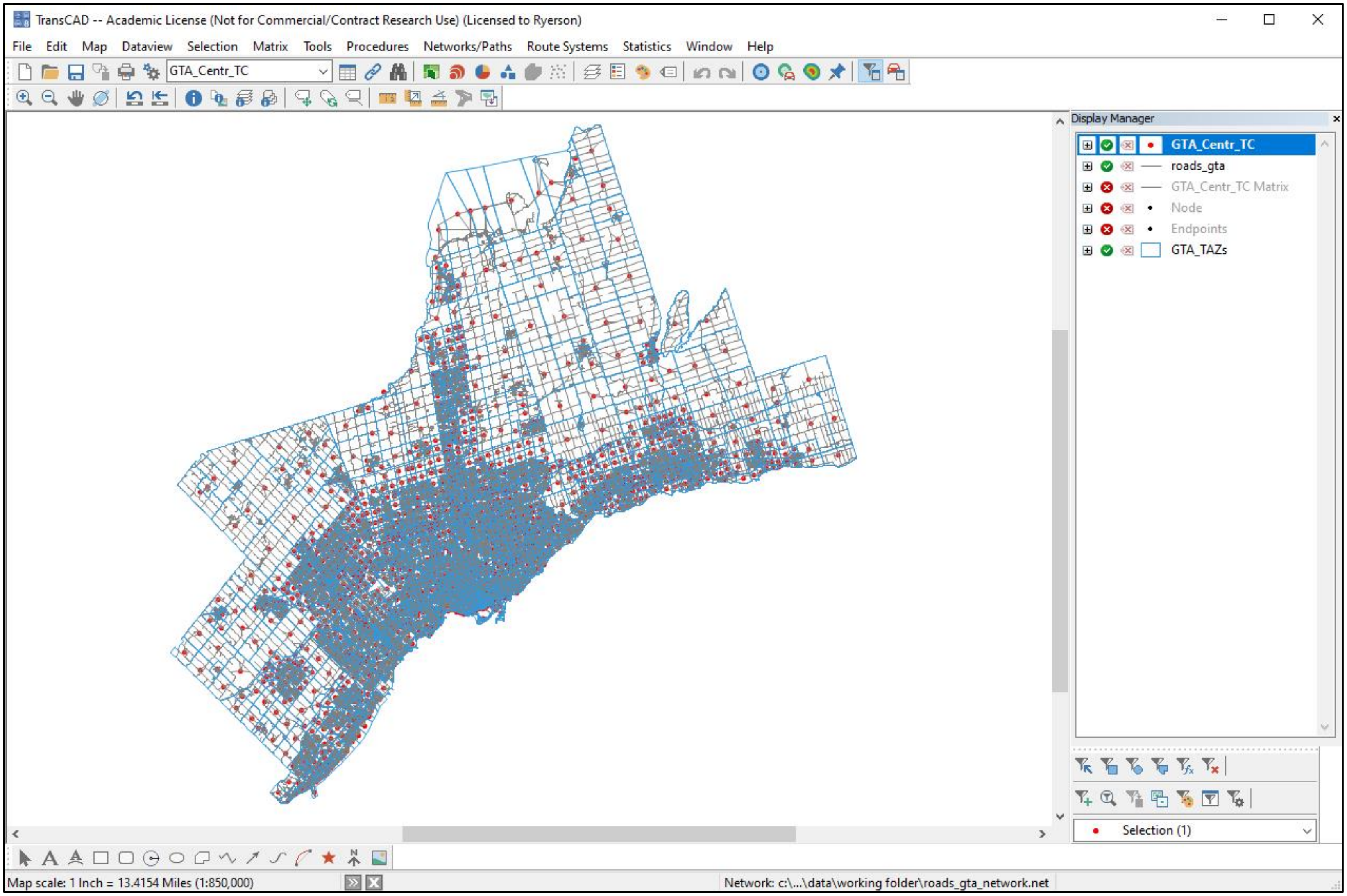
APPENDIX A – STUDY AREA – GREATER TORONTO AREA TRAFFIC ANALYSIS ZONES (TAZS)



APPENDIX B – STUDY AREA – GREATER TORONTO AREA TAZ CENTROIDS AND ROAD NETWORK WITH CLOSE-UP VIEW



APPENDIX C – TRANSCAD 8.0 SOFTWARE WINDOW AS USED FOR ROUTING, SHORTEST PATH ANALYSIS, AND MATRIX CALCULATION



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