Impact of Population Intensification near Transit Nodes on Montreal Traffic Assignment

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ABSTRACT

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Montreal Master Plan, 2005, proposed population intensification near transit nodes as a measure to reduce the dependency on cars. However, the impact of these policies has not been studied in detail. This research aims to analyze the influence of these policies on the Greater Montreal Area (GMA) traffic using a deterministic user-equilibrium traffic assignment model. Three intensification scenarios were considered to illustrate the volume-capacity ratio changes in GMA's road network under the impact of these scenarios in 2013 considering population increase. In the first scenario, the redistribution of the forecasted new trips among the 104 traffic zones of GMA was applied based on their natural growth rate. In the second scenario, 20% intensification of the GMA population growth was applied in the zones containing subway stations, and a modal shift from cars to subway was assumed for this population based on the modal ratios of the 2003 O D survey. The third scenario is similar to the second one, but with 50% intensification ratio.

The proposed approach is expected to provide a simplified method that can be applied to investigate intensification policies by assuming certain levels of intensification and modal shift at specific zones. However, the assumptions for this approach have to be used carefully to get meaningful results.

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LIST OF ABBREVIATIONS

Abbreviation	*Description*
2D	Two-dimensional
3D	Three-dimensional
AMT	Agence Métropolitaine de Transporte
CATI	Computer Aided Telephone Interviewing
CBD	Central Business District
CUM	Communauté urbaine de Montréal
DB	Database
DTA	Dynamic Traffic Assignment
GIS	Geographic Information System
GMA	Greater Montreal Area
ILUTE	Integrated Land Use, Transportation, and Environment Modeling System
ITS	Intelligent Transportation Systems
MTM	Modified Transverse Mercator
MTQ	Ministère des transports du Québec
O-D	Origin-Destination
RCM	Regional County Municipality
STA	Static Traffic Assignment
STM	Société de Transport de Montréal
TAZ	Traffic Analysis Zone
TDF	Traffic Demand Forcasting
UE	User Equilibrium
UTPP	Urban Transportation Planning Process
VOC	Volume over Capacity

CHAPTER 1 INTRODUCTION

1.1 GENERAL BACKGROUND

Montreal is a city with a specific boundary, and the maximum density is reached in the downtown core, where density approaches 44,000 persons per square kilometer (Montreal Statistics, 2006).

The factors that attract people to place of where to live could be the income, interaction between work and home, car ownership, etc., but one of the main reasons in attraction and production of trips in each zone is related to the land use and transportation policies. Since the Kyoto Accord came into effect on February, 2005, Canada is legally bound to reduce its greenhouse gas emissions – a significant portion of which comes from the transportation sector – by at least 20% by 2012. Clearly, widespread changes in people's travel behaviors are needed (Spurr, 2005). To change the people's travel behaviors, knowledge of trip behavior is needed. The latest travel behavior survey, 2003, provides information about household trips based on the sex, income, car ownership, etc.

Montreal Master Plan (2005) proposed population intensification near transit nodes as a measure to reduce the dependency on cars. However, the impact of these policies has not been studied in detail. One approach to study the impact of these policies is by applying Land Use and Transportation models using computer tools. The idea that computer models of urban land use and transportation might contribute to more rational urban planning was born in the 1950s and culminated in the 1960s (Wegener, 1994). Furthermore, the urban land use and transportation models can be better analyzed and visualized using Geographic Information System (GIS).

This study demonstrates a simplified method to analyze the impact of intensification policies using transportation modeling tools and GIS techniques, and how GIS can be profitably applied in the construction of a traffic assignment model with a very fine spatial resolution. The time savings incurred through the application of GIS permit the construction of a very detailed metropolitan street network comprising approximately 814416 directional links and a corresponding system of 104 traffic analysis zones.

1.2 RESEARCH OBJECTIVES

This research has the following objectives:

(1) To analyze the influence of intensification policies on Montreal traffic using a deterministic user-equilibrium traffic assignment model;

(2) To study the feasibility of applying the intensification policy near transit nodes from the point of view of land use based on volume ratio regulations;

(3) To investigate practical methods for realizing the proposed approach by integrating multiple data sources;

1.3 THESIS ORGANIZATION

This study will be presented as follows:

Chapter 2. Literature Review: This chapter provides a general review of the link between transportation and land use policies to coordinate transportation and land use planning decisions. In addition, methods to process the travel forecasting steps (especially traffic assignment) are discussed, and land use policies such as intensification are reviewed as a changing factor of the travel behavior. Moreover, the characteristics of the compact city, and the impact of transportation and land use plans on the environment are discussed.

Chapter 3. Methodology: This chapter aims to provide a simplified approach for analyzing the impact of population intensification near subway stations based on the traffic assignment of the GMA using a deterministic user-equilibrium traffic assignment model. The proposed approach uses the general methods of transportation forecasting processes, population forecasting methods, population intensifying, and visualizing methods to visualize the volume over capacity results in three dimensions (3D).

Chapter 4. Analysis of results: Most of the work in this chapter is analyzing results, based on the methods explained in Chapter 3, in four scenarios. The first case is applying the traffic assignment by gathering and integrating the required data, overlapping the different digital maps, and then visualizing the current Montreal traffic situation. The three future scenarios are applying the intensification policy in subway zones and validating their applicability. The required information to realize the future scenarios includes the growth rate for each zone based on the Canada Statistics to redistribute the increased trips in 2013 according to each scenario assumption. In addition, this chapter demonstrates how GIS can be profitably applied in the construction of a traffic assignment model with a very fine spatial resolution. Finally, the three dimensional model of intensified building is illustrated to accommodate the increased population.

Chapter 5. Summary, Conclusions, and Future work: This chapter summarizes the present research work, highlights its contributions, and suggests recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

Understanding the link between transportation and land use is critical to the development of policies and strategies of an effective comprehensive plan. As a result, it is important to coordinate transportation and land use planning decisions so they are complementary rather than contradictory. This insures that transportation planning decisions and land use planning objectives support each other (Litman, 2008). Another factor is the impact of transportation and land use plans on the environment, which is usually negative impact, unless it is integrated in the planning process.

To guide the future actions toward a desired direction, a detailed review is required. This chapter provides a general review of transportation and land use policies, planning processes, and transportation modeling methods.

2.2 TRANSPORTATION AND LAND USE

2.2.1 Transportation policies

The development of a city is always in parallel with the development of transportation systems. These systems through the time have required a huge infrastructure in urban areas and they have important influence on the society. Techniques for predicting the impact of transportation policies also have improved in recent years (Boyles et al., 2005). One example of such policies is congestion pricing, which charges users a fee for traveling on certain links at certain times, in an effort to efficiently allocate space on the network.

Some of the transportation policies that have been introduced are: (1) Assigning lanes for high occupancy vehicles; (2) Respond more rapidly to traffic blocking accidents and incidents; (3) Building more roads in growing areas; (4) Installing ramp meters; (5) Using intelligent transportation system devices to speed traffic flow; (6) Increasing the scope for non-motorized modes; (7) Creating park-and-ride facilities; (8) Increasing the real cost of car travel; and (9) Raising gasoline taxes (Alecsandru, 2007).

Table 2.1 (AMT, 2003) shows the tax collected from gasoline sales (1.5% per liter of the price of the gasoline) is forwarded to the Agency of Metropolitan Transport (AMT) for investment in public transportation. This policy encourages more people to shift to the public transportation that has the benefit of decreasing air pollution from 1/18 of greenhouse gas emission for automobiles to 3% of greenhouse gas emission for public transportation.

Table 2.1 Tax collected from gasoline sales and invested in public transportation (AMT, 2003)

Year	***Tax collected ($)***	***Gas sold (billion of liters)***
1996	43,240,000	2.883
1997	46,123,000	3.075
1998	44,894,000	2.993
1999	44,568,000	2.971
2000	44,440,000	2.963
2001	43,245,000	2.883

2.2.2 Land use policies

The term "land-use" refers to a range of human activities, the state of the built environment, and some aspects of the natural environment. Sometimes applying transportation policies is not enough to conduct the society towards a sustainable development, and they should be moderated by land use policies. For example, expanding and developing new highways are a temporary relief and, in the long term, they may lead to worsen the congestion. One of the key issues regarding sustainable transportation is to reduce developing new highways and to encourage people to use public transportation by applying one of the following methods: (1) Urban plans aiming to focus residential developments in denser settlements; (2) Creating mixed land use facilities, which increase the scope for multipurpose trips, reducing the need to travel; (3) Generating concentrations of trip origin and destination; and (4) Restricting very low-density peripheral development (Haider, 2005).

2.2.3 Integration of transportation and land use policies

Preferences for sustainable transportation modes and more compact neighborhoods, and impacts of modern lifestyle created combination of land use and transportation policies such as: (1) Concentrating high-density residential developments near transit stations and along public transport corridors; (2) Concentrating employment and other trip attracting activities in urban and suburban centers; (3) Favoring locations outside congested areas; (4) Focusing new residential development in areas well served by public transport; (5) Using developer contributions to finance new transport infrastructure; (6) Issuing guidelines which seek to ensure that new development is accessible to public transport; and (7) Creating a high density of trip-attracting activities in central areas and other locations well served by public transport (Haider, 2005).

Policies can be classified based on their functionalities: (1) Policies which interfere with other policies, such as investing in both a new road and a new rail system; (2) Policies with conflicting objectives, such as increasing vehicle speeds to save travel time, which causes increasing the number of accidents and generating more traffic, or developing out-of-town shopping centers to achieve cheap goods and easier parking, which causes rising the level of car travel; and (3) Policies which reinforce each other such as increasing the cost of car travel, when coupled to land use policies which brings homes near jobs, and encouraging people to shift from their cars to public transportation.

Policies from each category have impacts on the society. For example, new roads through the inner city provide quicker travel for suburban dwellers and poorer environment for inner city dwellers. On the other side, social changes have impacts on transportation and safety, such as safety implications of demographic changes and accident risks at the local and global scales (Haider, 2005).

2.2.4 Impact of transportation and land use policies on the environment

Since the introduction of motorized transportation systems, economic growth and advancing technology have allowed people and goods to travel farther and faster, steadily increasing the use of energy for transportation. Emissions of carbon dioxide (CO_2), the principal greenhouse gas produced by the transportation sector, have steadily increased along with travel, energy use, and oil imports. In the absence of any constraint or effective countermeasures, transportation energy use and greenhouse gas emissions will continue to increase.

The transportation system is essential for the mobility of any society. It is fundamental to the health of the Canadian economy and to its continued growth. But transportation is also the economy's largest source of CO_2 emissions, produced by burning petroleum fuels in internal combustion engines. The transportation sector was the second leading source of greenhouse gas emissions in Canada in 2004. The sector accounted for approximately 24% of Canada's greenhouse gas emissions (Environment Canada, 2006) Figure 2.1 shows total emissions were up 30% from their 1990 levels. This figure shows total emissions, emissions from cars and all emissions from other modes (Environment Canada, 2006).

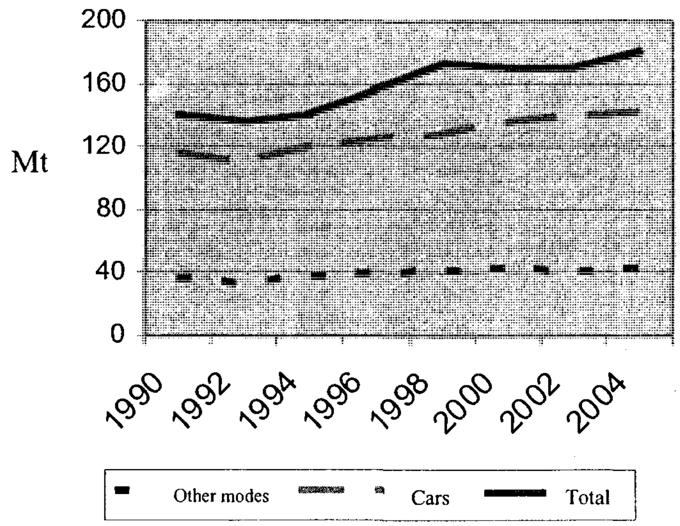


Figure 2.1 Greenhouse gas emission from transportation (Environment Canada, 2006)

Transportation energy use and greenhouse gas emissions are increasing because the growth of transportation activity exceeds the rate of improvement in energy efficiency. Road transportation was the mode that led to increase the emissions by 38.4 Mt between 1990 and 2004.

2.3 LAND USE FACTORS AND URBAN DENSITY

Land use patterns are defined by several components, such as community design, urban form, the built environment, spatial planning, and urban geography. Table 2.2 describes the factors that have impacts on land use. These factors influence the travel behavior and population health. Furthermore, combining these factors may change their effects. For example, combining the effect of transit accessibility and parking management tends to increase with higher density, so analysis that only considers a single factor may exaggerate its effect (Kuzmyak and Pratt, 2003).

Table 2.2 Land use factors (Litman, 2008)

Land Use Factor	*Description*
Density	People or jobs per hectare.
Regional Accessibility	A site's location relative to the regional urban center, and the number of jobs and public services available within a given travel time.
Centeredness	Degree to which commercial and other public activities are located in downtowns and other activity centers.
Land Use Mix	Degree to which residential, commercial and institutional land uses are located close together.
Connectivity	Degree to which roads and paths are connected and allow direct travel between destinations.
Roadway Design	Scale and design of streets, and how various uses are managed. Traffic calming refers to street design features intended to reduce traffic speeds and volumes.
Walking & Cycling Conditions	Quality of walking and cycling transport conditions. (Active transport is a general term for walking, cycling, and their variants).
Transit Accessibility	Degree to which destinations are accessible by quality public transit.
Parking Management	Number of parking spaces per building unit or hectare. Parking management includes pricing and regulations.
Transportation Demand Management	Various strategies and programs that encourage more efficient travel patterns, often implemented as an alternative to road and parking facility expansion, and in conjunction with land use policy reforms.

One of the important land use factors is density. Density refers to the number of people or jobs in an area (Campoli and MacLean, 2002; Kuzmyak and Pratt, 2003). Density can be measured at various scales such as: regional, county, municipal jurisdiction, neighbourhood, census track, city block or individual sites. Density affects travel behaviour through the following mechanisms:

(1) Land Use Accessibility: The number of potential destinations, located within a geographic area, tends to increase with population and employment density, reducing travel distances and the need for automobile travel (VTPI, 2005). For example, in low-density areas, a university may serve hundreds of kilometers, requiring most students to arrive by motor vehicle. In denser areas, schools may serve just a few square miles, reducing average travel distances and allowing more students to walk or cycle. Similarly, average travel distances for errands, commuting and business-to-business transactions tend to decline with density.

(2) Transportation Options: Increased density tends to increase the number of travel options available in an area due to economies of scale in providing facilities such as sidewalks and services such as public transit, taxis and deliveries.

(3) Reduced Automobile Accessibility: Increased density tends to reduce traffic speeds, increase congestion and reduce parking supply, making driving less attractive compared with other modes (Litman, 2008).

Increased density tends to reduce per capita vehicle ownership and use, and increase use of alternative modes (Jack Faucett Associates and Sierra Research, Inc., 1999; Ewing et al., 2002; Kuzmyak and Pratt, 2003). As shown in Figure 2.2, Ewing (1997) concludes that "doubling urban densities results in a 25-30% reduction in vehicle miles of travel (VMT), or a slightly smaller reduction when the effects of other variables are controlled."

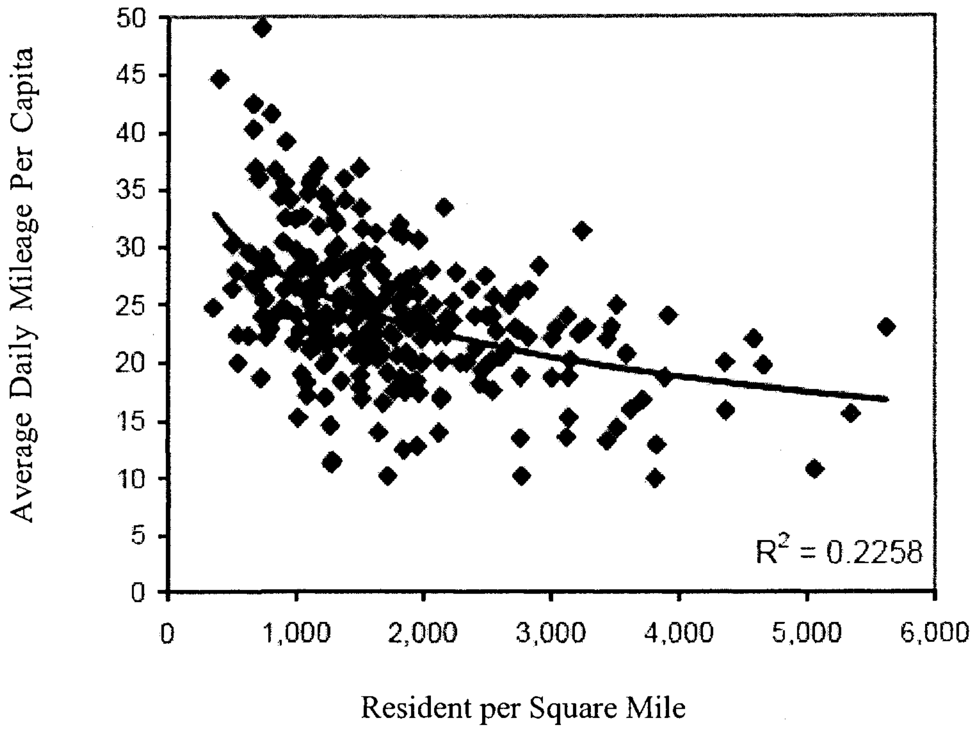


Figure 2.2 Density versus vehicle travel for U.S. urban areas (FHWA, 2005)

There are many studies on the concept of density, but there is not any optimized value to apply on cities. One of these studies was prepared by Urban Strategies Inc. (2005) for Ontario Ministry of Public Infrastructure Renewal as one input to the draft Greater Golden Horseshoe Plan in Ontario. This research explores the background and application of land use intensification targets to direct development to established areas and limit urban sprawl. It also examines intensification targets in use in the UK, Australia, British Columbia, and New Zealand, and provides recommendations for applying relevant lessons from those jurisdictions to Ontario's Greater Golden Horseshoe (GGH). Appendix A shows the map of GGH.

Currently under development, the Growth Plan will guide where and how the GGH will grow. A key element of the plan will be to encourage the efficient use of land through intensification. Taking as its starting point the 40% intensification target stated in the Ministry of Public Infrastructure Renewal's Places to Grow discussion paper (Urban Strategies Inc., 2005).

However, the impact of intensification policy has not been studied in detail. New scales have evolved ("mass matters"), including new dimensions of large high-density concentrations of population with immense sprawl and a serious increase in infrastructural, socio-economic and ecological overload. Furthermore, these may develop extreme dynamism in demographic, economic, social and political processes. Both phenomena - the new scale and dynamism - make mega cities (at least 2,000 persons/ km^2) vulnerable, especially where administrative direction is absent or weak. Figure B.1 and B.2 in Appendix B show the maps of mega cities.

Appendix C shows a list of the most populous cities of the world accompanied with their density. By comparing the Montreal density (4,439 persons/ km^2) with mega cities, we can claim that Montreal has an acceptable density.

2.4 THE COMPACT CITY

In the last twenty years or so there has been an increasing interest in the form of cities. Their densities, size, urban forms, configurations and layouts can contribute to their sustainability. The main focus has been on the impacts of different urban forms on travel behavior and transport provision, resource efficiency, social equity, accessibility and economic viability. One outcome from this debate, particularly in Europe, the USA and Australia was a strong advocacy of the 'compact city' model. Essentially, a compact city is a high-density, mixed-use city, with clear, non-sprawling boundaries (Jenks and Burgess, 2000; Williams et al., 2000). This model was supported for several reasons. First, compact cities are argued to be efficient for more sustainable modes of transport. The population densities should be high enough to support public transport and to make it feasible to operate. Also, because compact cities have a high density of population and mixed use, the theory is that people can live near their work place and leisure facilities. Hence, the demand for travel is reduced overall and people can walk and cycle easily. Second, compact cities are seen as a sustainable use of land. By reducing sprawl, land in the countryside is preserved and land in towns can be recycled for development. Third, in social terms, compactness and mixed uses are associated with diversity, social cohesion and cultural development. Some also argue that it is an equitable form because it offers good accessibility. Fourth, compact cities are argued to be economically viable because infrastructure, such as water distribution networks and street lighting, can be provided cost-effectively per capita. Also, population densities are sufficient to support local services and businesses (Jenks and Burgess, 2000)).

The major issue to consider about the ability of the compact city concept to deliver more sustainable cities could be the difference in the physical and demographic characteristics of cities globally. In the European context, the compact city model focuses on maintaining or increasing urban populations (which have been steadily declining) and making urban living popular again. In the UK, the government's urban policy in this area is known as the 'Urban Renaissance' (Rogers, 1999). Figure 2.3 shows a good example of compact urban area with clear districts and district neighborhoods (British Urban Task Force, 1999). Hence the focus is on providing a high quality of life in city centers, developing on infill sites and generally revitalizing towns and cities.

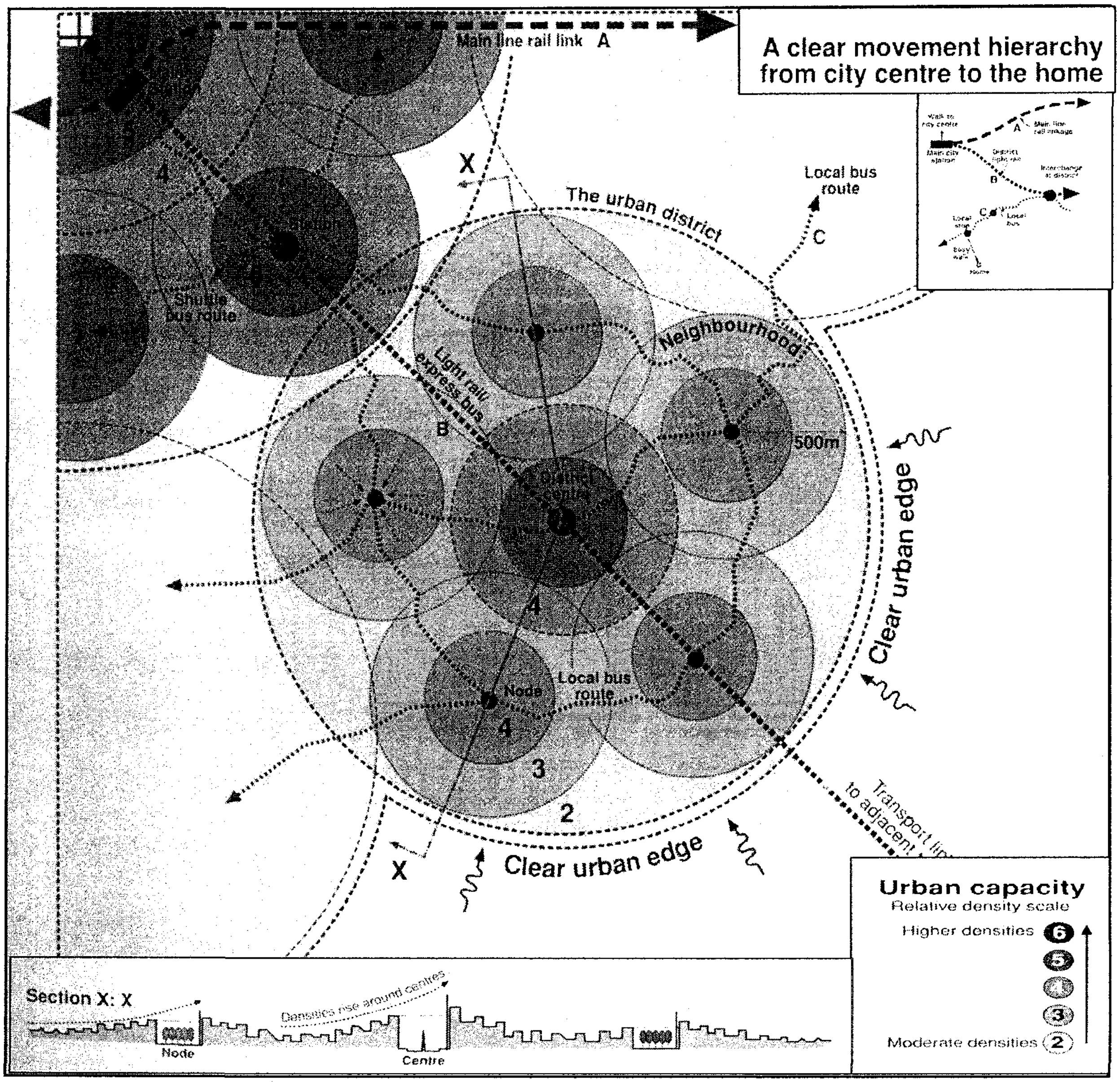


Figure 2.3 Compact urban area (British Urban Task Force, 1999)

We can classify the benefits of high urban density into the following groups: (1) Urban infill: it is limiting our conversion of rural lands into sprawling bedrooms; (2) Geometry: it is reducing the exposed surface area to volume ratio to save energy. For example town home developments on the city block scale are more efficient than single-family dwellings; and (3) Envelope design: For example, comparing the building envelopes of high-rise buildings with single houses, the building envelopes of high-rise buildings are more efficient in terms of energy consumption (air tightness, controlled ventilation, and thermal insulation) because the roofs of houses constitute a large portion of the building envelopes. However, many researchers have argued against the transferability of the compact city model on these grounds alone. For example, what is the sense of further densification given that densities are already high and associated with a range of problems including infrastructure overload, overcrowding, congestion, air pollution, severe health hazards, lack of public and green space, and environmental degradation? (Quoted in Jenks and Burgess, 2000)

2.5 SUSTAINABLE URBAN PLANNING AND INTEGRATED URBAN MODELS

Sustainable urban planning refers to urban development and intends to take a balanced approach based on economic vitality, social equity, environmental preservation and respect for the needs of future generations. Sustainable urban planning and development decisions are believed to be more successful when it encourages citizen involvement and respects the results of public consultations (El-Diraby et al., 2005).

An intensified system for urban modeling contains eight urban sub-systems, which can be categorized according to the time spans needed for changes: (1) Slow changes:

networks and land use; (2) Medium-speed changes: workplaces and housing location choice models; (3) Fast changes: employment and population; and (4) Immediate changes: goods transport and travel. There is also the ninth subsystem which is the urban environment. Its temporal behavior is more complex, and the direct impacts of human activities such as transportation noise and air pollution are immediate, but other effects such as water or soil contamination build up incrementally over time (Wegener, 1994).

There are various integrated urban modeling systems all around the world, but twelve of them are more well- known: MEPLAN, TRANUS, BOYCE, CUFM, POLIS, KIM, ITLUP, HUDS, LUT, LILT, RURBAN, and IRPUD (Wegener, 1994). These operational models represent the current state of the art of urban modeling, and they are all operational in the sense that they have been applied to real cities, but they are operational to different degrees. For example, only TRANUS and MEPLAN encompass all of the eight subsystems of spatial urban development. Moreover, these models benefit from the vast increase in memory and computing speed and the associated gain in autonomy, convenience and graphical capabilities offered by small computers. In the future, the only real test of a model's performance should be its ability to forecast the essential dynamics of the modeled system based on a past period at least as long as the forecasting period (Wegener, 1994).

Figure 2.4 shows a comprehensive integrated land use, transportation, and environment modeling system. The "behavioral core" of ILUTE system (shaded area of the figure) consists of four inter-related components (Salvini and Miller, 2005):

(1) Land development: includes both the initial development of previously "vacant" land and the redevelopment over time of existing land. This component could also be

labeled "building supply," since building stock supply functions (construction, demolition, renovation, etc.) are included.

(2) Location choice: includes the location choices of households (for residential dwellings), firms (for commercial locations), and workers (for jobs).

(3) Activity, travel and goods movement: whether performed by traditional four-step methods or by emerging activity-based models, this component involves predicting the trip making behavior of the population, ultimately expressed in terms of origin-destination flows by mode by time of day. It also, ideally, includes the prediction of goods and services movements associated with the functioning of the urban economic system.

(4) Auto ownership: models household auto ownership levels, an important determinant of household travel behavior (Salvini and Miller, 2005).

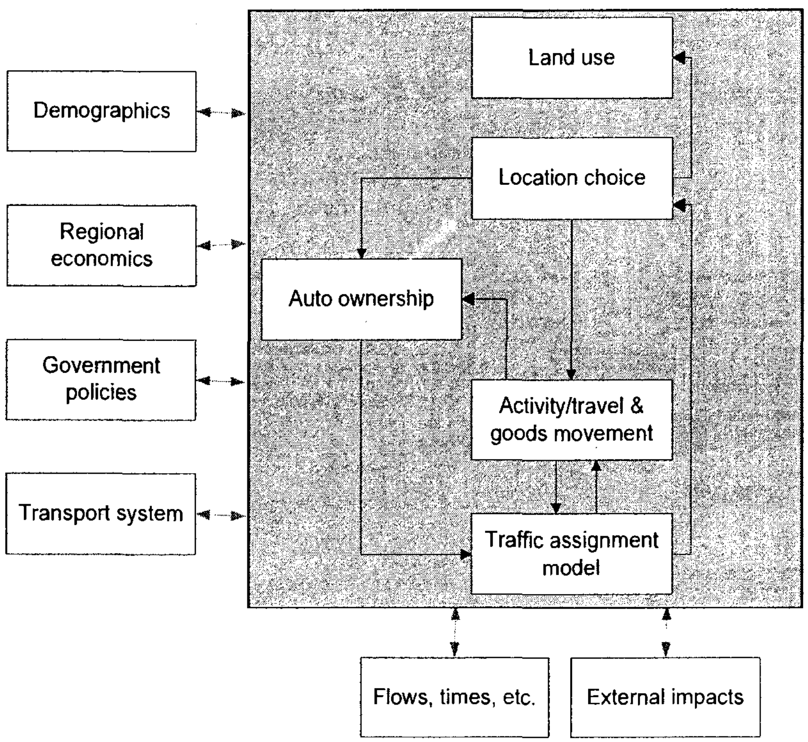


Figure 2.4 Integrated urban modeling system framework (Salvini and Miller, 2005)

2.6 TRANSPORTATION MODELING

The transportation modeling process provides the information needed for decision makers to choose among alternative strategies for improving transportation system performance. Models are based upon assumptions of the way in which travel occurs. Models provide forecasts only for those factors and alternatives which are explicitly included in the equations of the models. A clear understanding of the modeling process is important to understand transportation plans and their recommendations.

Figure 2.5 shows how the four-step classical forecasting and modeling process tries to model the trip behavior; whether to make a trip (trip generation); where to go (trip distribution); which mode of transport to use (modal split); and which route to use (traffic assignment). Models are used to analyze, simulate and forecast future traffic based on land use and socio-economic data, such as the distribution of residences, employment and commerce.

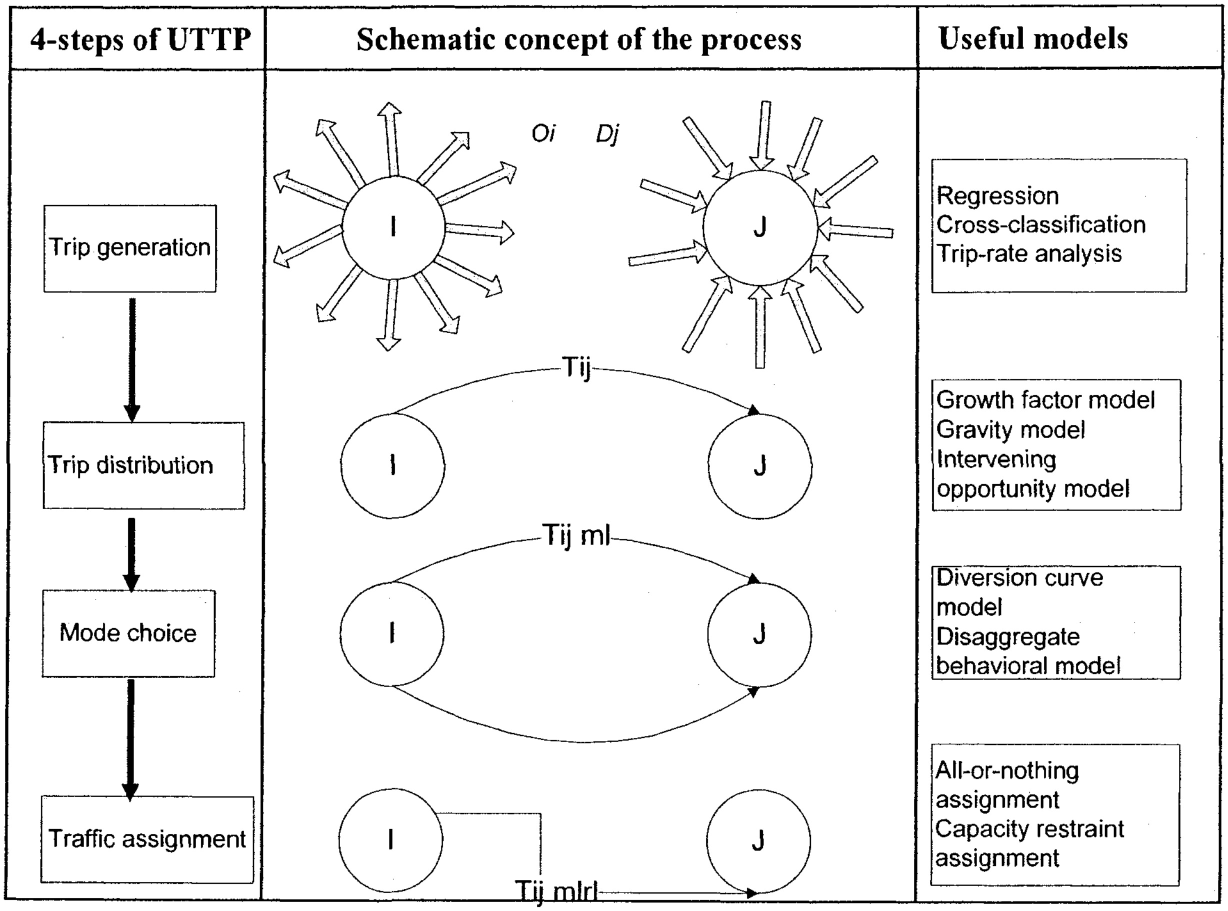


Figure 2.5 Schematic illustration of the four-step model (Bang, 1998)

2.6.1 Trip distribution models

2.6.1.1 Gravity model

For decades, social scientists have been using a modified version of Isaac Newton's Law of Gravitation to predict movement of people, information, and commodities between cities and even continents. The gravity model, as social scientists refer to the modified law of gravitation, takes into account the population size of two places and their distance; since larger places attract people, ideas, and commodities more than smaller places, and places closer together have a greater attraction.

Gravity models incorporate the ideas that trip patterns develop due to the activity of the origin, the relative attractiveness of the destination and the difficulty of making the trip. The interchange volume T_{ij} between two zones i and j can be described using Equations (2.1) and (2.2) (Travel demand modeling with TransCAD, 2005).

$$T_{ij} = P_i \frac{K_{ij} A_j f(d_{ij})}{\sum_z K_{iz} A_z f(d_{iz})} \qquad \text{(Constrained to production)} \qquad (2.1)$$

$$T_{ij} = A_i \frac{K_{ij} P_i f(d_{ij})}{\sum_z K_{zj} P_z f(d_{zj})} \qquad \text{(Constrained to attraction)} \qquad (2.2)$$

where z is all zones, T_{ij} is the forecast flow produced by zone i and attracted to zone j, P_i and A_j are the forecast number of trips produced by and attracted to zones i and j, respectively, K_{ij} is the K-factor for flow between zone i and zone j, d_{ij} is the impedance between zone i and zone j, and $f(d_{ij})$ is the friction factor between zone i and zone j.

2.6.1.2 Growth factor model

The Growth Factor Model, called also Fratar Model, has been developed to use with certain restrictions. Firstly, we need a basic trip matrix obtained from trip generation study or estimated from recent survey data. It is required to have an estimation of the volume of trips for the future "target year" of the study area, and the productions or attractions, or both in order to apply the growth factor method. To estimate trip patterns we have three alternatives:

(1) *Uniform Growth Factor:* It is used only if the data given is the growth rate for the whole study area; thus the factor will be applied to each cell in the matrix. The assumption of uniform growth is unrealistic because each area or zone has different growing factor, thus this case could be applied only for short time spans of one or two years.

(2) Single Constrained Growth Factor Method: This method can be applied when information is given about either total productions or attractions. In this case, there are different growth rates to each zone; these rates can be applied on the forecasted data by multiplying the number of trips and obtaining the updated O-D matrix.

(3) Doubly Constrained Growth Factor Method: Also known as 'Average Growth Factor' or 'Fratar Balancing'; this method is applied when both productions and attractions are given at a target year. The application needs a number of iterations to satisfy the required accuracy (Alecsandru, 2005).

2.6.2 Traffic assignment

The traffic assignment is the fourth and last of the fourth-steps forecasting process. As shown in Figure 2.6, the trip assignment estimates the volume on each link in the network system; such estimation is done for both transit (public transport) and non-transit (cars). The traffic assignment step assigns zonal destination flows to transportation routes, based on some factors that affect route choice (i.e., travel times, travel costs, comfort, and levels of service) (Hobeika, 1995).

The forecast of the person-trip and vehicle-trip flows that are expected to use the transportation system are both relevant to the assessment of its performance. The estimate of person-trips that desire to use a highway, for example, provides an indication of the passenger throughput that will be accommodated. On the other hand, the level of service that trip-makers experience when traveling on a highway is related to the vehicular flow that desires to use the highway (Papacostas and Prevendouros, 2001).

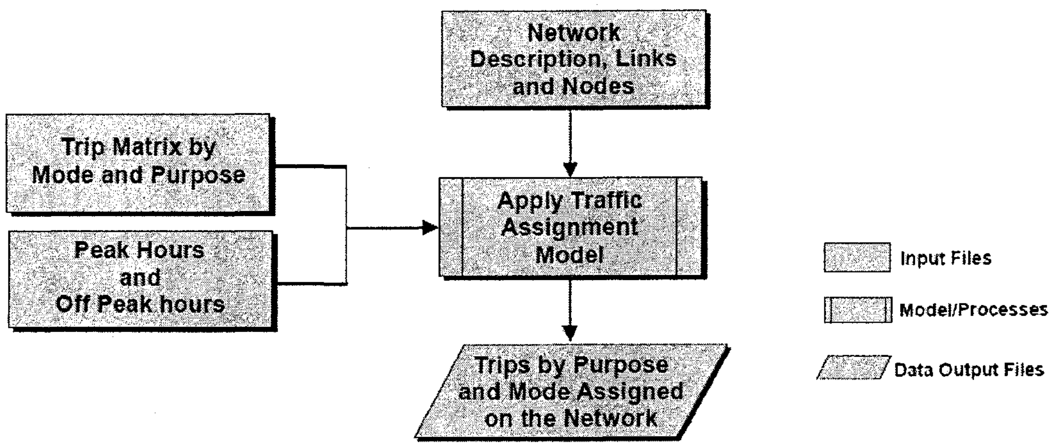


Figure 2.6 Traffic assignment process (Bhat, 2001)

Traffic assignment procedures are: (1) calculating the shortest path from each of the origin to all destinations (usually the minimum time path is used), (2) assigning the trip volume and comparing the capacity of the links to see if they are congested, and (3) repeating the whole process several times (iterated) to reach the equilibrium between travel demand and travel supply.

Different traffic assignment algorithms have been proposed over the years. The simplest is the all-or-nothing approach which assigns all the traffic between origin-destination pairs over the links that make up the shortest path between the two nodes.

This method is applicable to transit networks or uncontested road networks but not to congested networks where travel time is dependent upon traffic flows.

Probabilistic methods using logit models (Dial, 1971) were devised in an attempt to model route choice, although this methodology is not entirely suitable for dense urban networks (Easa, 1991). The dynamic models have been extensively researched and developed into complex mathematical formulations of travel behavior. These models, however, remain somewhat unworkable outside the theoretical setting (Peeta and Ziliaskopoulos, 2001). Until the problems of tractability and applicability which surround dynamic models are resolved, the method most often used in large-scale transportation planning remains the deterministic user-equilibrium static model. The first mathematical model of network equilibrium was formulated by Beckmann (Beckmann et al., 1956). User-equilibrium is based upon two methods of assigning flows between origin-destination pairs to links. The simpler method is all-or-nothing assignment, where the entire travel demand between any O-D pair is assigned to the minimum cost path. The second method incorporates the idea of capacity restraint, where the travel cost on a link increases with the flow over that link. The rate of cost increase accelerates as the volume of travel demand approaches the capacity of the link.

Wardrop (1952) proposed two fundamental principles which form the basis of the static traffic model. The first principle is that of user optimization, where each trip maker chooses the path that minimizes their individual trip cost. The optimization process includes the concept of equilibrium, which says that the system will tend toward a stable state where no individual traveler can reduce their travel cost by changing paths. According to the second principle, trips are assigned in such a way to minimize the overall cost to the system as a whole. The latter approach, while practical in some applications, is not usually realistic when applied to the highway network due to the selfish behavior of individual drivers.

As explained above, there are two methods to apply traffic assignment: (1) dynamic traffic assignment (DTA) and (2) static traffic assignment (STA). DTA is defined as the problem in which the road network is loaded with demand flows arising at different times from origin to destination on shortest paths. For dealing with the problem of DTA, we assume that there are given a set of travelers all with fixed starting time, and the task is to find possible routes. DTA plays a significant role in Intelligent Transportation Systems (ITS) by determining the path flows. On the other hand, in STA the travel times and generalized costs of travel via each route in the network will depend on physical characteristics such as the type and capacity of roads, and also on the effects of congestion caused by the interaction of traffic.

Static models, meanwhile, are rightly criticized for poorly representing utility-maximization theory and being unable to handle situations where demand exceeds capacity or where congestion is not continuous (Verhoef, 1999). While dynamic models are undoubtedly better at applying the theory, there are usually no direct comparisons of results with static models when used in planning practice (Wu et al., 2001; Nagel et al., 2000; Boyce and Bar Gera, 2003).

2.7 APPLICATION OF GIS IN TRANSPORTATION MODELING PROCESS

To integrate the huge amount of data used in certain transportation and land use analysis, Geographic Information Systems (GIS) can be used. GIS has two types of data, geographic (points, lines and areas) and non geographic (attributes of map features) that can be processed and displayed on computer screens. The most remarkable features of GIS are their capabilities to do spatial analysis and to manage information in a visual manner, simplifying the communication of analysis results.

Since the early 1990s, enormous progress has been made in the development of GIS which offer solutions to problems inherent in the transport modeling process, including the modifiable area unit problem (MAUP), boundary problems and spatial sampling, spatial dependency and spatial heterogeneity (Miller, 1999). Spiekermann and Wegener (2000) provided a good example of how GIS can be used to mitigate the problems inherent in the use of zone systems for transportation analysis. Furthermore, GIS allows for greater flexibility in managing data sources, can be used to construct highly detailed transportation networks and generate easily-decipherable visual output (Arampatzis et al., 2004). In addition, the general user-friendliness of a GIS interface can greatly reduce the costs, in terms of both time and money, incurred in the construction of a transportation planning module (Souleyrette and Anderson, 1998; Johnston and de la Barra, 1998). Finally, as the modeling practice becomes more and more concerned with spatial and temporal disaggregating, GIS plays an increasingly important role (Frihida et al., 2002).

A GIS is used for managing spatial databases, visualization, and spatial modeling and analysis. Current vector GISs can be categorized into one or more of the following: 2D

GISs, 2.5D GISs, or 3D GISs (Figure 2.7). 2D GIS databases contain only the X and Y coordinates of the objects stored in them (points, lines, and polygons). When a GIS database contains the Z coordinate as an attribute of the planar points, the GIS is considered to be a 2.5D GIS. Figure 2.7 (b) is a god example of 2.5D GIS models that can be represented using contour lines or a Triangulated Irregular Network (TIN). 3D GIS databases contain 3D data structure representing both the geometry and topology of the 3D shapes, and allowing 3D spatial analysis (ESRI, 2006).

(a) 2D GIS (b) 2.5D GIS (c) 3D GIS

Figure 2.7 Examples of different GIS categories

One of the software that allows to effectively visualizing and analyzing surface data is ArcGIS 3D Analyst. By using ArcGIS 3D Analyst, we can view a surface from multiple viewpoints, query a surface, determine what is visible from a chosen location on a surface, create a realistic perspective image that drapes raster and vector data over a surface, and record or perform three-dimensional navigation. ArcGIS 3D Analyst allows managing and visualizing, from a local or global perspective, large sets of three-dimensional geographic data.

2.8 TRANSPORTATION AND LAND USE PLANNING IN MONTREAL

2.8.1 Transportation planning organizations

In Montreal, there are three urban transportation planning players which are interrelated.

(1) Ministère des Transports du Québec (MTQ): MTQ ensures the mobility of passengers and freight through efficient and safe transportation networks that contribute to the sustainable economic and social development of Québec. The MTQ plans, designs, constructs and finances transportation infrastructure and systems, particularly expressways and public transportation networks (MTQ, 2000).

The planning and management of urban development are linked to land use planning, which is managed at the local and regional levels by municipal plans, urban planning by-laws and the Regional County Municipality (RCM) and Communauté urbaine de Montréal (CUM) development plans (MTQ, 2000).

(2) Agence Métropolitaine de Transport (AMT): AMT is a governmental agency whose mission is to improve the efficiency of the movement of people in the metropolitan area and to increase public transportation ridership. The AMT manages and funds the metropolitan commuter train network (consisting of 4 lines), park-and-ride centers, reserved bus lanes and bus terminals. It also looks after the planning, coordination, integration and promotion of public transportation services (AMT, 2003).

(3) Société de Transport de Montreal (STM): STM organizes public transportation for people within Montreal's boundaries. It manages the subway (consisting of 4 lines and 71

stations) and bus (consisting of 173 routes) networks while contributing to the development and promotion of public transportation (STM, 2008).

Although all these organizations are self dependent and they have their own responsibilities, they are somehow related to each other. Usually these institutes exchange their data and information to develop and realize their plans, which could be regional, provincial, federal, or in some cases international, such as complying with the Kyoto Protocol.

2.8.2 Montreal Master Plan

The City of Montreal is in charge of urban and land use planning. The Master Plan presents a planning and development vision for the city, as well as measures for implementing the goals and objectives resulting from that vision. Montreal Master Plan was adopted by the City Council in 2004, and it is the result of a planning and cooperative process initiated at the Montreal Summit in June 2002 (Montreal Master Plan, 2005).

The Master Plan recognizes transportation networks as fundamental components of the City's spatial organization. Accordingly, the plan emphasizes the consolidation of the various districts of Montreal that are already served by major transportation networks. The planning goals of the Master Plan are: (1) High-quality diversified and complete living environments; (2) Structuring, efficient transportation networks fully integrated into the urban fabric; (3) A prestigious, convivial and inhabited Centre; (4) Dynamic, accessible and diversified employment areas; (5) High quality architecture and urban landscapes; (6) An enhanced built, archaeological and natural heritage; and (7) A healthy environment.

Concerning the second goal (Structuring, efficient transportation networks fully integrated into the urban fabric), the sub-goals are: (1) Consolidate and develop Montreal's territory in relation to existing and planned transportation networks; and (2) Confirm the strategic function of freight transportation through the consolidation of existing infrastructure. The Plan sets five objectives relative to existing and planned transportation networks: (1) Facilitate travel between different areas of the city by establishing new public transportation services; (2) Promote urban development that favors the use of public transportation; (3) Strategically connect areas of the city by completing the road network; (4) Complete the city-wide bikeway network to provide access to activity areas and public transportation infrastructure; and (5) Promote urban development and the use of public transportation and bicycles by taking action on the supply of parking.

The City of Montreal has a strong tradition of support for public transportation and intends to optimize the use of existing networks by making public transportation a priority to serve the greatest possible number of residents. In keeping with its planning approach, the plan supports the preservation and optimal use of existing transportation networks and consequently calls for more intensive and strategic mixed land uses, with a greater emphasis on public transportation corridors. The plan encourages developments that take advantage of the proximity of public transportation, retail stores, and services that meet the needs of public transportation users, the proximity of trip generators, notably academic institutions, libraries, etc. In addition, it encourages high-quality urban design and safety, buildings oriented towards the street and designed in a way that contributes to street life, and maximized land use through the construction of underground parking (Montreal Master Plan, 2005) .

Montreal Master Plan recommends increasing the intensity and diversity of urban activities, particularly in the vicinity of subway and commuter train stations and major public transportation corridors that offer potential for consolidation due to the presence of vacant or underused land.

Given the role that the subway plays in intensifying activities, the high density residential and employment areas to be served near subway stations are subjects to detailed planning. The proposed public transportation corridors must continue to fit harmoniously into their built surroundings and contribute to revitalizing activities in the areas they serve. Vacant lots, shopping centre parking lots, park-and-ride centers and other underused lots within reasonable walking distance – approximately 500 meters – from train and metro stations are specifically targeted. However, guidelines must be developed for increasing the intensity and diversity of activities in order to maximize positive impacts, both on the surrounding urban environment and on the use of the public transportation network.

The implementation progress of Montreal's Master Plan is the object of a report published annually. For example in the implementation progress report of Montreal's Master Plan in 2004–2005, under a pilot project, four subway stations (Outremont, Radisson, Rosemont and Saint-Laurent) were affected by a program to promote the intensification and diversification of activities around subway stations, train stations and public transportation corridors (Bilan, 2004 – 2005). In addition, in the progress report of Montreal's Master Plan in 2005–2006, three areas (Décarie, Cavendish, and Jean-Talon West) were the potential targets for urban renewal and intensification of residential and employment. For the City of Montreal, the intensification of activities in these sectors is a priority because of the presence of Namur and De La Savane subway stations. Moreover, investigating the possibility of establishing a new train station on the Blainville line, which was suggested in Montreal Master Plan, was discussed in this progress report. Also, there is a program to support the creation of housing or investment real estate companies to provide grants for densification of employment or housing in the vicinity of certain subway stations (Bilan, 2005 – 2006). Master Plan Progress Reports are available for the public and it helps people to participate in this planning to achieve the vision of the city. Appendix E shows an example of applying the city infill in Griffintown (Montreal Master Plan, 2005).

2.8.3 Trip distribution by mode in Montreal

From 1982 to 1998, the travel within the GMA is on the rise, and the number of daily trips has increased from 6.2 to 8.9 million. During the same period, trips within Montreal itself rose from 4 to 5 million. By 2016, the MTQ projects that approximately two million more daily trips will be added to the 8.9 million observed in the GMA in 1998 (MTQ, 2000).

As Figure 2.8 shows, the increase in the travel was accompanied by an increase in automobile trips and a corresponding sharp drop in transit trips. The MTQ estimates that automobile use will continue to rise unless action is taken to counter-balance this trend.

Congestion on the expressway network in the central part of the island is already spilling over into the local network, which in many areas is incapable of absorbing any additional traffic (MTQ, 2000).

Public transportation networks are also heavily used, especially in the peak direction (for example, towards the centre in the morning), which causes a certain amount of discomfort for users. Public transportation is heavily used in Montreal compared with other large North American agglomerations. Montrealers average 222 trips by public transportation per year, compared to 210 in Toronto and an average of 63 in major American cities, such as New York, Boston, and Chicago (Montreal Master Plan, 2005).

Figure 2.9 shows the dynamics of the active population within the GMA for an average weekday. This figure is based on the processing of the individual origin and destination trips hour by hour. This animation emphasizes the importance of the Central Business District (CBD) for work, study and shopping trips.

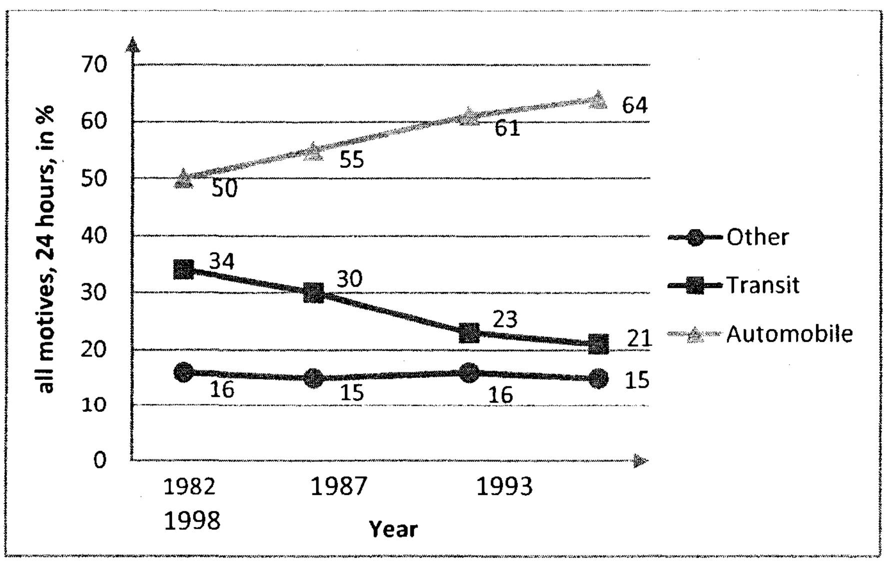


Figure 2.8 Trends in trip ending in Montreal (O-D survey of STM and AMT, 2003)

2.8.3.1 Montreal trip data collection

In Montreal, there is a trip surveying system, based on a sophisticated CATI (Computer Aided Telephone Interviewing) system. Generic in nature but specific to the methodological procedures undertaken in GMA, the CATI household survey is conducted about every five years over a 5% sample. CATI provides the flexibility and the power that are needed in conducting such a complex survey. It is complex because questions on households, people, and trips are interleaved with looping, every trip extremity needs to be geocoded, and the validity of trip chains within the household must be checked (Chapleau and Morency, 2006). The data structure of the O-D 2003 survey is shown in Appendix F.

2.9 SUMMARY

In this chapter, the literature about urban land use and transportation policies and its applications in Montreal Master Plan have been reviewed. Also the review was focused on the density concept and applying the intensification policy and its impacts in the urban context.

From a transportation point of view, the four steps of the conventional transportation modeling process were reviewed with specific emphasize on the user equilibrium method of traffic assignment.

Based on the literature review, The Montreal Master Plan, 2005, proposed population intensification near transit nodes as a measure to reduce the dependency on cars. However, the impact of these policies has not been studied in detail. Chapter 3 aims to analyze the influence of these policies on Montreal traffic using a deterministic user equilibrium traffic assignment model.

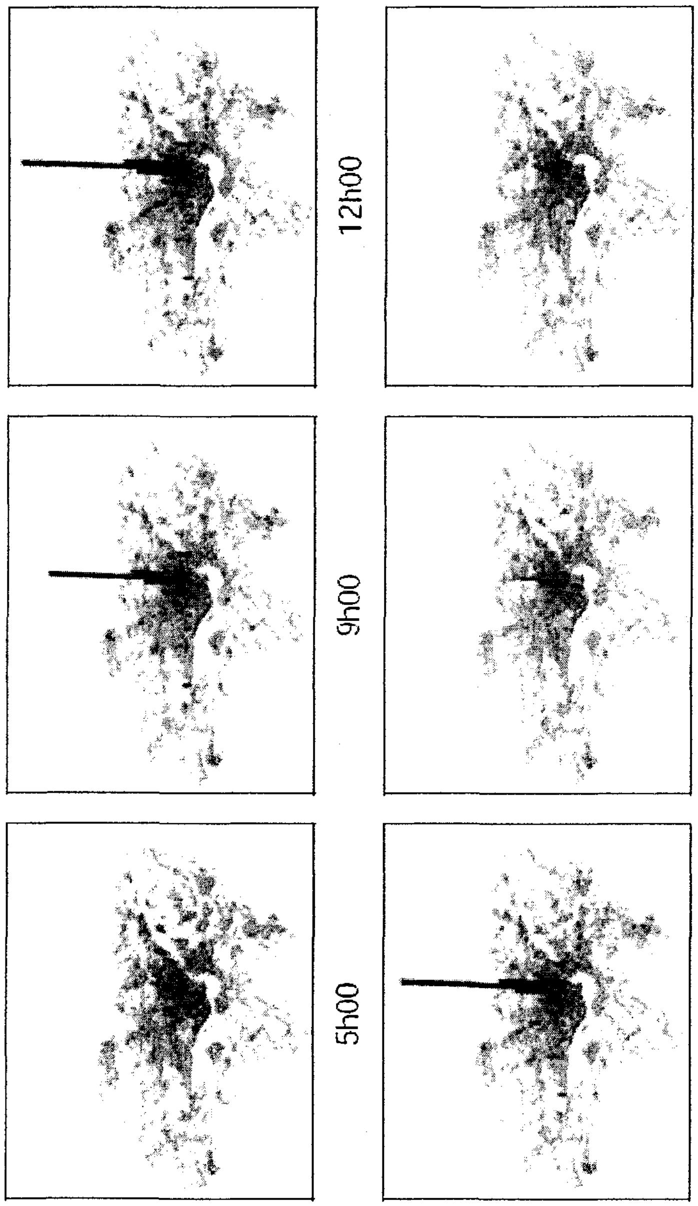


Figure 2.9 Temporal dynamics of the CBD occupancy resulting from the processing of every O-D trip over time (Chapleau, and Morency, 2003)

CHAPTER 3 METHODOLOGY

3.1 INTRODUCTION

Based on the discussion in Chapters 2, transportation and land use policies are applied to develop a sustainable urban plan. In particular, the issue of the effectiveness of urban intensification policies comes into question. If cities are to become more like the compact city model, this implies a process of constructing new buildings in cities at higher densities in vacant land, and redeveloping at high density. This population intensification will increase the amount of activities that take place within cities.

The purpose of this study is to analyze the impact of the intensification policy proposed in the Montreal Master Plan. Computer-based urban models, integrating land use and transportation models, have been developed continuously since the 1950s (Wegener, 1994). However, these models need huge amount of data and are not available for all municipalities. This chapter aims to provide a simplified approach for analyzing the impact of population intensification near subway stations based on the traffic assignment of the GMA using a deterministic user-equilibrium traffic assignment model.

As was explained in Chapter 2, land use changes are long term and the implementation of land use policies should be done over long period of time using taxation and incentive instruments, allowing higher volume ratio for buildings, etc. However, the impact of the intensification policy can be studied for any period of time based on the specific increase in population and the consequences on road congestions.

3.2 PROPOSED APPROACH

Figure 3.1 shows the main steps of the proposed approach: (1) Developing a detailed traffic assignment model for current GMA using TransCAD (Caliper, 2005); (2) Forecasting the population growth for GMA in 2013 based on the growth rate (GR) of each individual traffic analysis zone (TAZ). The population data were derived from Statistics Canada; (3) Applying intensification scenarios, redistributing the population among TAZs, and analyzing the impact of each assumption on future GMA traffic congestion by comparing changes in traffic flow; and (4) Assessing the feasibility of intensification based on the volume ratio regulations and visualizing the results in three dimensions (3D). Three main data sets are used in the proposed approach: (1) The road network data obtained from DMTI (DMTI, 2001), (2) Origin-Destination (O-D) survey matrix (AMT, 2003), and (3) population data from Statistics Canada. More details about these data sets are given in the next section. TransCAD (Caliper, 2005), ArcGIS (ESRI, 2005), and ArcView (ESRI, 2006) software systems were used in this study.

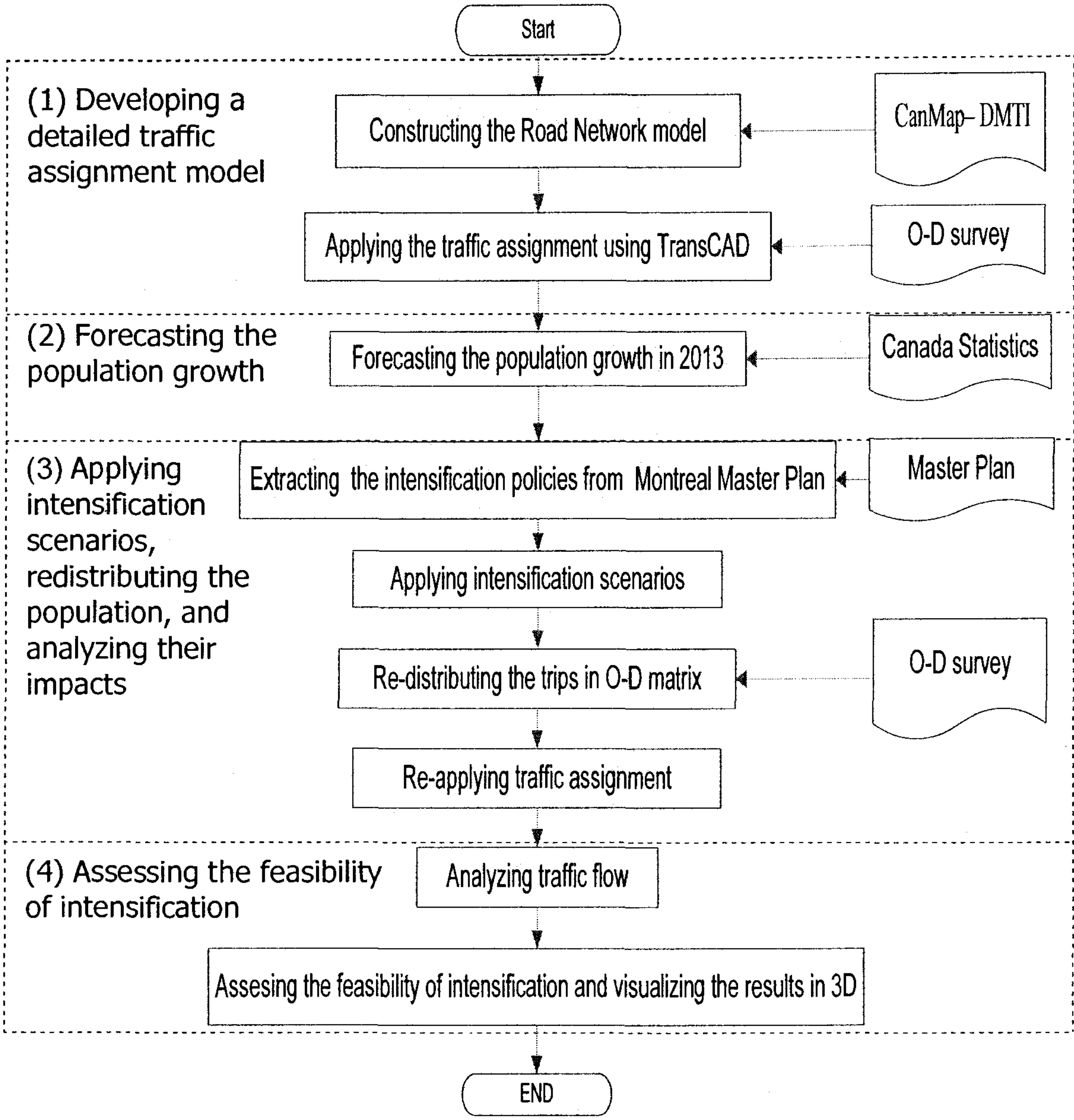


Figure 3.1 Proposed approach

3.3 CONSTRUCTING THE ROAD NETWORK MODEL

A transportation network consists of a set of physical links connected with each other which is used by any mobile mode with the purpose of transporting people or goods; this set of infrastructure includes roads, highways, railroads, etc. However, our analysis will focus on road networks, which represent the physical road network including all the attributes used in traffic forecasting.

The GMA road network has been modeled using TransCAD. While most models use greatly simplified networks containing only highways and major streets, the present model contains all roads in the GMA. This network of the GMA was obtained from Desktop Mapping Technologies Inc. (DMTI, 2001). The network was constructed as a line layer including series of nodes and directional links. The network must satisfy two important continuity requirements: (1) All links must be connected to two distinct nodes (referred to as "A" and "B"); and (2) For a node to be useful, it must connect to one or more links. Also the network should have a specific boundary.

The link attributes, such as length and travel time, were obtained from the DMTI data set, but the capacity, number of lanes, and delay functions for each link were assumed based on the road functional class as will be explained later. The following steps were used in preparing the data for the traffic assignment model.

3. 3.1 Traffic analysis zones (TAZs)

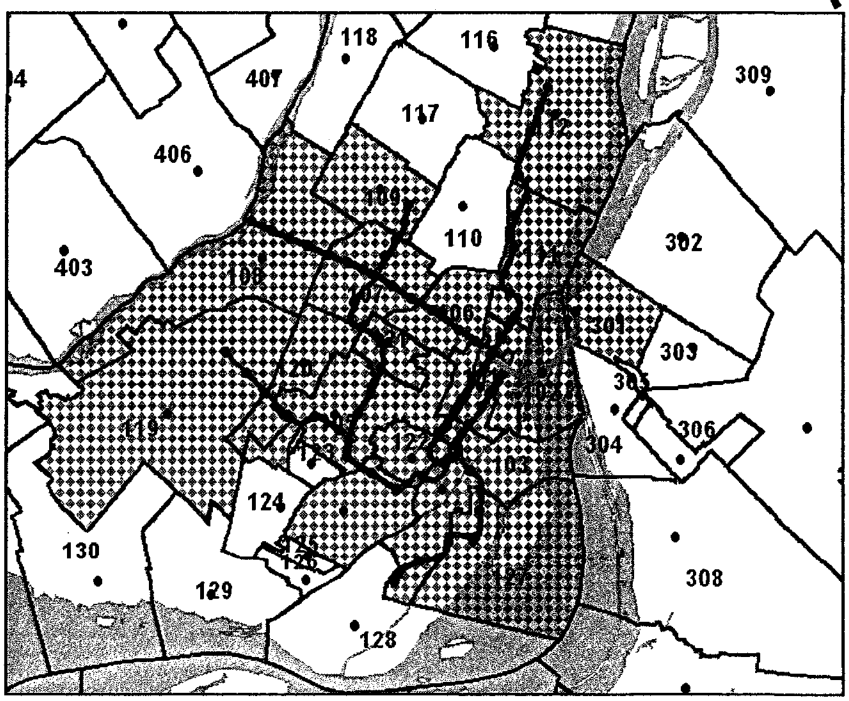
The zone data of the GMA were obtained from the Ministry of Transportation of Quebec (MTQ). A zone is a geographic area which is basically the unity of data aggregation. Trips have an origin and a destination in two specific zones. Usually for the purpose of transportation studies, they are called Traffic Analysis Zones (TAZs). TAZs are typically defined by a combination of major streets, highways, natural boundaries (such as rivers), and census boundaries. Many zones are combined to create a district.

The MTQ zonal map has a different coordinate system (Geographic System) from the DMTI road network (Modified Transverse Mercator (MTM) Projection), and to overlap these two maps, map projection was needed. A map projection represents a major mapping concept required to automate spatial data processing. Once map data are projected onto a planar surface, features can be referenced by a planar coordinate system. The geographic system (latitude-longitude), which is based on angles measured on a sphere, is not valid for measurements on a plane. Therefore, a Cartesian coordinate system is used. Projection formulas are mathematical expressions which convert data from a geographic location (latitude and longitude) on a sphere or spheroid to a representative location on a flat surface (ESRI, 1994).

The digital map of the subway lines obtained from Communauté Urbaine de Montreal was also projected using the MTM projection.

ArcMap software was used for applying the projection. Appendix G shows the projection steps. Figure 3.2 (a) shows the GMA containing 104 TAZs, and Figure 3.2 (b) shows the 17 TAZs having subway stations. Appendix H shows more details about subway zones.

(a) GMA containing 104 TAZs



(b) The 17 TAZs having subway stations

Figure 3.2 TAZs of GMA

3. 3.2 O-D matrix

In this research two kinds of O-D trip data were used to implement the traffic assignment: (1) Disaggregated O-D data, and (2) Aggregated O-D data. The aggregated 104x104 O-D matrix for car driver trips was obtained based on the trip data provided in the O-D survey (AMT, 2003) for the period of 6-9 AM. Origin and destination TAZs of all trips should be identified in order to produce traffic flows among the TAZs (Meyer and Miller, 2001).

In addition, the latest O-D survey (AMT, 2003) contains the disagregated trip data including the point location of the origin and distination of each trip. Appendix F shows the format of the survey data used to prepare the disagregated trip data for the 2003 O-D survey.

3. 3.3 Allocating centroids and centroid connectors

In order to apply the traffic assignmnet, each TAZ should be represented with a single point (centroid). A centroid is not necessarily the geometric center of a TAZ; instead it can be considered as its gravity center.

The centroids of TAZs were assigned according to the following steps: As explained above, the latest O-D survey (AMT, 2003) contains the disagregated trip data including the point location of the origin and distination of each trip. The origin and distination points were plotted in GIS and used to allocate the centroids for each TAZ based on their density as shown in Figure 3.3(a). Each centroid was linked to the network by one or more centroid connectors, as shown in Figures 3.3 (b) and (c). The travel speed of local streets was assigned to these connectors.

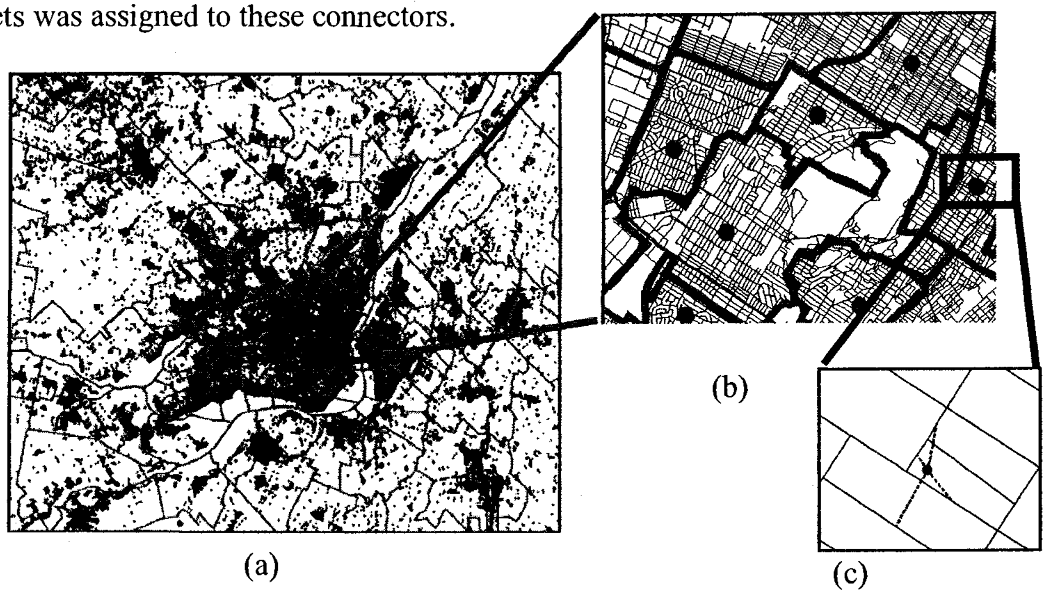


Figure 3.3 Connecting the centroids to the road network by centroid connectors

3. 3.4 Assuming the number of lanes per link and link capacity

The capacity depends mostly upon the free-flow speed and the number of lanes. However, the number of lanes and link capacity are not included in the DMTI data. Therefore the number of lanes in each direction of each road was assumed based on the road functional class. Table 3.1 shows the number of lanes and link capacity per lane considered for each functional class. These estimations were based on the try and error method to reach acceptable values of the traffic assignment.

Table 3.1 Assuming the number of lanes and the capacity

Carto value	*Functional class*	*Speed (km)*	*Number of lanes*	*Capacity per lane (vehicle/h)*
1	Freeway	100	3	1900
2	Primary highway	80	3	1500
3	Secondary Highway	60	3	1200
4	Collector roads	50	2	900
5	Local roads	40	1	400

3.3.5 Defining the delay function

Most of the traffic assignment procedures update travel time based on link performance functions, which are mathematical descriptions of the relationship between travel time and link volume. The BPR (Bureau of Public Roads) formulation is one of the most commonly used link performance functions (Eq. 3.1) (BPR, 1964).

$$t = t_f \left[1 + \alpha \left(\frac{V}{C} \right)^{\beta} \right] \tag{3.1}$$

where t is the congested link travel time, t_f is the link free flow travel time, α and β are calibration parameters, C and V are the link capacity and volume, respectively. Table 3.2 shows different values of α and β, which are assigned based on the road functional class.

Table 3.2 Estimated BPR function parameters for multilane links (BPR, 1964)

Roads functional class	Alpha	Beta
Locals	0.25	4.0
Collectors	0.45	4.0
Minor Arterial	0.55	3.0
Major Arterial	0.65	3.8
Freeway	0.84	5.5

3. 4 APPLYING THE TRAFFIC ASSIGNMENT

In order to measure the current and future traffic volume, proper principles and methods to implement the traffic assignment were considered.

3.4.1 User equilibrium process

There are two principles in traffic assignment: (1) user equilibrium in which no user can reduce his travel time by using an alternative route, and (2) system optimum in which the traffic assignment should minimize the total travel times of all users (Wardrop, 1952). In this study, the aim was to reach the user equilibrium traffic assignment and to predict the traffic patterns in the road network. In user equilibrium traffic assignment, the average travel time is minimized by assuming that each motorist behaves cooperatively in choosing his own route to ensure the most efficient use of the whole system.

As shown in Figure 3.4, the equilibrium process starts by importing the O-D matrix in the defined traffic network, and then computing the initial path to embed the flow related to each link. After running the traffic assignment, if the path travel time was satisfactory, the process will end, otherwise we have to compute the new set of available paths.

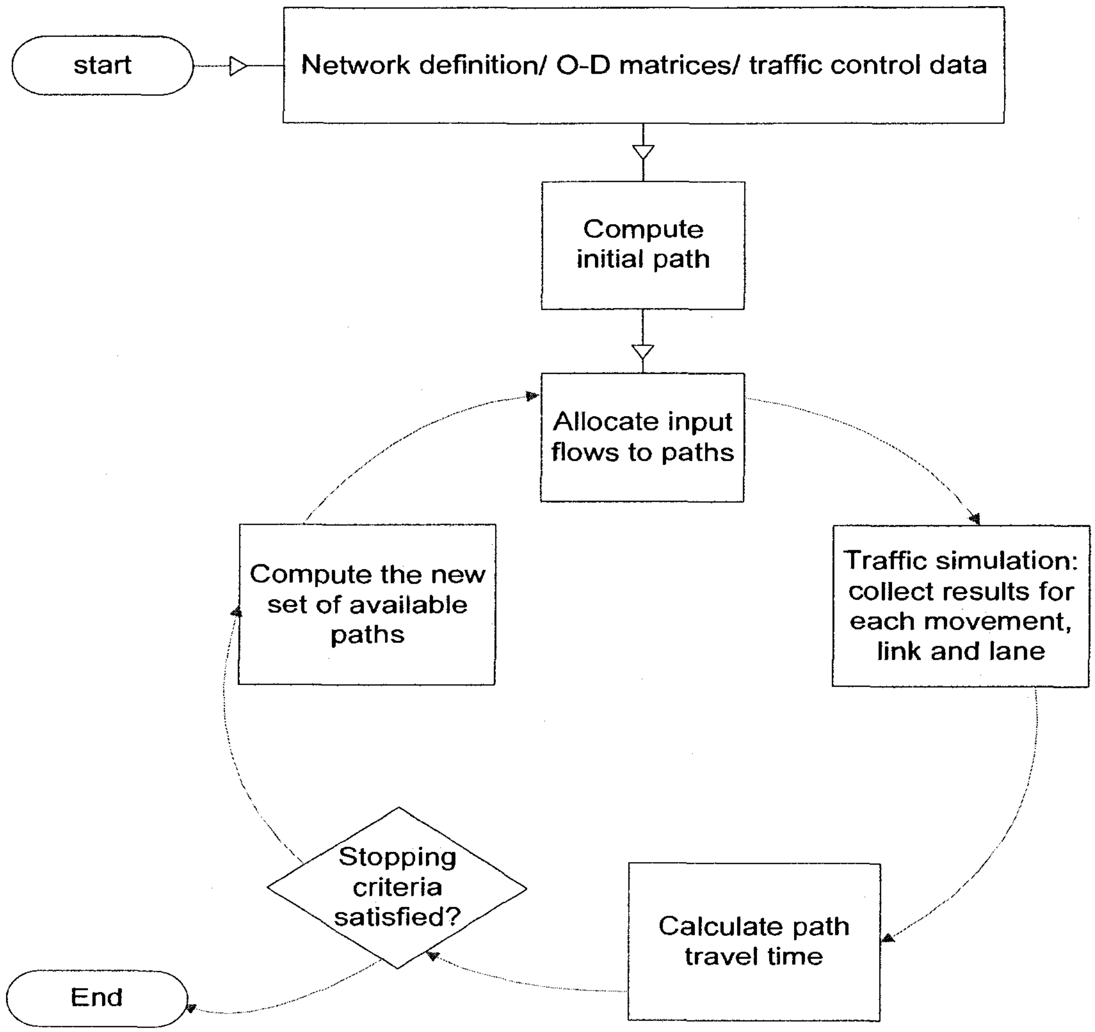


Figure 3.4 Equilibrium process (Transportation planning modeling with EMME/2, 2008)

3.4.2 Applying static traffic assignment

As was discussed in Chapter 2, most of the recent research in traffic modeling describes theoretical formulations of dynamic modeling that are even more capable of capturing the temporal distribution of choices and activities.

In this research, STA modeling was used because of is simplicity. STA has the following characteristics: (1) STA modeling has no concept of arrival or departure times, and the issue of trips departing late in the peak period is not relevant; (2) STA modeling has the potential to significantly under-predict congestion levels due to changes in demand over the peak period; (3) Large-scale traffic assignment models are often static in nature; and (4) STA modeling does not need the time-dependent O-D matrix and a single O-D matrix for the entire peak period suffices for STA, but for DTA one needs to know how this demand changes during the peak period (Boyles et al., 2005).

3.5 FORECASTING THE POPULATION GROWTH

Population growth is the change in population over time, and can be quantified as the change in the number of individuals in a population per unit time. In demographics and ecology, population growth rate (GR) is the change in population over a specific time period expressed as a percentage of the number of individuals in the population at the beginning of that period. This can be written in the following equation (Association of Public Health Epidemiologists in Ontario, 2006).

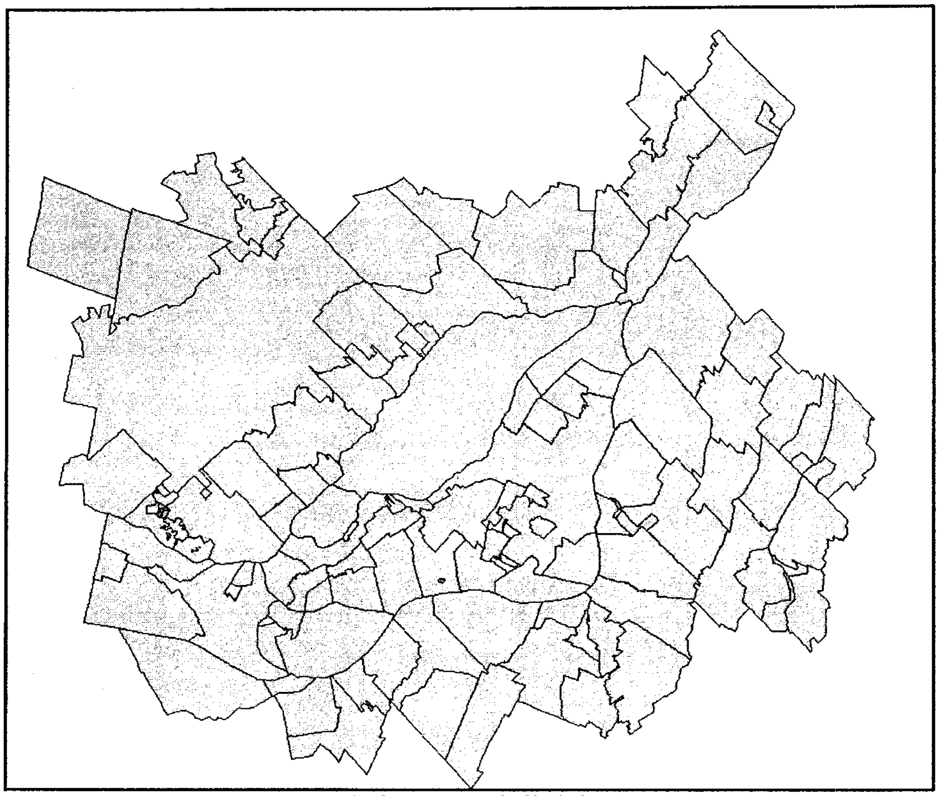
$$GR = \frac{\textit{Population at end of period - Population at beginning of period}}{\textit{Population at beginning of period}} \tag{3.2}$$

In Quebec, many of merging and de-merging of metropolitan governance happened in Montreal, which changed the structural shape of the metropolitan area every time (Gilbert, 2004). Due to this matter, studying and assessing the data for each merging or de-merging period should be linked together by using some assumptions. Based on the O-

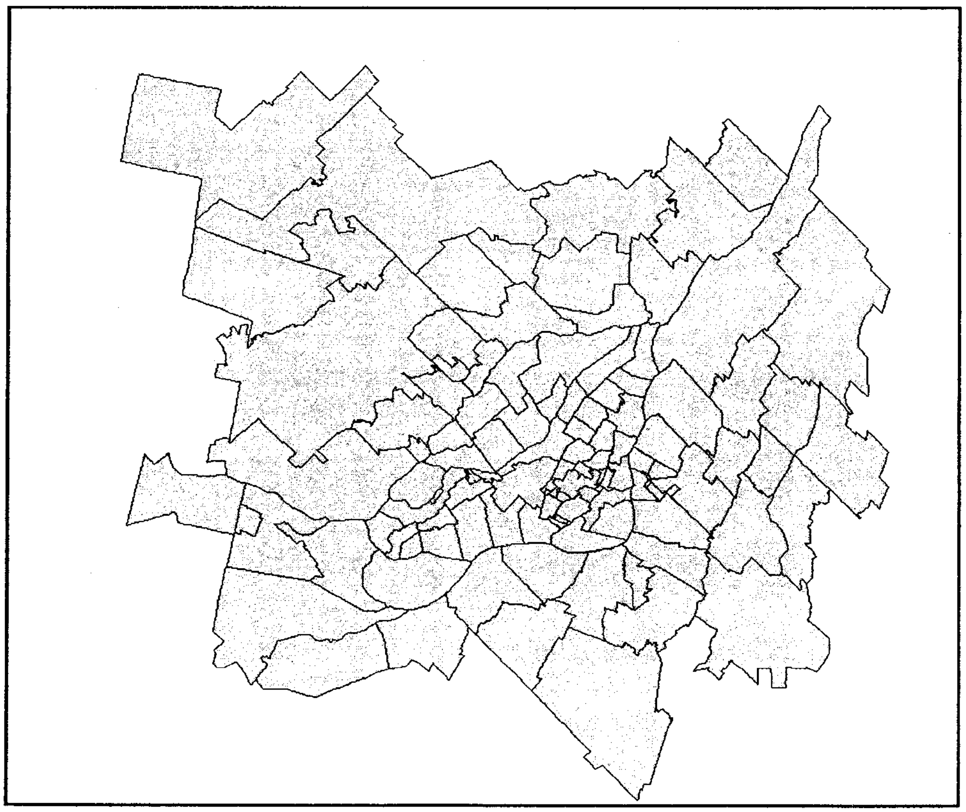
D survey (2003), GMA was composed of one urban community, eight regions and 104 TAZs in 2003. The population data were obtained from Statistics Canada, which produces population statistics every 5 years. Although the census data for 2006 were available, the subdivisions of 2006 did not match those of 2001. Therefore, in this study, it was decided to use the census data of 1996 and 2001 to calculate the GR. Moreover, the census subdivisions for 2001 do not match the TAZs. Therefore, as it is shown in Figure 3.5, it was necessary to modify the census subdivisions to match TAZs by grouping together several census subdivisions to approximately match the TAZs and then to add their population as the population of the corresponding TAZ. Furthermore, in order to calculate the GR, it was necessary to get the difference of two sets of population data. The census data of 1996 and 2001 were used to obtain the GR for each TAZ and this GR was applied twice to get the population of 2011, which is assumed equal to the population of 2013. Figure 3.6 shows the population growth for two census periods (1996 and 2001) and the forecasted population at 2011 for each zone. Table 3.3 shows the data set used in this study.

Table 3.3 The linked data sets

Data	***Year***	***Number of zones***
Digital zonal map	2003	104 TAZs
O-D	2003	104 TAZs
Census	1996, 2001	109 Census subdivisions
Current study	2013	104 TAZs



(a) Census subdivisions



(b) GMA TAZs

Figure 3.5 grouping census subdivisions to approximately match the TAZs

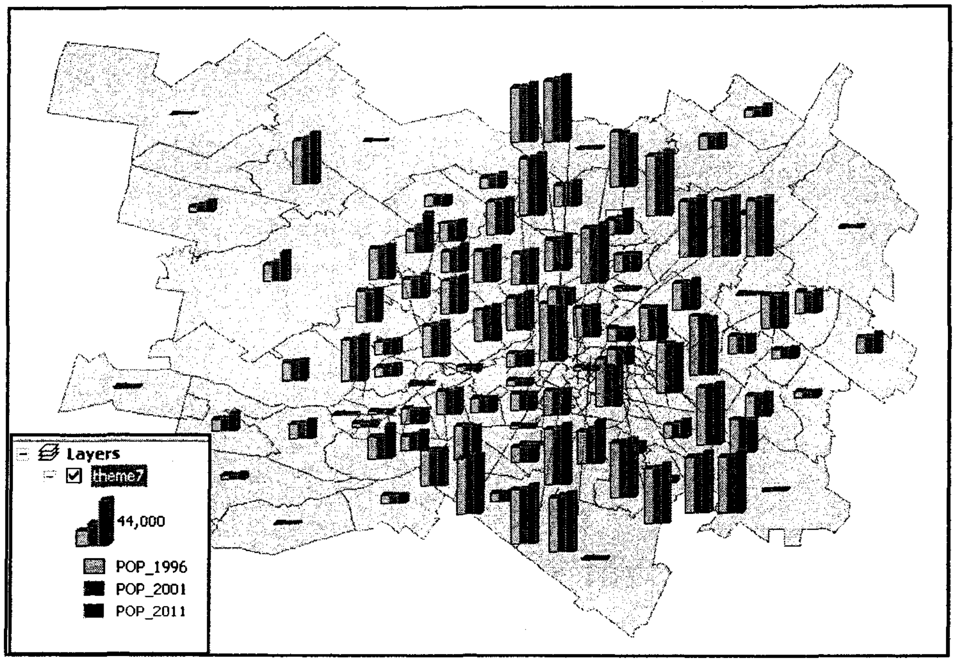


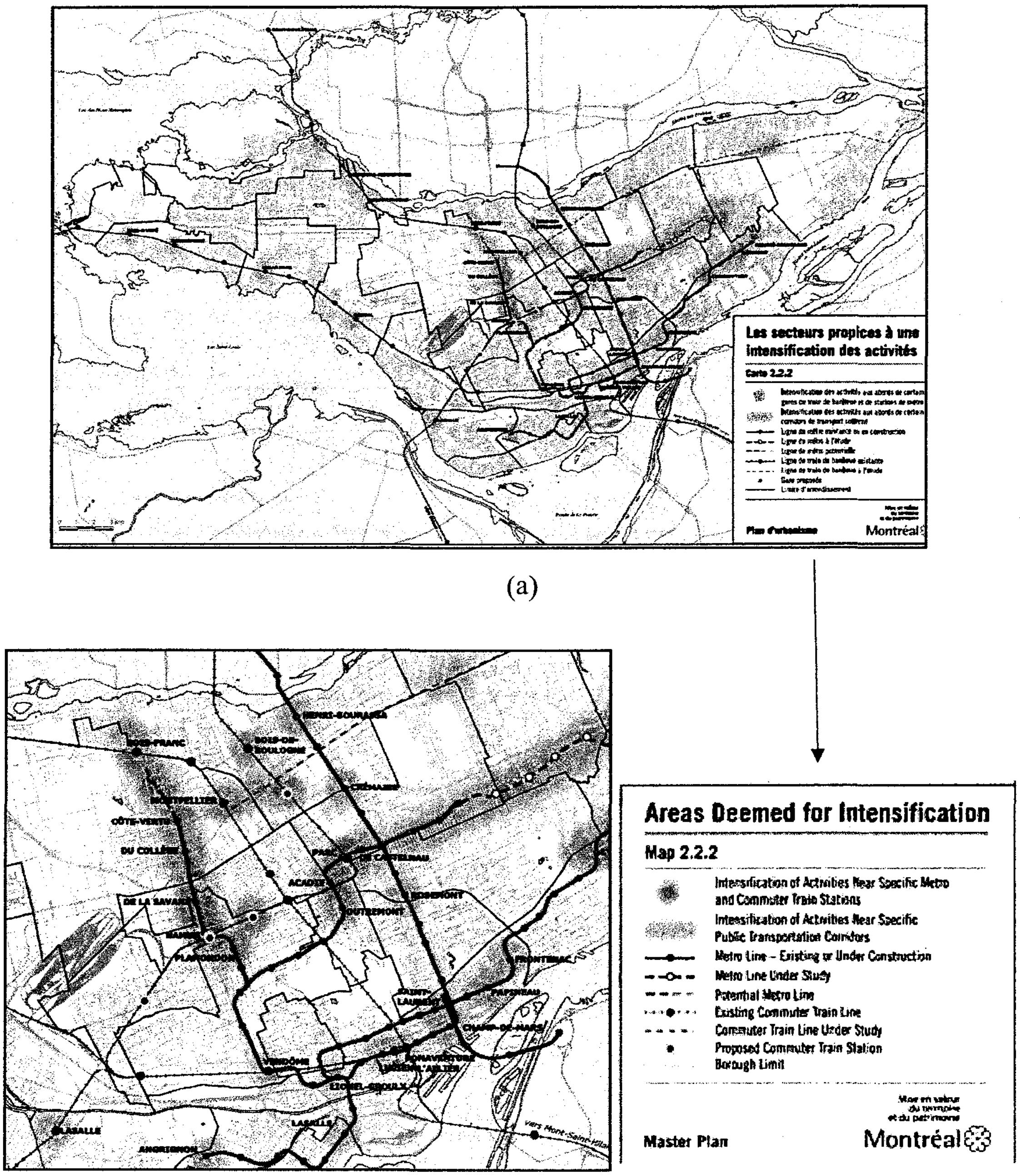
Figure 3.6 Changes of the population of the GMA

3.6 EXTRACTING THE INTENSIFICATION POLICIES FROM MONTREAL MASTER PLAN

As was explained in Chapter 2, the Master Plan of Montreal recommends increasing the density and diversity of urban activities, particularly in the vicinity of subway and commuter train stations, and major public transportation corridors that offer the potential for consolidation due to the presence of vacant or underused land (Montreal Master Plan, 2005).

Figure 3.7 (a), shows the area deemed for intensification according to the Master Plan (2005). Figure 3.7 (b) shows that most of the intensification areas are along subway lines.

Therefore, in this study, the intensification policy will be applied in TAZs containing subway stations (Figure 3.2).



(a)

(b)

(c)

Figure 3.7 Areas deemed for intensification (Master Plan, 2005)

3.7 APPLYING THE INTENSIFICATION SCENARIOS

Three intensification scenarios were considered to illustrate the volume-capacity ratio changes in Montreal's road network under the impact of these scenarios in 2008 considering population increase. In the first scenario, the redistribution of the forecasted new trips among 104 TAZs of GMA was applied based on their observed growth rate. Two parameters were used to represent the level of intensification and the level of modal shift from cars to subway in the intensified zones. These parameters are called intensification factors and modal shift factor. Because the Master Plan does not provide any specific values of the level of intensification, several values have been applied in this study to investigate the impact of intensification on road congestion. Other values can be applied in future studies for more detailed sensitivity analysis. In the second future scenario, 20% intensification of the GMA population growth was applied in the zones containing subway stations, and 10% and 40% modal shift factors from cars to subway were assumed based on the modal ratios of the 2003 O-D survey. The third future scenario is similar to the second one, but with 50% intensification factor and different modal shift factors. The definitions of the intensification factor and modal shift factor are given in the following sub-sections. The results of the above three future scenarios will be shown in Chapter 4.

3.7.1 Distributing the increased population without intensification

In this case, the only available information is the population GR for each individual TAZ and this is assumed as an approximation of the growth factor. The growth factor method was used to predict future trips between origin and destination TAZs. This factor is applied to the production of each TAZ in the O-D matrix to build a new forecasted flow matrix using the growth factor method (Eq. 3.3).

$$T_{ij} = F_i t_{ij} \tag{3.3}$$

where T_{ij} and t_{ij} are the future and present trip volumes between zones i and j, respectively; and F_i is the growth factor.

3.7.2 Distributing the increased population with intensification

In this case, the applied approach is changing the travel behavior in TAZs by changing the demand for car-based trips. The factors influencing travel demand could be: (1) the location and intensity of land use, (2) socioeconomic characteristics of people in the study area, and (3) extent, cost, and quality of transportation (Alecsandru, 2007). We assume that the intensification of population is applied only in the TAZs containing subway stations, and the subway system can attract people to substitute their car-based trips with subway trips. The socio economic characteristics like household income, household size, age, etc., were not considered.

The following steps are used to distribute the increase of population with intensification:

(1) Calculating the total population (Eq. 3.4);

$$P_t = \sum_{i=1}^{n+m} P_i \tag{3.4}$$

where P_t is the total present population, P_i *is* the present population of zone i, n is the number of subway zones, and m is the number of other TAZs.

(2) Calculating the portion of population to be intensified (Eq. 3.5);

$$\Delta P_i = P_i \times GR_i \tag{3.5}$$

where GR_i is the growth rate and ΔP_i is the population increase in zone i.

(3) Calculating the population to be redistributed in the region (Eq. 3.6);

$$P_d = \sum_{i=1}^{n+m} a \times \Delta P_i \tag{3.6}$$

where P_d is the population to be redistributed and a is the intensification factor.

(4) Redistributing P_d in all subway TAZs proportional to their population ratio with respect to the total population of subway zones (Eq. 3.7);

$$D_i = \frac{P_i}{\sum_{i=1}^{n} P_i} \times P_d \tag{3.7}$$

where D_i is the increase of the population because of intensification in subway zone i.

(5) Calculating the population with intensification (Eq. 3.8, and 3.9);

$$\begin{cases} P_i'' = P_i + D_i & (3.8) \\ P_j'' = P_j + (1-a)\Delta P_j & (3.9) \end{cases}$$

where P_i'' and P_j'' are the future populations with intensification for subway zones and other zones, respectively.

(6) Obtaining the new growth factor considering intensification (Eq. 3.10).

$$F_i = \frac{P_i''}{P_i} \tag{3.10}$$

3.7.3 Distributing the increased population with intensification and modal shift

According to the modal distribution of trip making in North America (AMT, 2003), we can observe the great usage of personal cars. Figure 3.8 shows the percentage of trips based on personal cars and subway trips in Montreal subway zones. It can be observed that zones with greater number of subway stations have more subway usage. For example zone 111 (South-east) with 6 subway stations has higher ratio in comparison to zone 119 (Saint-Laurent) with 2 subway stations.

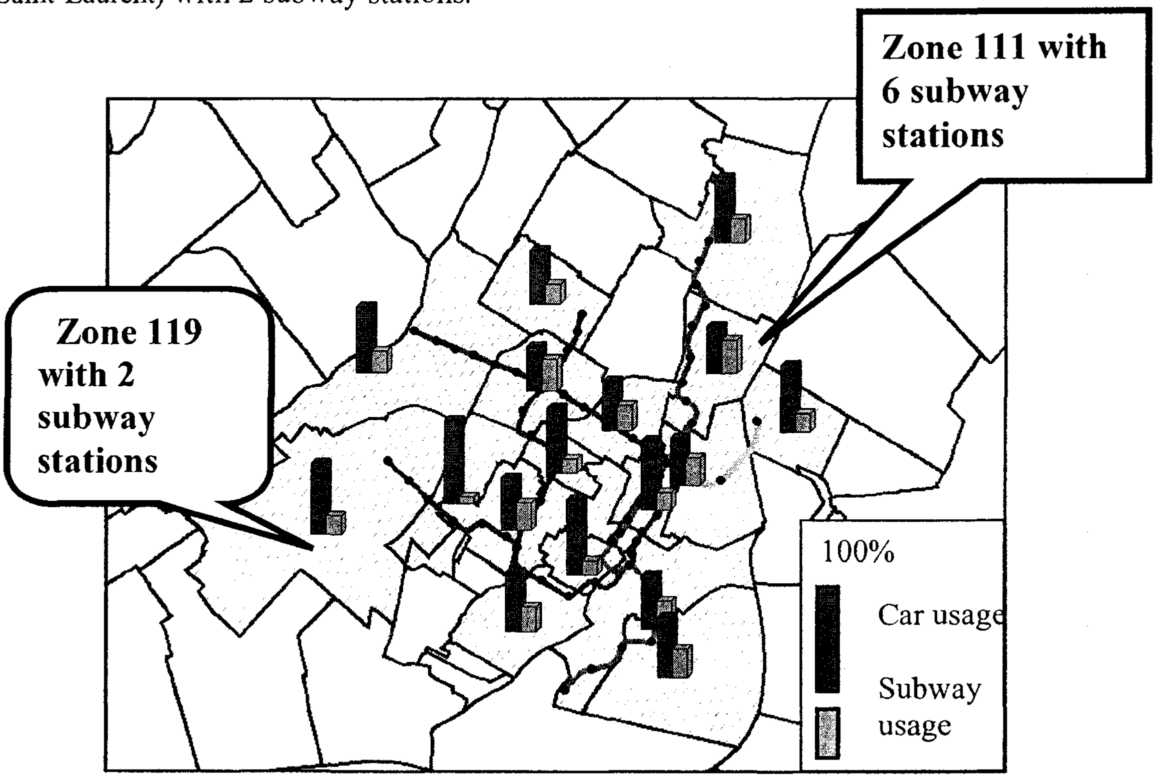


Figure 3.8 Percentage of the personal cars usage and subway usage

In order to decrease the congestion caused by personal vehicles, the intensification plan is combined with a pre-assigned modal shift from car usage to subway usage. A *modal shift factor* (*b*) representing this shift is introduced considering the modal split ratio (i.e., the ratio between subway trips and vehicle trips). The modified growth factor is calculated by introducing the above two ratios to Eq. 3.3 as shown in Eq. 3.11.

$$F'_i = (1 - b \times \frac{M_i}{\overline{M}}) \times F_i \qquad (3.11)$$

Where F'_i is the modified growth factor, F_i is the growth factor calculated in Eq. (3.10), M_i is the modal split ratio (subway vs. cars) based on the O-D survey, and $\overline{M}$ is the average M_i. Table 3.4 shows the modal split ratios in Montreal subway zones using the modal trip shares in the 2003 O-D survey.

Table 3.4 The modal split ratios in Montreal subway zones

Subway Zones	***101***	***102***	***103***	***104***	***105***	***106***	***107***	***108***	***109***	***111***	***112***	***119***	***120***	***121***	***122***	***127***	***301***
Subway trips (%)	15	24	25	22	23	22	28	19	17	29	21	16	6	12	12	24	16
Car trips (%)	59	40	47	52	44	42	38	56	45	40	55	60	71	55	63	51	57
M_i *(%)*	25	60	53	42	52	52	74	34	38	73	38	27	8	22	19	47	28

3.8 APPLYING THE GROWTH FACTOR METHOD TO REDISTRIBUTE THE INCREASED TRIPS

Trip distributing model was used to redistribute the predicted future trips between origins or destinations. In trip distribution, a new flow matrix is forecasted based on estimates of future productions and attractions. In this research, the growth factor method was applied because of the lack of information about friction factor of each zone, and the amount of their activity as an origin and attractiveness as a destination. The growth factor method involves scaling an existing matrix by applying multiplicative factors using Eq. 3.10 or 3.11 to matrix cells.

3.9 REAPPLYING THE TRAFFIC ASSIGNMENT FOR EACH FUTURE SCENARIO

After redistributing and modifying the O-D matrix based on each scenario, we imported these matrices into TransCAD and ran the traffic assignment aiming to compare the future traffic congestion to the current traffic situation in GMA and to analyze the feasibility of each intensification policy. The implementation of each scenario is discussed in Chapter 4.

3.10 ANALYZING THE TRAFFIC FLOW

After reapplying the traffic assignment for each scenario, analyzing the impact of each intensification case on the network performance is important. Traffic assignment results are compared using the flow map. The flow map is a combination of two thematic map types: a color theme, and a scaled symbol theme. Each link is assigned a color based upon its volume-capacity ratio and a width based upon its hourly volume. In addition, the average VOC ratio for links in both directions are calculated for the whole GMA (104 TAZs) and for the subway zones (17 TAZs). This analysis will be explained in Chapter 4.

3.11 ASSESSING THE FEASIBILITY OF INTENSIFICATION

In order to accommodate the intensified population in TAZs, there are different methods including: redevelopment of the lots using the maximum allowed volume capacity ratio.

This option is investigated, and to visualize it, the current permitted height of each building should be used. In this research, the only borough for which the layer of buildings and regulations were available for this research is the South-West Borough located southwest of downtown Montreal. The borough is served by the green and orange subway lines.

The volume ratio, and the maximum and the present height of each building are available as attributes and the following steps are used:

(1) Estimating additional floor area (Eq. 3.12).

$$A' = \sum A(N_1 - N_2) \tag{3.12}$$

where A', A are the additional floor area and the area of polygons , respectively, and N_1, N_2 are the maximum and present number of floors assigned to the buildings, respectively.

(2) Evaluating the maximum additional population that can be accommodated in these buildings. The additional capacity population of the buildings should be greater than the intensified population (Eq. 3.13)

$$P' = \frac{A'}{a} > P'' \tag{3.13}$$

where P', P'' are the additional capacity population and intensified population, respectively, and a is the average floor area per person.

3.12 SUMMARY AND CONCLUSIONS

In this chapter, the proposed approach for analyzing the impact of population intensification near subway stations based on traffic assignment using a deterministic user equilibrium traffic assignment model was discussed. The proposed approach has the following main steps: (1) STA model is used to build a detailed traffic assignment model for the GMA using TransCAD; (2) The GR of each individual TAZ were derived from Statistics Canada (1996 and 2001); (3) The census subdivisions of 2001 were modified by grouping together several census subdivisions to approximately match the TAZs in order to link the population of the corresponding TAZ; (4) The target forecasting year was taken as 2013; and three future intensification scenarios were proposed to apply in subway zones; (5) The growth factor method was used to redistribute the population among TAZs using MATLAB; (6) In order to decrease the congestion caused by cars, the intensification plan is combined with a pre-assigned modal shift from car usage to subway usage. A *modal shift factor* (b) representing this shift is introduced considering the modal split ratio (i.e., the ratio between subway trips and vehicle trips in each TAZ); (7) The impact of each assumption on future GMA traffic congestion is analyzed by comparing changes in traffic flow; and (8) In order to accommodate the intensified population in TAZs the feasibility of intensification based on the volume ratio regulations was discussed and the results were visualized in three dimensions.

The proposed approach is expected to provide a simplified method that can be applied to investigate intensification policies by assuming certain levels of intensification and modal shift at specific zones. However, the assumptions for this approach have to be used carefully to get meaningful results as will be explained in Chapter 4.

CHAPTER 4 ANALYSIS OF RESULTS

4.1 INTRODUCTION

This chapter presents the analysis results based on the methods explained in Chapter 3. The traffic assignment is applied after gathering and integrating the required data overlapping the different digital maps. Then the results are analyzed to study current and future GMA traffic situation. The feasibility of the intensification policy is studied by applying this policy in subway zones through three different future scenarios, and validating their applicability in Montreal. The required information to realize the analysis includes the growth rate for each zone based on Canada Statistics to redistribute the increased trips in 2013 according to each scenario assumption.

4.2 SELECTION OF ANALYSIS TOOLS AND STUDY AREA

TransCAD and ArcGIS products were chosen as our analysis tools.

(1) TransCAD: is software that combines GIS and transportation modeling capabilities in a single integrated platform. TransCAD can be used for all modes of transportation, at any scale or level of detail by providing: (1) A powerful GIS engine with special extensions for transportation; (2) Mapping, visualization, and analysis tools designed for transportation applications; and (3) Application modules for routing, travel demand forecasting, public transit, logistics, site location, and territory management (Caliper, 2005). In addition, TransCAD makes it possible for models to be much more accurate.

Network distances and travel times are based on the actual shape of the road network and a correct representation of highway interchanges. Also, with networks it is possible to specify complex road attributes such as truck exclusions, delays at intersections, one-way streets, and construction zones.

TransCAD was chosen to apply the analysis for four reasons: first and foremost, it can be used to efficiently link travel behavior patterns and socio-economic data within a spatial framework. Secondly, it incorporates geographic details which are essential in the construction of realistic links and nodes as well as in the discretization of space. Thirdly, it requires little formal programming although such capabilities are available for complex analyses. Finally, TransCAD generates visual output of the analysis results which are invaluable in both the application and validation of the model (Spurr and Haider, 2005).

In this research, each group of geographic data is shown in a different layer, which allows visualizing different maps and their attributes. These attributes are associated numerically with graphic information; for example a road network (geocoded spatial data) has certain attributes such us number of lanes, traffic volumes, etc. The database of the TransCAD, except the data that were available in each layer as attributes, is designed with Microsoft Access to represent the information needed to be added or modified.

(2) ArcScene: this software was used to generate 3D maps of intensified building from South-West Borough using ArcMap/ArcScene 8.3 tool box. It has the ability to: (1) Create 3D views directly using GIS data; (2) Visualize modeling or analysis results in 3D; and (3) Apply projection to overlap digital layers with different coordinate system (ArcView 3D Analyst, 2006).

The GMA, Montreal Island's subway lines, and South-West Borough, were chosen as the subjects of the case studies. The GMA was used to illustrate the current traffic situation. Secondly the subway lines were used to intensify the increased population in the subway zones, and South-West Borough was chosen to visualize the possible increasing volume ratio for each building in 3D model as a result of applying intensification policy.

South-West Borough is located southwest of downtown Montreal. The borough is served by the green and orange subway lines, including Place-Saint-Henri, Lionel-Groulx, Charlevoix, Angrignon, Georges-Vanier, Monk, and Jolicoeur stations (Ville de Montreal, 2007)

4.3 APPLYING TRAFFIC ASSIGNMENT

As was explained in Section 3.4, four scenarios have been applied: the present case and three future scenarios. Table 4.1 is a summary of these four scenarios.

Table 4.1 Analysis scenarios

Scenarios	a (%) (intensification factor)	b (%) (modal shift factor)	Comment
Present scenario	N.A.	N.A.	
First future scenario	0	0	Forecasted new trips were redistributed based on the natural GR of each zone.
Second future scenario	20	10, 40	Intensification of 20% of the forecasted population was applied in subway zones.
Third future scenario	50	10, 20, 30, 40	Intensification of 50% of the forecasted population was applied in subway zones.

Figure 4.1 shows an example of the traffic assignmnet flow results for the base year (2003). The flow map is a combination of two thematic map types: (a) color theme, and (b) scale theme. Each link is assigned a color based upon its volume over capacity (VOC) ratio and a width based upon its hourly volume. The dark green color represents less volume-capacity, and it goes toward light green, red, or black illustrating heavier traffic.

Figure 4.1 Example of the traffic assignment results for the base year 2003

4.4 FIRST FUTURE SCENARIO WITHOUT APPLYING INTENSIFICATION POLICY

In the first future scenario, we assumed that no intensification is applied in 2013. According to this assumption, we can find the worst traffic condition of Montreal in the absence of policies. Based on the population GR from 2001 to 2006, the number of trips for 2013 can be calculated (Eq. 3.3). In this case, the increased number of trips was applied on the O-D matrix based on the GR of each TAZ. The results are show in Figure 4.2. The VOC ratios are clearly higher in this figure compared with Figure 4.1; therefore, the impact of intensification will be investigated in the following sections.

Figure 4.2 Montreal traffic assignment in 2013 without applying intensification

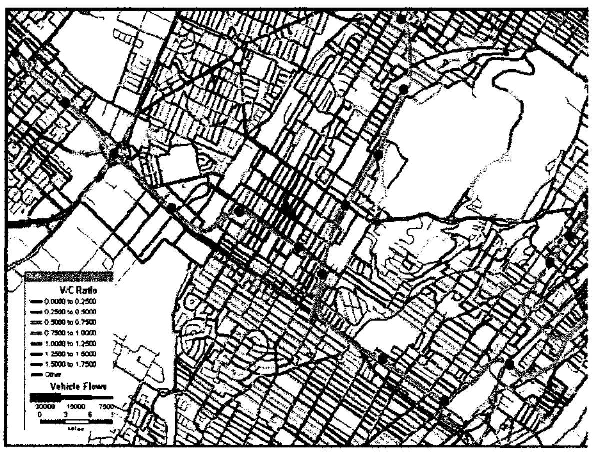
4.5 SECOND FUTURE SCENARIO WITH 20% POPULATION INTENSIFICATION

Usually central business district (CBD) gets most of the transit flow. In Montreal the subway system is spread over in 17 TAZs which are concentrated mostly in the central part. In the second future scenario, the intensification factor *(a)* is taken as 40%, and the increased population (P_d=125,965 persons) is intensified in the subway zones using Eqs. 3.6-10. The calculations were coded in MATLAB (Pratar, 2006). The new trip distribution is obtained by modifying the future O-D matrix using Eq. 3.11 and assuming the modal shift factor *(b)* as 10% or 40%. Figure 4.3 shows the reduction in the VOC ratio in comparison to the first scenario (Figure 4.2). The average VOC for the 104 zones and subway zones were for b=10% 0.66 and 1.46, respectively. The average VOC for the 104 zones and subway zones were for b=40% 0.66 and 1.43, respectively. The script of MATLAB and the growth factor results are given in Appendix I.

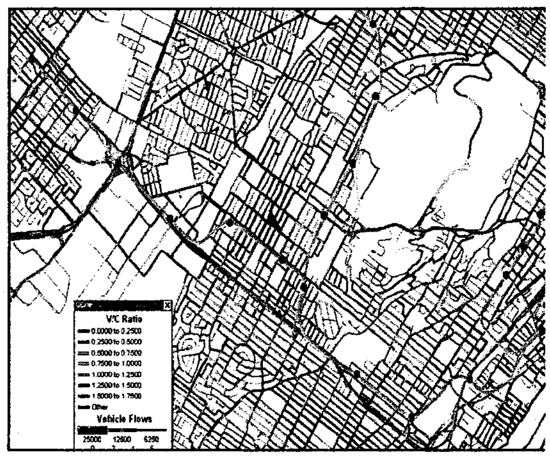
Figure 4.3 Montreal traffic assignment in 2013 with 20% intensification in subway TAZs and 40% modal shift

4.6 THIRD FUTURE SCENARIO WITH 50% POPULATION INTENSIFICATION

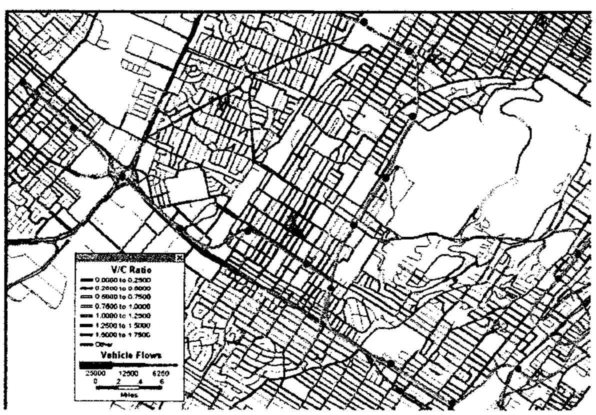
The third future scenario follows the same procedures explained in the second future scenario, but in this case 50% of intensified population (P_d=125,965 persons) is shifted from car to subway mode by different ratios, therefore a is equal to 50% in the subway zones, and b is applied in four different cases (10, 20, 30, and 40%) to compare the influence on congestion. Figures 4.4 (a-d) show the decrease in the volume of the traffic in links surrounding subway stations. By tracking these color themes from (a) to (d), we can observe a perceptible color change to the darker green, which indicates less VOC ratio. Figures 4.5 (a-c) show the scaled themes, which represent the width of a link based upon its hourly volume. By comparing these scaled themes, we can see that the hourly volume for each link is becoming narrower in Figures 4.5 (a) to (c). Table 4.2 shows the average VOC for the 104 zones and subway zones only for the cases of 10% and 40% modal shift, because the results of b=20 and b=30% were very similar. The increase in the average VOC ratios can be explained by the high value of the intensification factor. The script of MATLAB and the growth factor results are given in Appendix I.



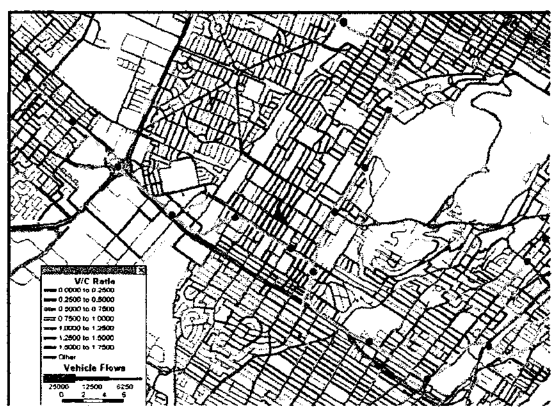
(a)



(b)



(c)



(d)

Figure 4.4 VOC ratios for the third scenario with model shift ratios: (a) 10%, (b) 20%, (c) 30%, and (d) 40%

(a) (b) (c)

Figure 4. 5 Shifting hourly volume for 10%, 20%, and 30% modal shift ratios from left to right

4.7 VISUALIZING THE TRAFFIC FLOWS ON THE GOOGLE EARTH

As was explained in Section 2.7, 2.5 GIS is an efficient way to analyze attribute data of maps, such as the VOC ratio of the links of the road network. The results of TransCAD were converted to shape file format and then imported into Google Earth Professional (Google Earth Professional, 2008). Google Earth provides an excellent tool to visualize traffic information by overlaying the road network on the remote sensing images of the city and sharing this information over the Internet (Hammad and Gauthier, 2008).

Figure 4.6 shows an example of visualizing Montreal road network VOC ratio on Google Earth (exaggerated 100 times). This visualization method can facilitate public involvement in future urban and transportation planning activities.

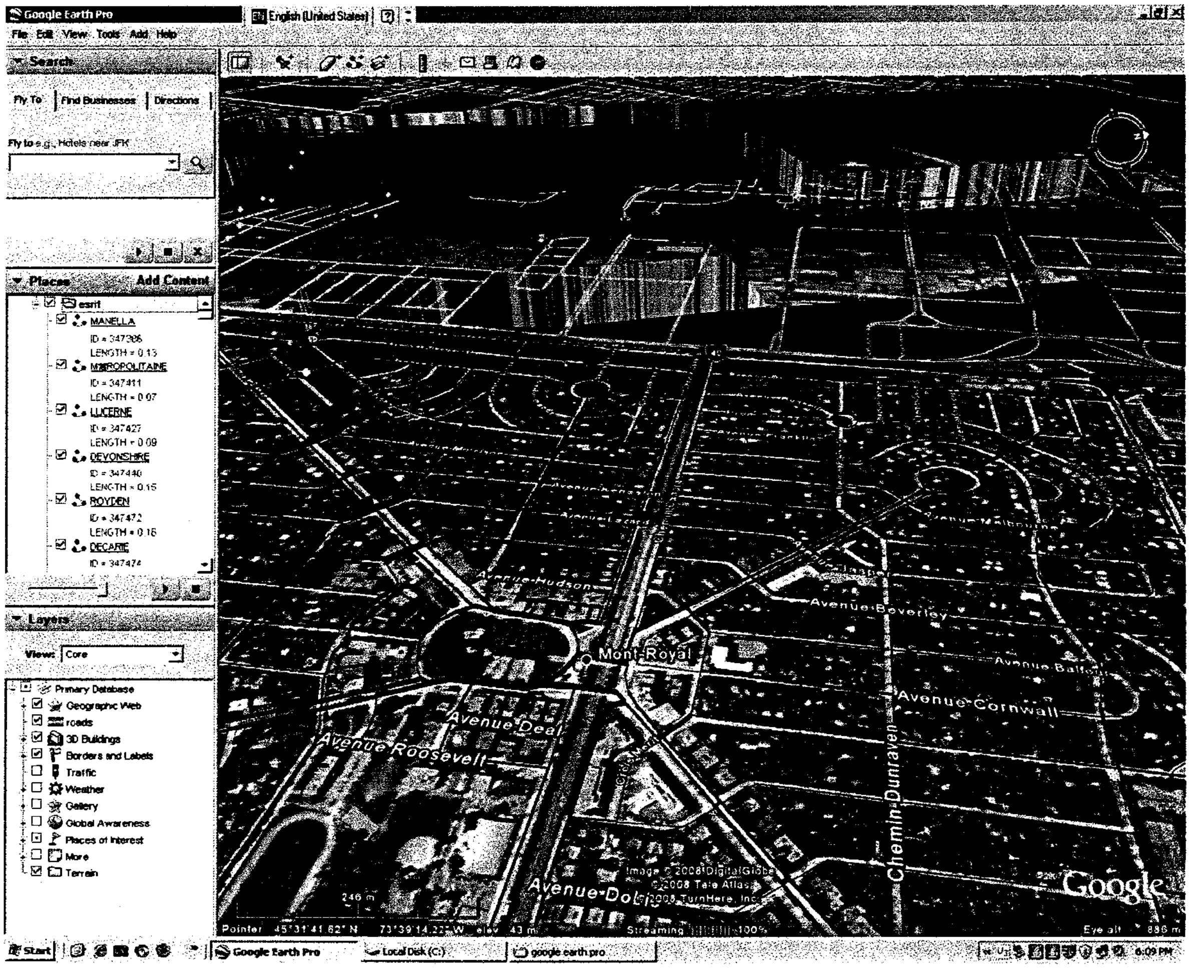


Figure 4.6 Visualizing Montreal road network VOC ratio on Google Earth

4.8 RESULTS OF INTENSIFICATION SCENARIOS

In order to compare the results of the different scenarios explained above, the average VOC ratio for links in both directions are calculated for the whole GMA (104 TAZs) and for the subway zones (17 TAZs) as shown in Table 4.2. From this table, the decreasing values of average VOC ratios of the subway zones can be observed, from 1.62 in the first scenario to 1.46, and 1.43 in the second future scenario with 10% and 40% modal shift ratio, respectively. In the third future scenario, the increase in the average VOC ratios can be explained by the high value of the intensification factor.

Table 4.2 shows that the lowest values of the average VOC ratios for the subway zones and the whole TAZs were achieved in the second future scenario with 20% population intensification and 40% modal shift. These results can be considered in future urban studies in Montreal.

Table 4.2 Comparison of average VOC ratio under different scenarios

Scenarios	a (%)	b (%)	Average VOC ratio	
			GMA	Subway zones
Present scenario	N.A.	N.A.	0.07	0.16
First future scenario	0	0	0.71	1.62
Second future scenario	20	10	0.66	1.46
	20	40	0.66	1.43
Third future scenario	50	10	0.71	1.60
	50	40	0.70	1.52

4.9 INCREASING THE SOUTH-WEST VOLUME RATIO

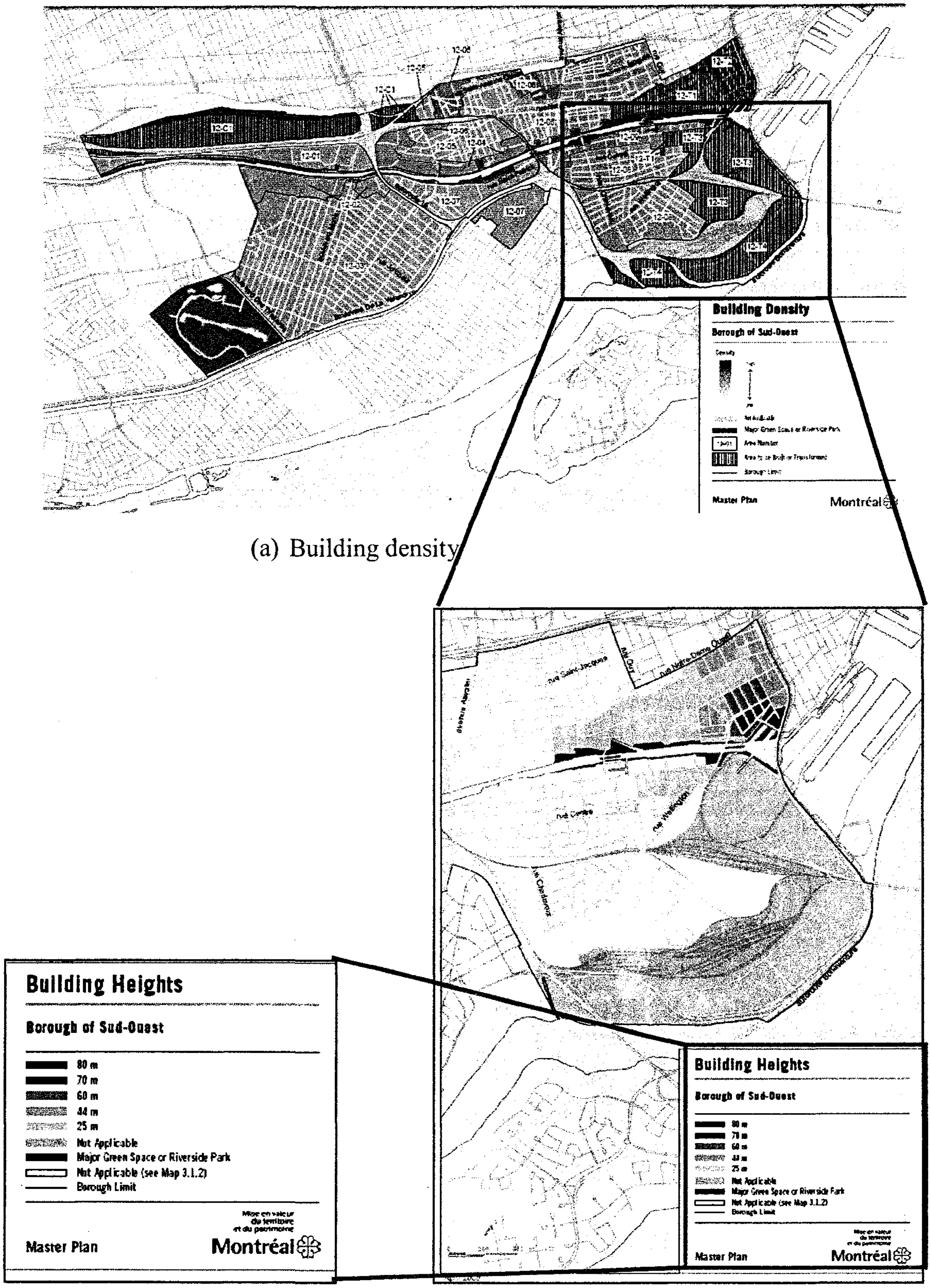
This section demonstrates the process of applying the Equations 3.12 and 3.13. As was explained in Section 3.11, the South-West borough is used to investigate the feasibility of accommodating the intensified population in subway zones. In order to realize this goal, the present volume ratio is compared to the maximum permitted one. Figure 4.7 shows the proposed new regulations of the building density and height limits, which are provided for the South-West Borough (Montreal Master Plan, 2008). The parts with darker color have higher potential of intensification, and the maximum height of buildings can be up to 80 meter.

Figure 4.8 (a) shows 3D models of South-West with the actual heights of buildings with 500% exaggeration, and Figures 4.8 (b) and (c) show the maximum height regulations overlaid on actual heights the buildings using ArcScene with 70 % and 0% transparency, respectively.

Figure 4.9 shows the overlapping the South-West Borough with GMA TAZs containing 11,133 buildings (polygons). The red border shows the boundary of South-West Borough and the grey border shows the boundary of South-West TAZ. Because the data of land use regulations were not available for this research, it is assumed that very large lots (more than 300 m^2) are more suitable for non-residential usage and will be eliminated from the areas for intensification.

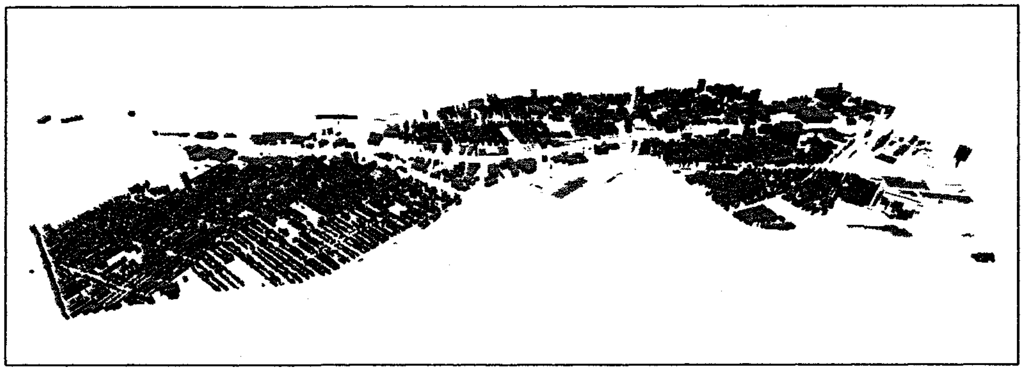
After eliminating large lots, the difference between the maximum and present number of floors was calculated. Figures 4.10 (b) and (c) show the land use regulations for maximum building heights and calculated additional number of floors, respectively. This additional capacity of floor area is equal to 1,735,418 m^2 according to Eq. 3.12. Assuming the average floor area per person as 50 m^2, the additional capacity population is about 34,000 persons based on Eq. 3.13.

As discussed in Section 4.8, the second future scenario with 20% population intensification and 40% modal shift factor had the best results in applying the intensification policy. This scenario resulted in an intensified population of 3,538 persons. By comparing the above two populations, it is clear that the intensification level of 20% is very feasible.

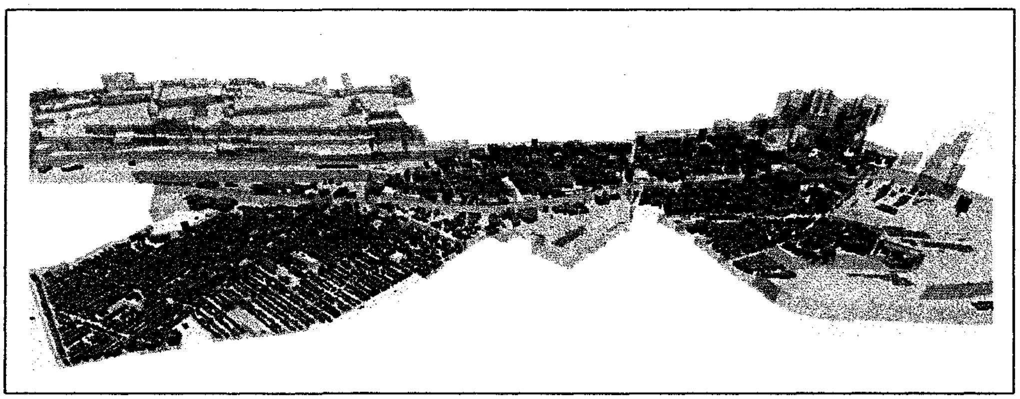


(a) Building density

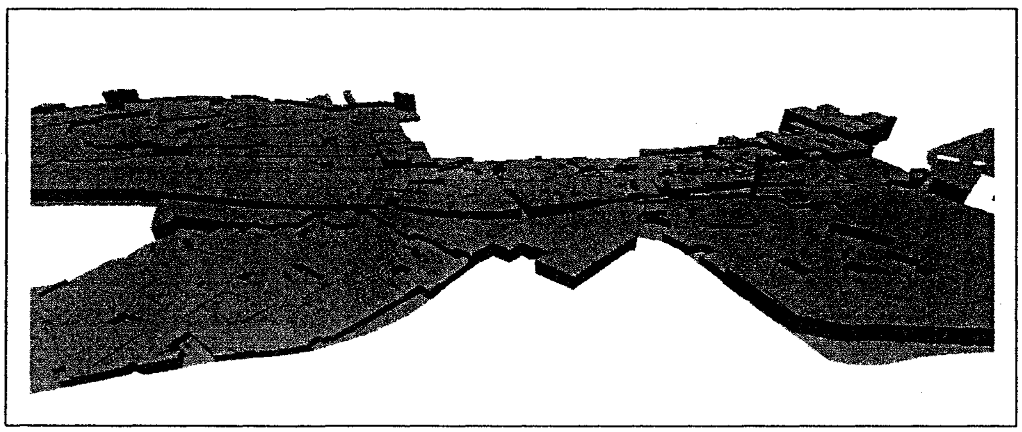
Figure 4.7 Height regulations in South-West borough (Montreal Master Plan, 2008)



(a) Actual heights of buildings in South West Borough



(b) Maximum height regulations (with 70% transparency) overlaid on actual heights



(c) Maximum height regulations (opaque) overlaid on actual heights

Figure 4.8 South West Borough with maximum height regulations and actual heights

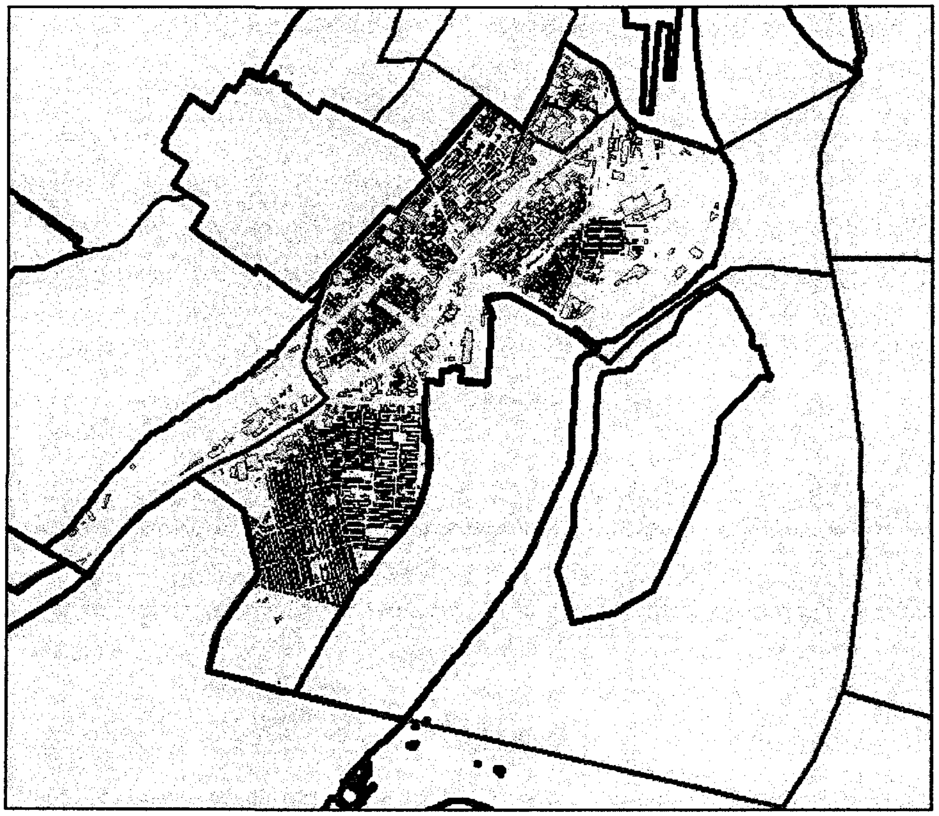
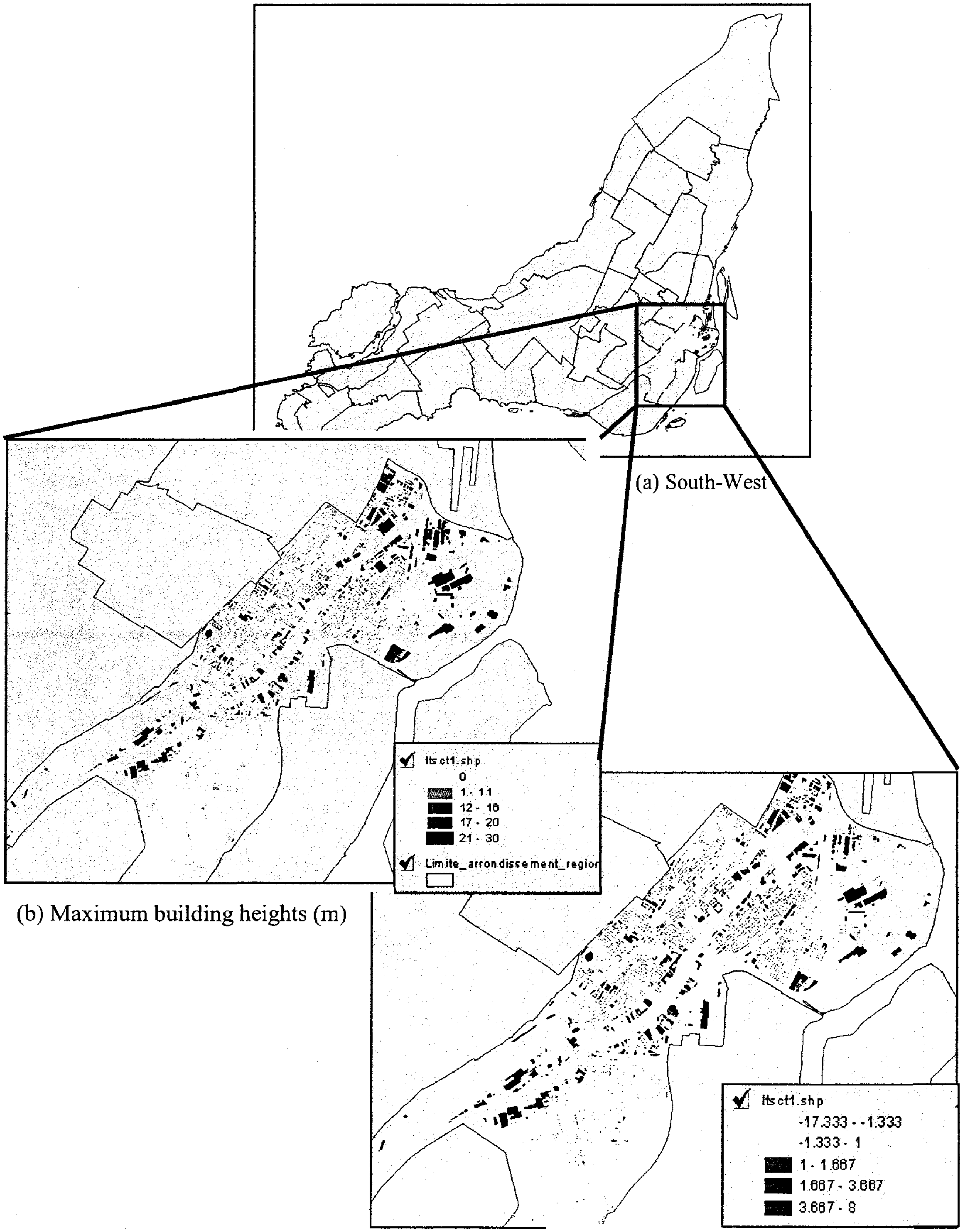


Figure 4.9 Overlapping the South-West Borough with GMA TAZs



(a) South-West

(b) Maximum building heights (m)

(c) Additional number of floors

Figure 4.10 South-West building layer and regulations

4.10 SUMMARY AND CONCLUSIONS

This chapter described the implementation of the proposed approach and methods discussed in Chapters 3. A detailed traffic assignment model for the GMA was built using TransCAD, and three future intensification scenarios were applied in the subway zones. In the first future scenario, the growth factor method was applied to redistribute new trips among TAZs without applying intensification. In the second future scenario, 20% intensification of the GMA population growth was applied in the subway zones and 10% and 40% of this increased population were shifted from vehicle to subway in two cases. The third future scenario is similar to the second one, but with 50% intensification ratio and varied modal shift factors. Table 4.2 shows that the lowest values of the average VOC ratios for the subway zones and the whole GMA were achieved in the second future scenario with 20% population intensification and 40% modal shift.

The feasibility of the results of one future scenario has been tested based on maximum height regulations. These results are based on many assumptions and they do not consider the long term nature of the changes of land use. However, they provide basic data about the impact of intensification that can be considered in future urban studies in Montreal.

There are some limitations in applying the intensification policies; for instance, all land use factors overlap and analyzing a single factor like intensification may exaggerate its effect (Kuzmyak and Pratt, 2003). Future work includes investigating the feasibility of the proposed intensification scenarios in more detail including other factors, such as mix land use policies and the practical aspects of applying the intensification policies.

CHAPTER 5 SUMMARY, CONCLUSIONS, AND FUTURE WORK

5.1 SUMMARY

As introduced in the Chapter 2, The Montreal Master Plan, 2005, proposed population intensification near transit nodes as a measure to reduce the dependency on cars. However, the impact of these policies has not been studied in detail. In this research, three future intensification scenarios were applied near transit nodes, the impact of these intensification policies on Montreal traffic was studied using a deterministic user-equilibrium traffic assignment model, and the feasibility of the proposed intensification scenarios from the point of view of land use based on volume ratio regulations was investigated.

The proposed simplified method requires several assumptions for each step, such as intensification and model shift factors, and these assumptions have to be used carefully to get meaningful results.

5.2 CONCLUSIONS AND CONTRIBUTIONS

The contributions of this research are grouped into the following areas:

1. A new approach for analyzing the impact of population intensification near subway stations based on traffic assignment using a deterministic user equilibrium traffic assignment model was discussed;

2. Three future intensification scenarios were applied in the subway zones. In the first future scenario, the growth factor method was applied to redistribute new trips among TAZs without applying intensification. In the second future scenario, 20% intensification of the GMA population growth was applied in the subway zones and 10% and 40% of this increased population were shifted from cars to subway in two cases. The third future scenario was similar to the second one, but with 50% intensification ratio and varied modal shift factors. Results show that the lowest values of the average VOC ratios for the subway zones and the whole GMA were achieved in the second future scenario with 20% population intensification and 40% modal shift.
3. In order to decrease the congestion caused by cars, the intensification plan is combined with a pre-assigned modal shift from car usage to subway usage. A *modal shift factor* representing this shift is introduced considering the modal split ratio (i.e., the ratio between subway trips and vehicle trips);
4. The feasibility of the results of one future scenario has been tested based on maximum height regulations.

These results are based on many assumptions and they do not consider the long term nature of the changes of land use. However, they provide basic data about the impact of intensification that can be considered in future urban studies in Montreal.

5.3 LIMITATIONS AND FUTURE WORK

There are some limitations in applying the intensification policies; for instance, all land use factors overlap and analyzing a single factor like intensification may exaggerate its effect (Kuzmyak and Pratt, 2003). It is blatantly clear that simply increasing densities and mixing uses will not lead to sustainable outcomes. High quality infrastructure needs to be provided, public transport needs to be well managed, affordable and reliable, noise and air pollution have to be maintained at acceptable standards, and levels of public facilities such as health care and education have to be appropriate for the high numbers of city dwellers. Furthermore, urban environments have to be kept clean, safe and 'livable'. As Burgess states: 'High demographic growth, low levels of economic development, high income inequalities, small urban budgets and shortages of environmental infrastructure, shelter and basic services have a critical effect on densification policies and the effectiveness of policy instruments (Jenks and Burgess, 2000).

The desire, by urban managers at least, is to have cities that improve social conditions and cohesion, that are resource efficient and economically sustainable, and that provide a high quality of life. It seems that there is much to admire in the compact city model – in the right place and at the right time. But as a universal response to unsustainable cities, it can only be seen as a small part of the solution.

In addition, the following specific recommendations for future research are given:

1. Investigating the feasibility of intensification near subway stations proposed by the City of Montreal as a pilot project including the four stations: Outremont, Radisson, Rosemont, and Saint-Laurent.

2. Proposing a method to modify the TAZ system so that it matches the census data. This will help in matching the population data with O-D survey data.

3. Investigating methods to relate statistical data obtained at different years.

4. Improving the data used in the traffic assignment by adding missing information, such as the delays at signal and intersections, and the attributes of the links which were assumed in this study (capacity and number of lanes).

5. Integrating transit modes (bus and subway) in the traffic assignment analysis.

6. Investigating measures and policy packages which can be used to help realizing the intensification policy, such as land use taxes and regulations, and transportation fares.

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Appendix A: Map of Greater Golden Horseshoe (GGH)

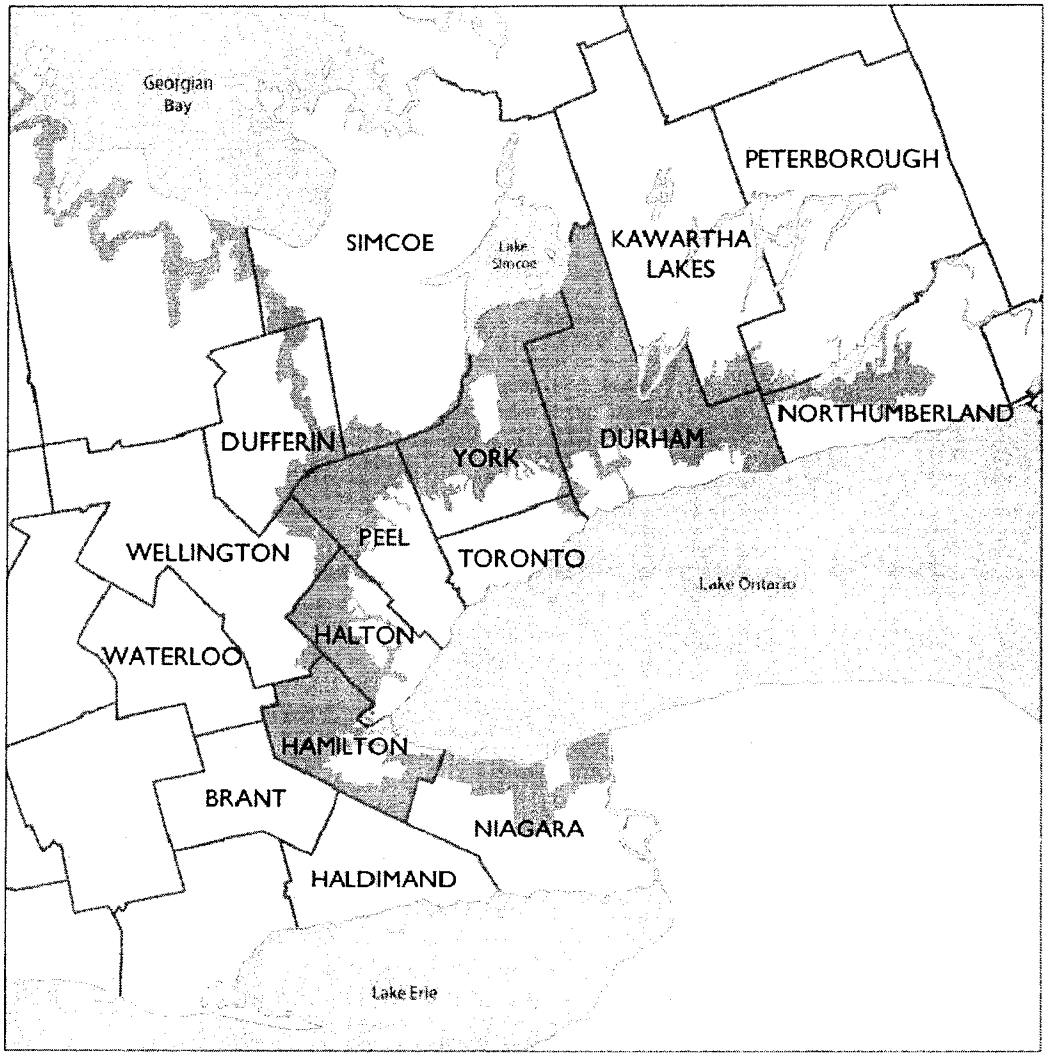

Figure A.1 Map of GGH (Urban Strategies Inc., 2005)

Appendix B: Map of mega cities in 2000, 2015

Mega cities have particular significance in this world-wide process of urbanization. According to different definitions, mega cities are on a purely quantitative level those metropolises with a population of over 5 M, more than 8 M or more than 10 M inhabitants. Some authors also set a minimum level for population density (at least 2,000 persons/ km2) and only include cities with a single dominant centre, whereby polycentric agglomerations such as the Rhein-Ruhr area in Germany, for example, with 12.8 M inhabitants, are excluded.

While in the 1950s there were only four cities with a population greater than 5 M, by 1985 there were already 28 and in 2000 39. Depending on the threshold accepted as a lowest population value for a mega city, there are currently worldwide 16, 24 or 39 mega cities; in the year 2015 there will probably be almost 60. Before World War II mega cities were a phenomenon of industrialized countries; today by far the greater numbers are concentrated in developing countries and Newly Industrializing Countries (NICs). Two thirds of the mega cities are now in developing countries, most of them in East and South Asia. Just fewer than 394.2 M people live in mega cities, 246.4 M of them in developing countries, more than 214.5 M in Asia. In 2015 there will be about 604.4 M people living in mega cities. In some of these - Mexico City, São Paulo, Seoul, Mumbai, Jakarta and Teheran - the population figures have almost tripled between 1970 and 2000 (Mega city task force of the international geographical union, 2008).

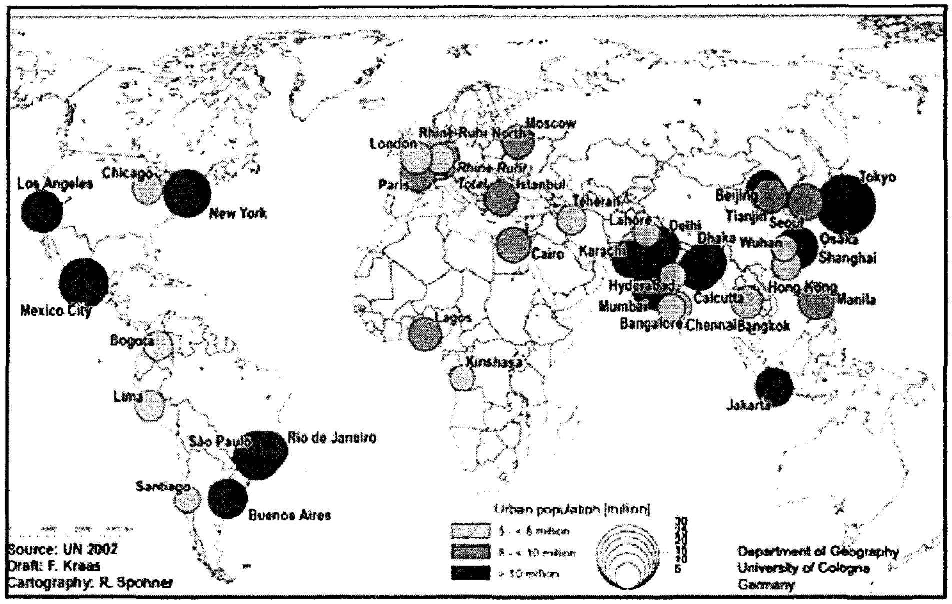

Figure B.1 Map of mega cities in 2000 (Mega city task force of the international geographical union, 2008)

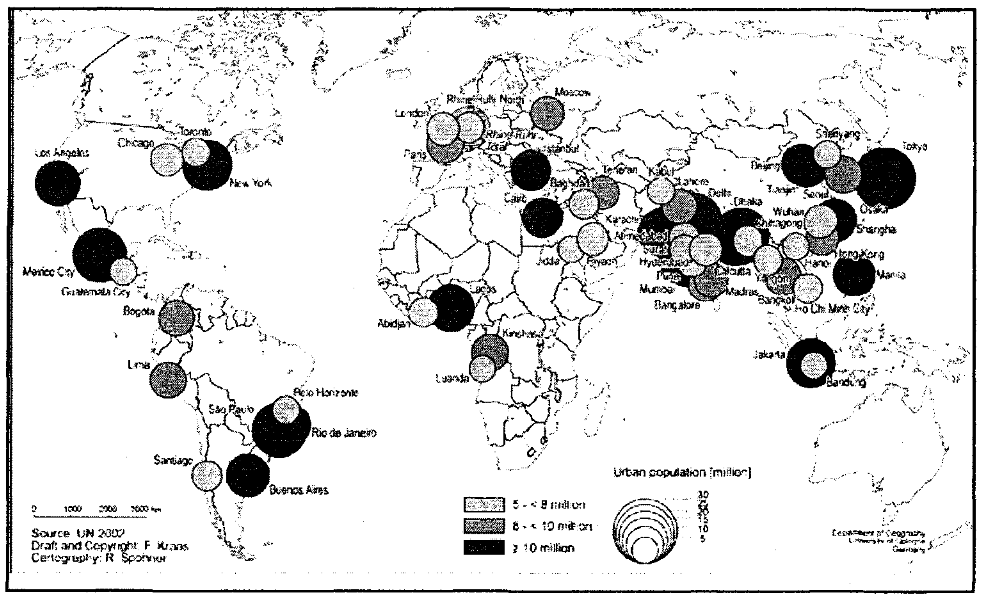

Figure B.2 Map of mega cities in 2015 (Mega city task force of the international geographical union, 2008)

Appendix C: List of cities proper by population

This is a list of the most populous cities of the world defined according to the concept of city proper. The list ranks the world's urban municipal units (or well-defined statistical groupings of such units) according to population. Note that the populations listed are for the city proper and neither for the urban area nor the metropolitan area. As it is shown in the following table, Cairo and Dhaka have the highest population density and Alexandria and Ankara have the lowest ones (Wikipedia, 2008) via <http://en.wikipedia.org/wiki/List_of_cities_by_population>.

Table C.1 List of cities proper by population

Rank	City	Population	Area (km^2)	Population density ($/km^2$)
1	Mumbai	13,662,885	437.7	31,215
2	Karachi	12,130,000	3,530	3,957
3	Istanbul	11,372,613	1,831	6,211
4	Delhi	11,325,124	1,483	11,500
5	São Paulo	10,886,518	1,523	7,148
6	Moscow	10,452,000	1,081	9,644
7	Seoul	10,356,202	605.4	17,213
8	Shanghai	10,030,788	1,600	6,775
9	Mexico City	8,609,347	1,550	5,626
10	Jakarta	8,576,788	660	12,738
11	Tokyo	8,535,792	620	13,682
12	New York City	8,250,567	789.4	10,452
13	Cairo	7,947,121	214	37,071
14	Lagos	7,937,932	1,000	
15	Kinshasa	7,843,000		
16	Tehran	7,797,520	760	10,260
17	Beijing	7,699,297	1,370	5,650
18	London	7,581,052	1,580	4,697
19	Hong Kong	7,206,000	1,092	6,183
20	Bogotá	7,137,849	1,590	4,523

21	Lima	6,954,517	804	8,544
22	Dhaka	6,724,976	145	46,379
23	Bangkok	6,704,000	1,568.70	3,630
24	Lahore	6,577,000	1,010	6,329
25	Rio de Janeiro	6,093,500	1,180	5,200
26	Baghdad	5,258,383		
27	Bangalore	5,180,533	230	22,426
28	Kolkata	5,021,458	185	24,760
29	Tianjin	4,933,106		
30	Yangon	4,886,305		
31	Santiago	4,668,473	2,030	
32	Guangzhou	4,653,131		
33	Wuhan	4,593,410	400	12,868
34	Chennai	4,562,843		
35	Riyadh	4,465,000	800	1,500
36	Singapore	4,436,000	699	6,306
37	Ho Chi Minh City	4,331,288		
38	Alexandria	4,247,414	2,680	1,378
39	Chongqing	4,239,742		
40	Ankara	4,140,890	2,500	1,424
41	Saint Petersburg	4,035,751		
42	Shenyang	3,995,531		
43	Hyderabad	3,980,938	170	21,293
44	Ahmedabad	3,867,336	190	19,979
45	Los Angeles	3,849,378	1,290	2,980
46	Abidjan	3,802,000		
47	Chittagong	3,654,939		
48	Yokohama	3,602,758	440	8,182
For comparison	Montreal	1,620,693	365	4,439
For comparison	GMA	3,635,571	4,259	853

Appendix D: Transportation planning processes (four-steps forecasting process)

1. Trip generation

The trip generation is the first step in the four-steps forecasting process. The objective of this step is to predict the number of trips generated (productions and attractions) by each zone; thus this step requires the definition of the study area and the analysis units called traffic analysis zones (TAZ). Before working with the models, we need to have: (1) the study area boundaries, (2) the survey file, (3) demographic census, (4) land-use inventory, and (5) the number of TAZ. In addition to the internal zones, a number of external zones should be considered in order to predict the number of trips coming inside or going outside of the study area in order to balance the number of trips. Figure D.1 shows the process for trip generation and the inclusion of external trips; as the figure shows, production and attraction are the output for this step.

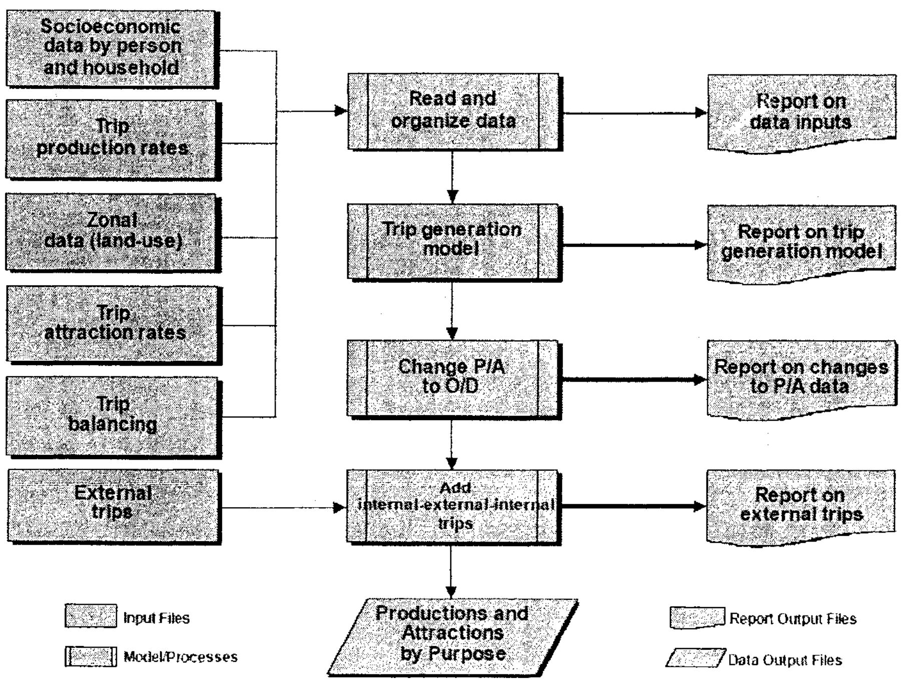

Figure D.1 Trip generation modeling process (Bhat, 2001)

The difference between production-attraction and origin-destination should be clear. The term *origin-destination* is defined in terms of the direction of a given inter-zonal trip. As can be seen in Figure D.2, the production and attraction are defined as a trip ends connected to zones. This definition must be taken into account at the time of change from production-attractions to origin-destination in the construction of matrices for the next step "Trip Distribution" (Institute of Washington DC Transportation Engineers, 2003).

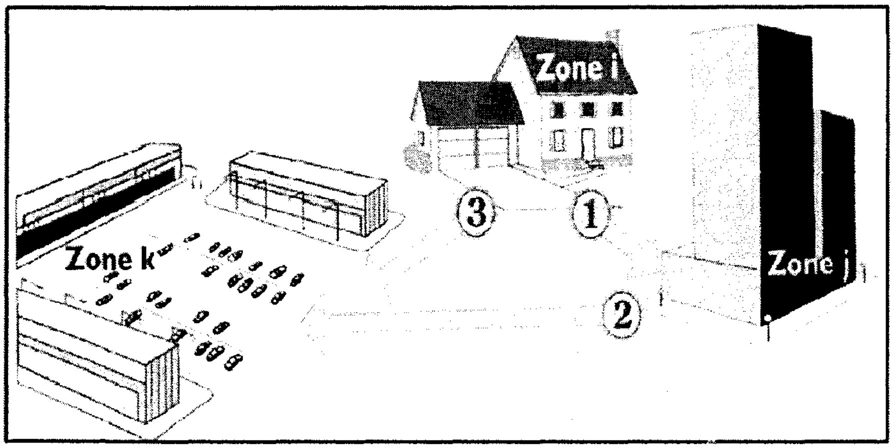

Figure D.2 Trip production and attraction (EMME/2, 2005)

2. Trip distributions

The trip distribution is the second of the four-steps forecasting process. Trip distribution finds the numbers of person trips that go between all pairs of zones. Usually, 24-hour person trips are distributed separately for each trip purpose. The results of the trip distribution step can also be shown in the form of a matrix, with as many rows and columns as zones. Each row represents a production zone and each column represents an attraction zone.

The task of trip distribution modeling is to distribute or link up the zonal trip ends (either productions or attractions) generated in the first step in order to predict the volume of trips T_{ij} from each production zone i to each attraction zone j (Travel demand modeling with TransCAD, 2005). Figure D.3 shows the trip distribution process including the inputs and outputs that are needed for this step.

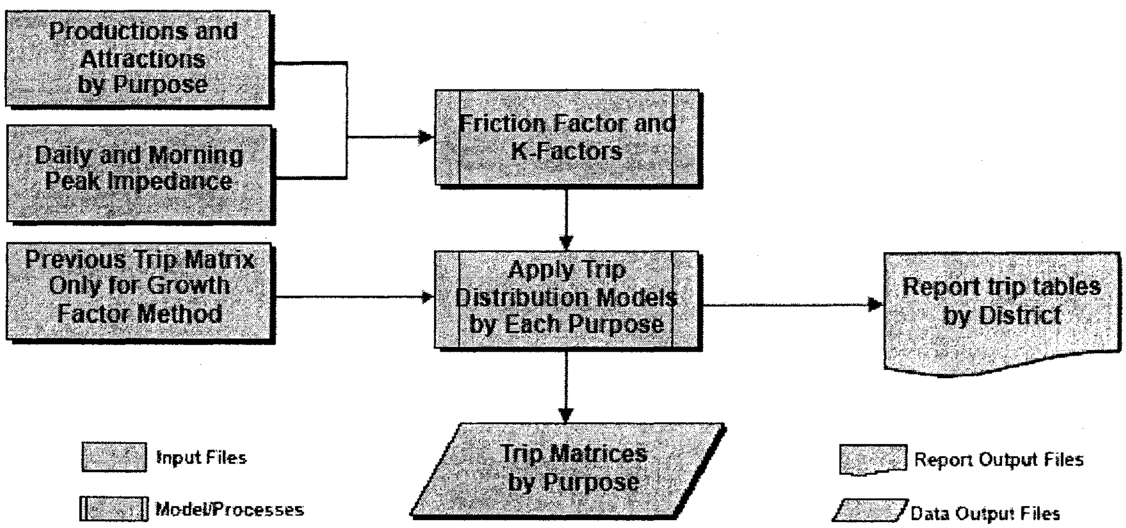

Figure D.3 Trip distribution modeling process (Bhat, 2001)

3. Modal split

The modal split or modal choice is the third of the four-steps forecasting process. The issue of this step is concerned with the trip-maker's behavior regarding the selection of travel mode. The objective of this step is to predict the choices that people make regarding the mode they use in their trips. The trips resulting from trip distribution are split between the available travel modes through the application of the modal choice analysis. The reason of a choice varies among individuals, trip type, and relative level of service and cost associated with the available modes. When significant changes in these conditions occur, people have different degrees of responses; in many cases by shifting from one mode to another.

Socioeconomic status also affects the choice of travel mode. Thus, trips can be classified in categories, such as income or age. However, there is a particular group, the 'captive transit-group' that needs a particular attention; they are called captive because they do not have any other option than using public transit (people less than 16 years old, older people and some handicaps). Figure D.4 shows the modal split process including the inputs and outputs (Bhat, 2001).

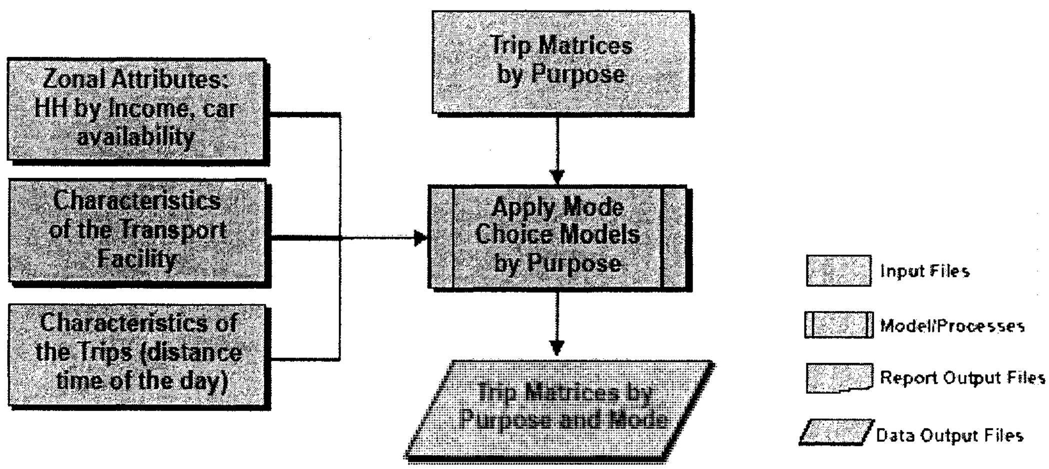

Figure D.4 Modal split/choice modeling process (Bhat, 2001)

4. Traffic assignment

The traffic assignment concerns the selection of routes (alternative called paths) between origins and destinations in transportation networks. It is the fourth step in the conventional transportation forecasting model, following trip generation, trip distribution, and mode choice. More details are given in Chapter 2.

Appendix E: Applying the city infill in Griffintown (Montreal)

Griffintown is the popular name given to the former southwestern downtown part of Montreal, Quebec, which existed from the 1820s until the 1960s and was mainly populated by Irish immigrants and their descendants. It defined by Notre-Dame street to the North, McGill and Guy streets to the East and the West respectively, and the Lachine Canal. In 1962, the city of Montreal re-zoned the neighborhood as "light industrial", and the Irish left the district as their fortunes improved and those who stayed were forced out during the rezoning in the seventies that saw the residential areas turned into industrial zones (Wikipedia, 2008).

Figure E.1 shows the current geographic construction of Griffintown. Master Plan provides the possibility of building residential projects in Griffintown, which until now has been largely devoted to other activities. It also reiterates the City's support for locating the Cité universitaire internationale in the Centre. The general goals are (1) Preserving the character and scale associated with the area's industrial past, (2) Intensifying and diversifying the area's activities by fostering the cohabitation of economic and residential activities, and (3) Reinforcing recreational and tourism uses in the Peel Basin area as well as the nautical vocation of the Lachine Canal, by taking advantage of the proximity of Old Montréal, the Old Port and the Central Business District.

Now there is a $1.3 billion residential-and-commercial project that aims to revitalize Griffintown and it is one of the biggest private investments in Montreal history. This project would include 3,830 residential units, retail outlets, a concert hall and a network of parks and public spaces (Riga, 2007). Figure E.2 shows what the project might look like when it is finished (Erb, 2008).

Figure E.1 Current geographic construction of Griffintown (Wikipedia, 2008)

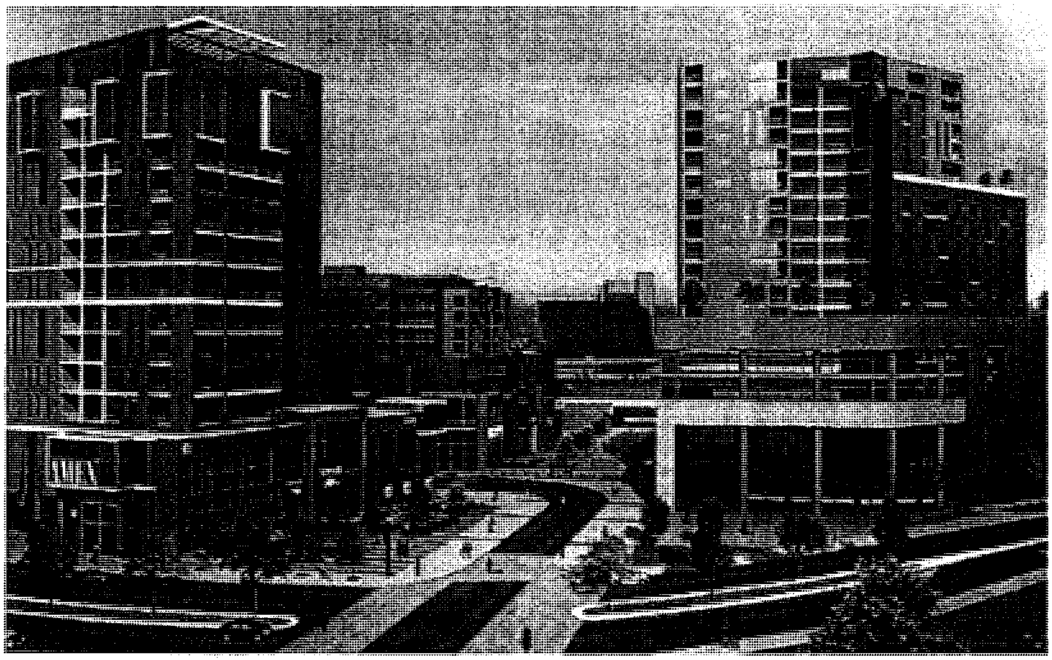

Figure E.2 The future project of Griffintown that might look like when it is finished (Erb, 2008).

APPENDIX F: O-D surver Data structure (AMT, 2003)

Origin destination survey 2003		
Structure of the EOD03NIV2 file		
Number of recording: 329 353	**56965 house** **137042 persons** **300794 asset Replacements** **(total= 301 645)**	**Type:** **N: number** **C: character**

Relative variable of the file

Name of the field	type	Length	Description
ipere	**N**	**6**	**Unique sequence numbers**

Relative variable of the households

Name of the field	type	Length	Description
m-number	**N**	**6**	Number of the households
m- debut	**C**	**1**	Registration of the head of association of the household T: for the 1st instance Null: for the following (one)
m-fexp	**N**	**5.2**	-The expansion factors base on the households. -These factors of ponderation should not be used except for estimating the household's character
m-car	**N**	**2**	Number of the car per house 0 to 14
m-persons	**N**	**2**	Number of the person per house 0 to 19

Resident house

Name of the field	type	Length	Description
m-domrmr	**N**	**3**	Code of the population census of metropolitan area 459 462 465
m-domsdr	**N**	**6**	Metropolitan population subdivision 2001(municipality)
m-domsr	**C**	**10**	Population sector(Population administrative district) 2001 (null except RMR)
m-domsm	**N**	**3**	Municipality Sectors (102 Municipalities)
m-domxcoor	**N**	**8**	**X coordinate MTM NAD 83**
m-domycoor	**N**	**8**	**Y coordinate MTM NAD 83**

Relative variable of the PERONES

Name of the field	type	Length	Description
P-rang	**N**	**2**	Number of the people
P-debut	**C**	**1**	Registration the head of the family. T: for the head of the family NULL: for others
P-fexp	**N**	**5.2**	-factors of ponderation base on the households. -These factors of

			ponderation should be used for estimating the household's character. Using P-Mobil=1
P-sex	**N**	**2**	Gender 1=male 2=female
P-age	**N**	**2**	Age: 1 to 99
P-grage	**N**	**2**	Age groupe: 1: 0-4 7:35-44 2: 5-9 8:45-54 3:10-14 9:55-64 4:15-19 10:65-74 5: 20-24 11:75 &. 6:20-24
P-statut	**N**	**2**	Occupation 1=full time job 3=students 6=N/A kids 2=part time job 4= retired 5=other 7=in the house 8=refused
P- permis	**N**	**2**	Driving license 1=yes 2=no 3=doesn't know 4=refused 5=not applicable(under 16)
P-Mobil	**N**	1	Person trip 1=yes 2=doesn't move 3=N/A(CHILD) 4= doesn't know how to move 5= refused 6= he is moving but he doesn't know how to do that(not moving well)

Name of the field	type	Length	Description
d-deplac	N	2	Number of the person's trip
d-fexp	N	5.2	-factors of ponderation base on the trip. -These factors of ponderation should be used for estimating the trip's character. Using P-Mobil=1 just to keep the persons on hold and for whom the factor of ponderation(p-fexp) is not null
d-hrede	N	4	Departure time (hhmm=0 to 2800)
d-grhre	N	2	Group of the Departure time: 1=0h to 5h59 2==6h to 8h59 3=9h to 11h59 4=12h to 15h29 5=15h30 to 18h29 6=18h30 to 23h59 7=24h to 28h
d-motif	N	2	Trip motivation: 1.travel 2.appointment 3.on the road 4.school 5.shopping 6.pleasure 7.visiting friends/parents 8.health 9.giving a ride 10.pick up someone 11.returning home 12.other 13refused/NSP

Name of the field	type	Length	TRIP MODE
d-mode1	N	2	First mode taken(the other is null) 1. car driver 2. car passenger 3. bus STM 4. metro 5. bus RTL 6. bus STL 7. bus CIT 8. TRAIN 9. school bus 10.othe bus 11.taxi 12. motorcycle 13.bycicle 14.walking 15.transformed transport 16.communication mode 17.jonction point 18.indeterminate
d-mode2	N	2	Second taken mode
d-mode3	N	2	Third taken mode
d-mode4	N	2	Fourth Taken mode
d-mode5	N	2	Fifth taken mode
d-mode6	N	2	Sixth taken mode
d-mode7	N	2	Sixth taken mode
d-mode8	N	2	Sixth taken mode e
d-jontyp	N	2	Indicating the type of the junction point 1=private(car, metro, taxi, bicycle), (bus, motorcycle, train) 2=public(bus, motorcycle, train), private(car, metro, taxi, bicycle) 3= private(car, metro, taxi, bicycle), exogene (airplane,

			auto car, train,..) 4= exogene (airplane, auto car, train,..), private(car, metro, taxi, bicycle) 5= public (bus, metro, train), exogene (airplane, auto car, train,..) 6= exogene (airplane, auto car, train,..), public (bus, metro, train), 7=others
			Trip origin
d-orimr	N	3	Code of the region of metropolitan census 459 462 465
d-orisdr	N	6	census subdivision 2001
d-orisr	C	10	census sector 2001 (null except RMR)
d-orism	N	3	Municipality sector(102 Municipality sector)
d-orixcoor	N	8	X coordinate MTM NAD 83
d-oriycoor	N	8	Y coordinate MTM NAD 83
			Trip destination
d-desmr	N	3	Code of the region of metropolitan census 459 462 465
d-dessdr	N	6	census subdivision 2001
d-dessr	C	10	census sector 2001 (null except RMR)

d-dessm	N	3	Municipality sector(102 Municipality sector)
d-desxcoor	N	8	X coordinate MTM NAD 83
d-desycoor	N	8	Y coordinate MTM NAD 83
			Place of the census junction
d-jonmr	N	3	Code of the region of metropolitan census 459 462 465
d-jonsdr	N	6	census subdivision 2001
d-jonsr	C	10	census sector 2001 (null except RMR)
d-jonsm	N	3	Municipality sector(102 Municipality sector)
d-jonxcoor	N	8	X coordinate MTM NAD 83
d-jonycoor	N	8	Y coordinate MTM NAD 83

Figure F.1 O-D Survey data structure (AMT, 2003)

APPENDIX G: **Set the coordinate system for projection**

The coordinate systems of zonal map and subway lines were adjusted according to road network coordinate system (ESRI, 1994)

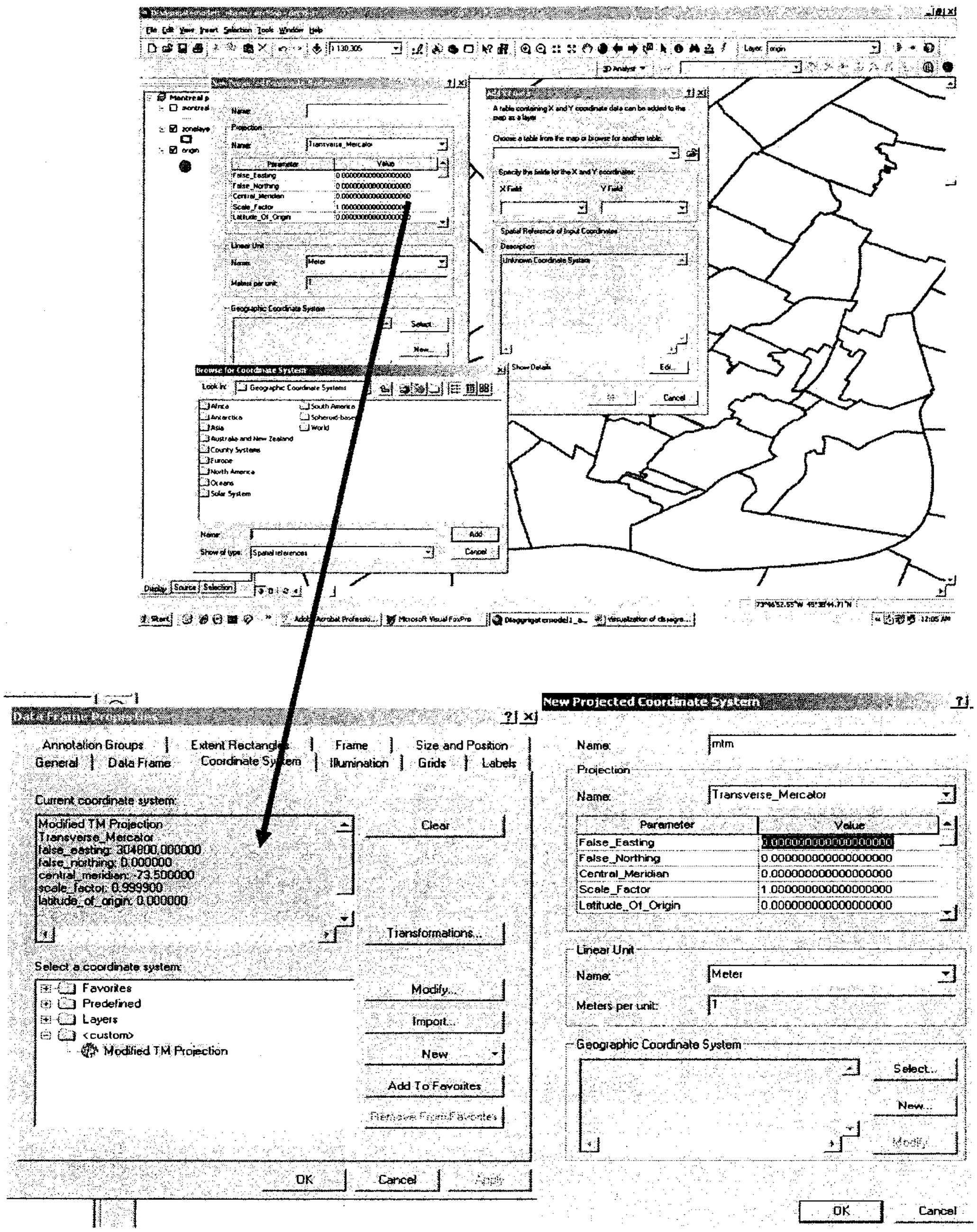

Figure G.1 Projection framework (ESRI, 1994)

Appendix H: Zones containing subway stations

Table H.1 Zones containing subway stations

Subway Zones	*Name*	*Number of subway stations*
101	Centre-Vill	9
102	Centre-ville peripherique	2
103	Sud-Ouest	7
104	Notre-Dame-de-Grace	2
105	Cote-des-Neiges	6
106	Plateau Mont-Royal	3
107	Villeray	11
108	Ahuntsic	4
109	Saint-Michel	2
111	Sud-Est	6
112	Mercier	5
119	Saint-Laurent	2
120	Mont-Royal	1
121	Outremont	3
122	Westmount	1
127	Verdun	3
301	Vieux-Longueuil	1

Appendix I: Redistributing the increased population and trips using MATLAB

Program (1): First future scenario without applying intensification policy in MATLAB

```
% ====================================================================== %
% Case # 1
% New version
% Modified: Feb, 2008
% ====================================================================== %
clc
T=Timp;
[m,n]=size(T);

P2006=Pimp(:,1);
P2011=Pimp(:,2);

kProduct=(P2011./P2006)';
kAtract=kProduct;

sumProduct=kProduct.*sum(T');
sumAtract=kAtract.*sum(T);

err=1;

while err >= 0.01
    for i=1:n
        T(:,i)=(kProduct').*T(:,i);
    end
    sumAtractNew=sum(T);
    kAtract=sumAtract./sumAtractNew;
    for i=1:n
        T(i,:)=(kAtract.*T(i,:));
    end
    sumProductNew=sum(T');
    kProduct=sumProduct./sumProductNew;
    errProduct=max(abs(ones(1,n)-kProduct));
    errAtract=max(abs(ones(1,n)-kAtract));
    err=max(errProduct, errAtract);
end
err
T
```

Program (2): Second, and third future scenario with applying population intensification policy, modal shift in MATLAB

```
% ====================================================================== %
% Case # 3
% Created by: Sara Fadaee
% Date: 2008
% ====================================================================== %
clc

T=Timp;
[m,n]=size(T);

P2006=Pimp(:,1);                    % Population of 2006
P2011=Pimp(:,2);                    % Population of 2011
P2011new=Pimp(:,2);                 % New population of 2011

delPi=P2011-P2006;
delP=sum(delPi);
delP17=1.0*delP;                    % 100% intensifying the new population

Zone17=[1 2 3 4 5 6 7 8 9 11 12 19 20 21 22 27 42];
PT17=0;
DP17=0;
for i=1:17
    PT17=PT17+P2006(Zone17(i));

    DP17=DP17+delPi(Zone17(i));
end
PT=sum(P2006);                     % Total pop of 17 zones in 2006
PT87=PT-PT17;                      % Total Pop of 87 zones in 2006

GR17=delP17/PT17;                  % Growth rate

P2011new= P2006 + 0.6*delPi;

for i=1:17
    P2011new(Zone17(i))=P2006(Zone17(i))*(1+GR17);
end

% --------------- Finding the new T matrix -----------------
kProduct=(P2011new./P2006)';
kAtract=kProduct;

sumProduct=kProduct.*sum(T'); % Redistributing the new trips by applying the growth factor model
sumAtract=kAtract.*sum(T);
```

```
err=1;

while err >= 0.1
    for i=1:n
        T(:,i)=(kProduct').*T(:,i);
    end
    sumAtractNew=sum(T);
    kAtract=sumAtract./sumAtractNew;
    for i=1:n
        T(i,:)=(kAtract.*T(i,:));
    end
    sumProductNew=sum(T');
    kProduct=sumProduct./sumProductNew;
    errProduct=max(abs(ones(1,n)-kProduct));
    errAtract=max(abs(ones(1,n)-kAtract));
    err=max(errProduct, errAtract);
end

B=ones(m,1);                % Calculating the modal split factor

U=Uimp;
Ucar=U(:,1);
Umetro=U(:,2);
modal_ratio = Umetro./Ucar;   % calculating the modal ratio
modal_ratio_av = sum(modal_ratio)/17;
modal_ratio_weighted = modal_ratio/modal_ratio_av;
ShiftRate = 0.1* modal_ratio_weighted;

for i=1:17
    B(Zone17(i))=B(Zone17(i)) - ShiftRate(i);
end

for i=1:m
    for j=1:n
        Tnew(i,j)=T(i,j)*B(i);      % calculating the new trip matrix
    end
end
```

Appendix J: Table of zonal growth factor for each scenario

Table J.1 Table of zonal growth factor for each scenario

Subway Zones are highlighted	*Present growth factor (F_i)*	*First scenario F_i*	*Second scenario F_i with a=20% intensification*	*Third scenario F_i with a=50% intensification*	$(1-b\times\frac{M_i}{M})$ *b=10%*	$(1-b\times\frac{M_i}{M})$ *b=40%*
101	2.3	2.3	4.66	11.64	0.94	0.75
102	2.3	2.3	4.66	11.64	0.85	0.41
103	2.3	2.3	4.66	11.64	0.87	0.48
104	2.3	2.3	4.66	11.64	0.90	0.58
105	2.3	2.3	4.66	11.64	0.87	0.49
106	2.3	2.3	4.66	11.64	0.87	0.49
107	2.3	2.3	4.66	11.64	0.82	0.28
108	2.3	2.3	4.66	11.64	0.92	0.67
109	2.3	2.3	4.66	11.64	0.91	0.63
110	2.3	2.3	1.38	1.38	1.00	1.00
111	2.3	2.3	4.66	11.64	0.82	0.29
112	2.3	2.3	4.66	11.64	0.91	0.63
113	2.3	2.3	1.38	1.38	1.00	1.00
114	2.3	2.3	1.38	1.38	1.00	1.00
115	0.7	0.7	0.42	0.42	1.00	1.00
116	1.9	1.9	1.14	1.14	1.00	1.00
117	-2.4	-2.4	-1.44	-1.44	1.00	1.00
118	2.5	2.5	1.50	1.50	1.00	1.00
119	4.2	4.2	4.66	11.64	0.93	0.74
120	2.2	2.2	4.66	11.64	0.98	0.92
121	1.6	1.6	4.66	11.64	0.95	0.79
122	-3.4	-3.4	4.66	11.64	0.95	0.81
123	-0.2	-0.2	-0.12	-0.12	1.00	1.00
124	1.8	1.8	1.08	1.08	1.00	1.00
125	-1.6	-1.6	-0.96	-0.96	1.00	1.00
126	0.8	0.8	0.48	0.48	1.00	1.00
127	1.4	1.4	4.66	11.64	0.88	0.54
128	2.7	2.7	1.62	1.62	1.00	1.00
129	1	1	0.60	0.60	1.00	1.00
130	0.8	0.8	0.48	0.48	1.00	1.00

131	3	3	1.80	1.80	1.00	1.00
132	0.8	0.8	0.48	0.48	1.00	1.00
133	-2.5	-2.5	-1.50	-1.50	1.00	1.00
134	6.3	6.3	3.78	3.78	1.00	1.00
135	-1.8	-1.8	-1.08	-1.08	1.00	1.00
136	3.4	3.4	2.04	2.04	1.00	1.00
137	9.4	9.4	5.64	5.64	1.00	1.00
138	-0.5	-0.5	-0.30	-0.30	1.00	1.00
139	1	1	0.60	0.60	1.00	1.00
140	7.7	7.7	4.62	4.62	1.00	1.00
141	7.1	7.1	4.26	4.26	1.00	1.00
301	0	0	4.66	11.64	0.93	0.72
302	0	0	0.00	0.00	1.00	1.00
303	0	0	0.00	0.00	1.00	1.00
304	0.4	0.4	0.24	0.24	1.00	1.00
305	-3.9	-3.9	-2.34	-2.34	1.00	1.00
306	-2.1	-2.1	-1.26	-1.26	1.00	1.00
307	-1.5	-1.5	-0.90	-0.90	1.00	1.00
308	-1.4	-1.4	-0.84	-0.84	1.00	1.00
309	3.6	3.6	2.16	2.16	1.00	1.00
310	0.5	0.5	0.30	0.30	1.00	1.00
401	4	4	2.40	2.40	1.00	1.00
402	4	4	2.40	2.40	1.00	1.00
403	4	4	2.40	2.40	1.00	1.00
404	4	4	2.40	2.40	1.00	1.00
405	4	4	2.40	2.40	1.00	1.00
406	4	4	2.40	2.40	1.00	1.00
407	4	4	2.40	2.40	1.00	1.00
408	4	4	2.40	2.40	1.00	1.00
501	3	3	1.80	1.80	1.00	1.00
511	4	4	2.40	2.40	1.00	1.00
521	4	4	2.40	2.40	1.00	1.00
522	5.2	5.2	3.12	3.12	1.00	1.00
523	4	4	2.40	2.40	1.00	1.00
524	7.5	7.5	4.50	4.50	1.00	1.00
525	4	4	2.40	2.40	1.00	1.00
531	4	4	2.40	2.40	1.00	1.00
532	4	4	2.40	2.40	1.00	1.00
541	6.5	6.5	3.90	3.90	1.00	1.00

542	10.3	10.3	6.18	6.18	1.00	1.00
543	7.4	7.4	4.44	4.44	1.00	1.00
544	10	10	6.00	6.00	1.00	1.00
545	3	3	1.80	1.80	1.00	1.00
546	-1	-1	-0.60	-0.60	1.00	1.00
547	4	4	2.40	2.40	1.00	1.00
551	4	4	2.40	2.40	1.00	1.00
561	-1	-1	-0.60	-0.60	1.00	1.00
562	4	4	2.40	2.40	1.00	1.00
571	11	11	6.60	6.60	1.00	1.00
572	22	22	13.20	13.20	1.00	1.00
573	6	6	3.60	3.60	1.00	1.00
574	15	15	9.00	9.00	1.00	1.00
575	4	4	2.40	2.40	1.00	1.00
601	20	20	12.00	12.00	1.00	1.00
611	3	3	1.80	1.80	1.00	1.00
612	1	1	0.60	0.60	1.00	1.00
613	4	4	2.40	2.40	1.00	1.00
621	17.4	17.4	10.44	10.44	1.00	1.00
622	2.2	2.2	1.32	1.32	1.00	1.00
623	5.2	5.2	3.12	3.12	1.00	1.00
624	8.7	8.7	5.22	5.22	1.00	1.00
631	1.3	1.3	0.78	0.78	1.00	1.00
632	7.1	7.1	4.26	4.26	1.00	1.00
633	4	4	2.40	2.40	1.00	1.00
641	6	6	3.60	3.60	1.00	1.00
642	3.4	3.4	2.04	2.04	1.00	1.00
643	21.7	21.7	13.02	13.02	1.00	1.00
644	9	9	5.40	5.40	1.00	1.00
645	0	0	0.00	0.00	1.00	1.00
651	20.8	20.8	12.48	12.48	1.00	1.00
661	6	6	3.60	3.60	1.00	1.00
662	30	30	18.00	18.00	1.00	1.00
801	0	0	60.00	60.00	1.00	1.00
802	0	0	60.00	60.00	1.00	1.00

Appendix k: Publication

Fadaee, S., and Hammad, A. (2008). “Impact of Population Intensification near Transit Nodes on Montreal Traffic Assignment.” 7th Transportation specialty conference, Quebec City, QC, Canda.