DEVELOPMENT OF A 24-HOUR TRANSPORTATION NETWORK AND EMISSION MODELLING SYSTEM FOR HALIFAX

by

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DEDICATION

To my Parents

MOHAMMAD ABDUL JALIL

And

RASHIDA BEGUM

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ABSTRACT

The objectives of this study is to develop a 24-hour transportation network model for Halifax, to estimate emission by using the modeling system and to evaluate alternate transit infrastructure projects. A regional transportation network model was developed and validated. Emissions from GHG, GHG, CO, NOx, THC, VOC, PM_{10}, and $PM_{2.5}$ were estimated. Model results reveals that annual per capita GHG emission was found 3.09 ton in 2011 and forecasted 3.41 ton for 2021. The results also suggests that emission polluting power and pollution experienced demonstrates difference for instance, suburban and rural areas experiencing more emission than they generate. Study results suggests that modal shift from auto to transit or active transportation would help to reduce emissions, for example, 3.81% less emission for a 5% shift towards transit. Alternative transit infrastructure evaluation concludes that rail and BRT would decrease auto ridership and emission whereas BRT would reduce travel time.

LIST OF ABBREVIATIONS USED

BAU	Business as usual
BPR	Bureau of Public Roads
BRT	Bus Rapid Transit
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CT	Census Tract
EMME	Equilibre Multimodal Multimodal Equilibrium
EPA	Environmental Protection Agency
GEH	Geoffrey E. Havers, Statistics
GHG	Greenhouse Gas
GTA	Greater Toronto Area
GSS	General Social Survey
HBO	Home Based Other (Trip)
HBW	Home Based Work (Trip)
HFCs	Hydro Fluorocarbons
HMTS	Household Mobility and Travel Survey,2012-13
HRM	Halifax Regional Municipality
iTLE	integrated Transportation, Land-use and Energy (Model)
ITS	Intelligent Transportation System
LRT	Light Rail Transit
MNL	Multinomial Logit
MOVES	Motor Vehicle Emission Simulator
Mt CO_2 Eq.	Metric Tons of Carbon Dioxide Equivalent
N_2O	Nitrous Oxide
NCHRP	National Cooperative Highway Research Program

NF_3	Nitrogen Trifluoride
NHB	Non Home Based (Trip)
NHS	National Household Survey
NLOGIT	Nested Logit
NOx	Nitrogen Oxides
NSTIR	Nova Scotia Transportation and Infrastructure Renewal
O-D	Origin-Destination
PFCs	Per Fluorocarbons
PM_{10}	Particulate matter under 10 μm
$PM_{2.5}$	Particulate matter under 2.5 μm
RMPS	Regional Municipal Planning Strategy
SF_6	Sulphur Hexafluoride
SP	Stated Preference
TAZ	Traffic Analysis Zone
THC	Total Hydrocarbons
UNFCCC	United Nations Framework Convention on Climate Change
UTEC	Urban Transportation Emission Calculator
VDF	Volume Delay Function
VHT	Vehicle Hour Traveled
VKT	Vehicle Kilometer Traveled
VOC	Volatile Organic Compounds

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CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Greenhouse Gas (GHG) emission estimation is becoming an increasingly important field of study to combat the global issue of climate change. Greenhouse gases absorb radiation in the atmosphere and are largely responsible for the greenhouse effect which is one of the leading causes of global warming. Hence, GHG emissions has become a growing concern nowadays around the globe. Developed countries including Canada are leading research on GHG emission estimation to address the issue and develop effective strategy to reduce greenhouse effect.

According to the National Inventory Report 1990-2014 of Environment and Climate Change Canada, GHG emissions in Canada in 2014 was 733 Mt CO_2 Eq. This value is 20% above the 1990 total of 613 Mt. CO_2 Eq. Figure 1-1 shows steady increases in annual emissions characterized the first 10 years of this period, followed by fluctuating emission levels between 2000 and 2008, a steep drop in 2009, and a gradual increase thereafter. From 2005 to 2009, emissions decreased by 6.8% and from 2009 to 2014, emissions increased by 5.2%, resulting in an overall decrease of 15 Mt CO_2 Eq. between 2005 and 2014.

At the 15th session of the United Nations Framework Convention on Climate Change (UNFCCC) in 2009, Canada committed to reduce its GHG emissions to 17% below the 2005 level by the year 2020. In May 2015, Canada further indicated its intent to reduce GHG emissions by 30% below 2005 levels by 2030.

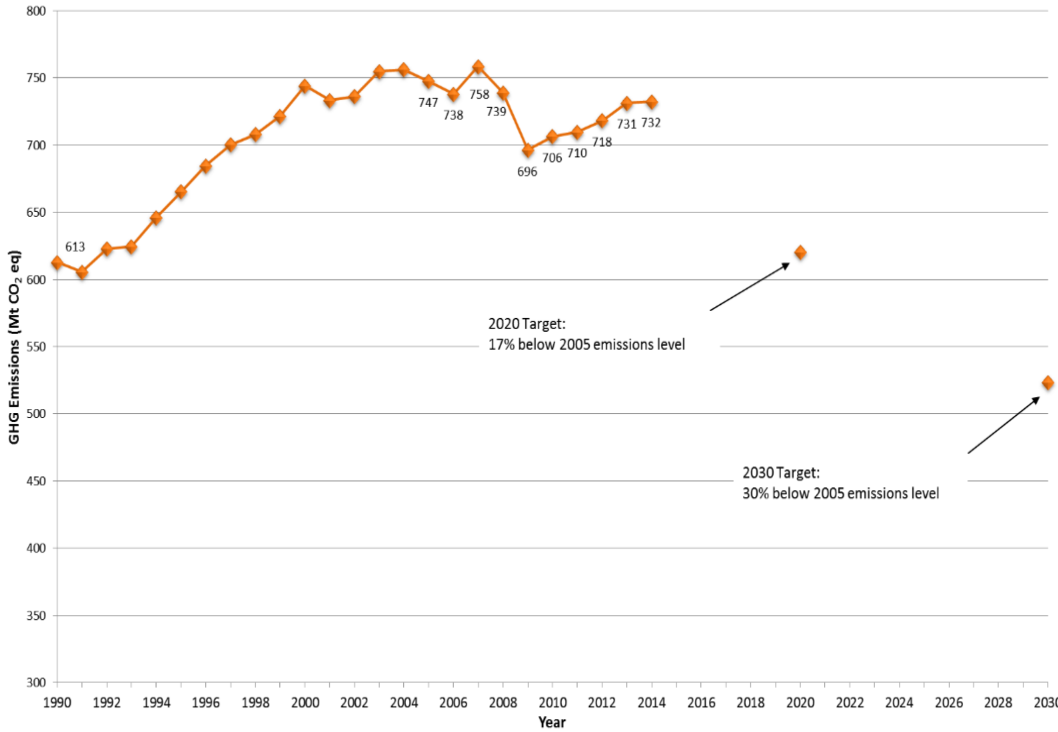


Figure 1-1 Canadian GHG Emission Trend and Target (*Environment and Climate Change Canada, 2016***)**

Identifying the major contributors of GHG emission is a necessary preliminary step for emission study. Transportation is the second largest contributor of GHG emissions in Canada after oil and gas. Figure 1-2 shows that in 2014, transportation generated 171 Mt CO_2 Eq emission, which is 23% of Canadian total GHG emission. Passenger cars and passenger light trucks contributed 50.11% of this emission in 2014, whereas freight trucks generated 31.95% of this emission. (*Environment and Climate Change Canada, 2016*).

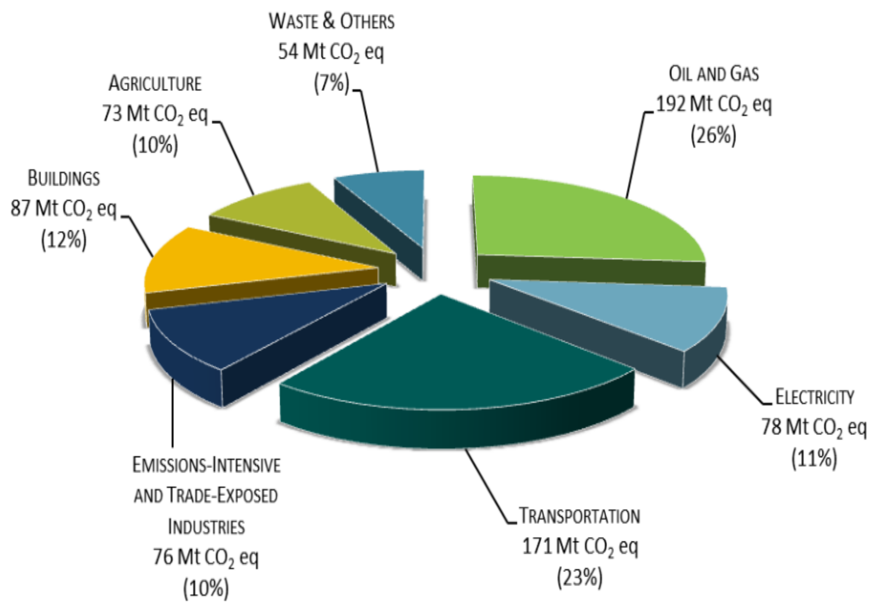


Figure 1-2 Canada's Emissions Breakdown by Economic Sector for 2014

(*Environment and Climate Change Canada, 2016*)

Moreover if we analyze emissions from different source categories between 2005-2014, it becomes evident that even though overall emissions decreased during this period, the emissions produced by the transportation sector has increased by 4% (8 Mt) from 2005 to 2014 (Figure 1-3). Whereas all other sectors were able to reduce emissions in this period, emissions from transportation sector has increased. Therefore, emissions from transportation especially from passenger transportation needed to be at the forefront of GHG emissions reduction initiative.

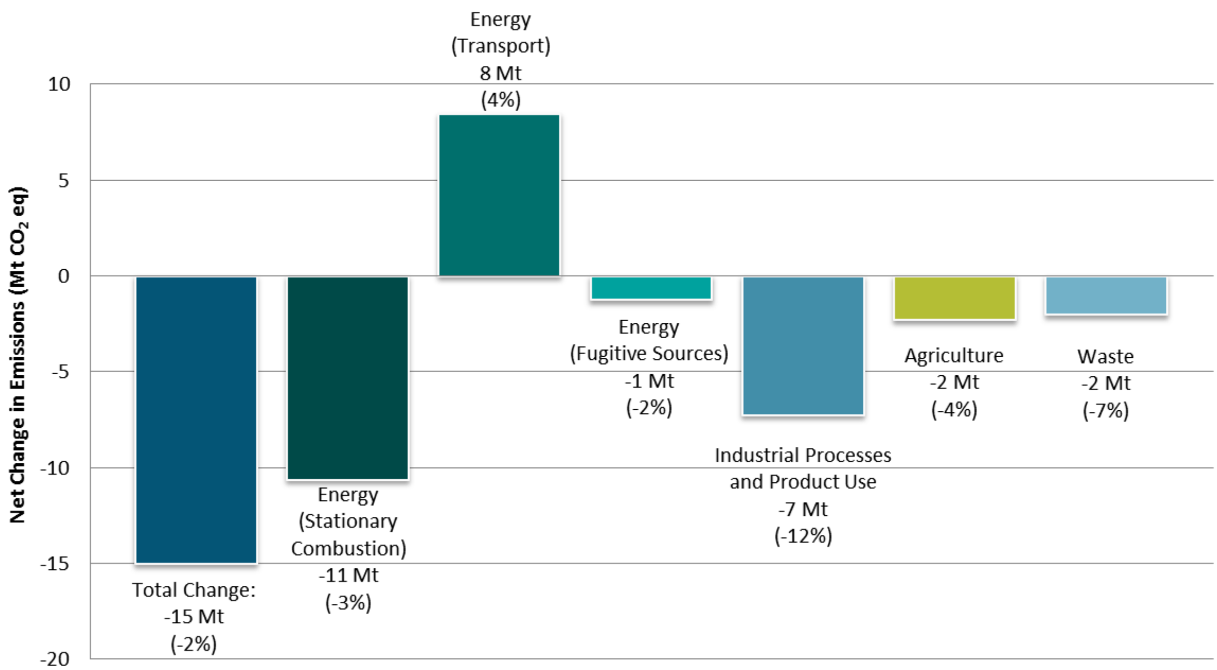


Figure 1-3 Canadian sector wise net change in Emissions 2005-2014 *(Environment and Climate Change Canada, 2016***)**

In addition to GHG, motor vehicles in transportation sector are responsible for emission from other pollutants such as, particulate matter under 10 µm (PM_{10}), Total Hydrocarbons (THC), particulate matter under 2.5 µm ($PM_{2.5}$) Carbon monoxide (CO), Volatile organic compounds (VOC), Nitrogen Oxides (NOx) which have serious health consequences on human body. A comprehensive transportation network and emission modeling framework can provide estimation of all those pollutants.

The combined use of regional transportation network modeling in conjunction with energy and emission modeling can be utilized for the evaluation of environmental impacts of transportation related emissions. Transportation modeling research field has also moved in recent times towards developing analytical framework that provides a comprehensive analysis of vehicle emissions. By using transport network and emission modeling framework, emissions can be estimated illustrating both temporal and spatial variation. Therefore, a regional 24-hour transportation network and emission modeling system can quantify aggregate emissions for an area as well as provide understanding about from which area the pollution is generating and which area is experiencing that pollution. This understanding would be hugely beneficial for a city like Halifax, where there are urban, suburban and rural areas within its boundary.

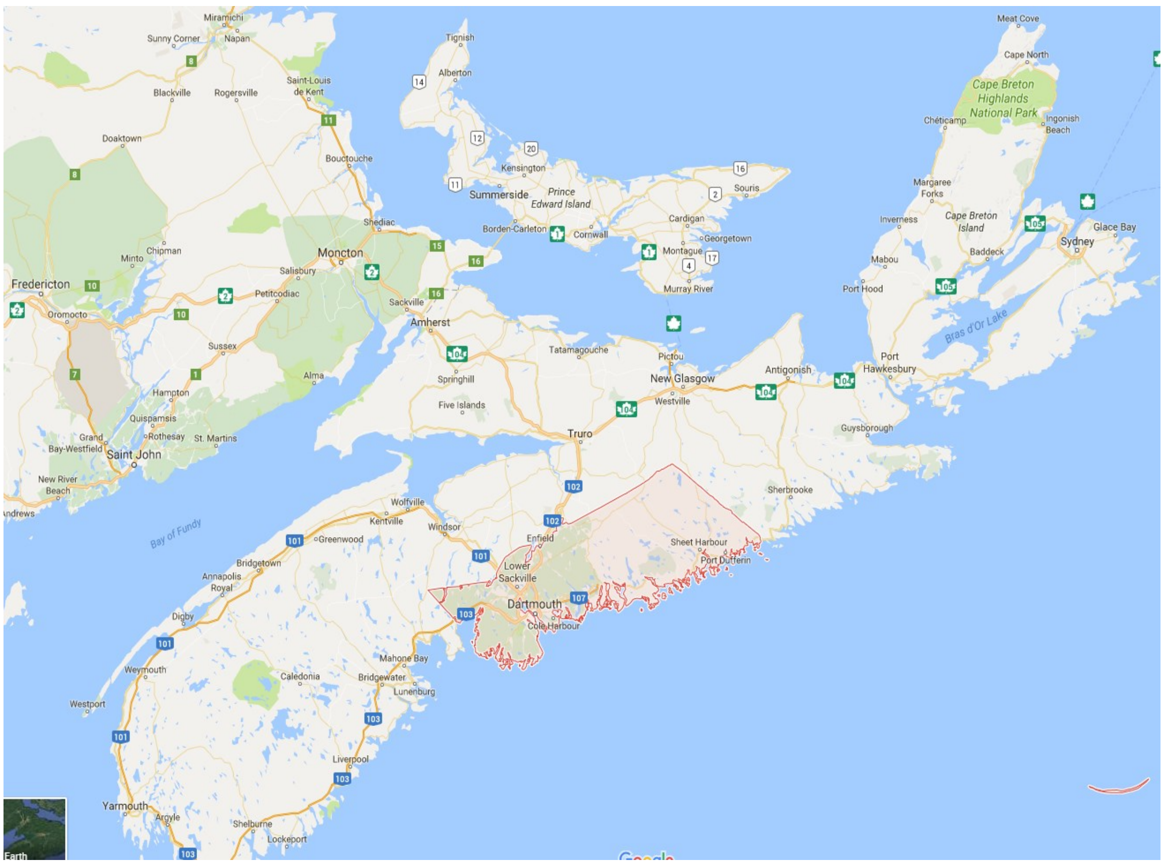


Figure 1-4 Map of Halifax Regional Municipality, Nova scotia

Halifax is the capital of the province of Nova Scotia, Canada (*Figure 1-4*). In 2011, the Halifax Regional Municipality (HRM) had a population of 390,096. It is the largest population center in Atlantic Canada, and has one of the world's largest natural harbor.

Halifax is the combination of urban, suburban and rural areas due to amalgamation of the City of Halifax, the City of Dartmouth, the Town of Bedford and Halifax County in 1996 (*Halifax Regional municipality Report, 2013).* The growth pattern and travel behaviors differ significantly between the urban core, suburban and rural areas. It will be interesting to observe which of these areas are polluting more and which area are experiencing the pollution. This can be done by examining polluting power and pollution experienced in these areas. Therefore, the development of a 24-hour transport network model for emissions estimation is required for a comprehensive study on emission of Halifax.

Hence, the motivation of the thesis is to provide a modeling framework to quantify transportation emissions in Halifax. The modeling is further used to evaluate alternative transit infrastructure projects in Halifax.

1.2 Research Objectives

The research objectives of this study were as follows:

1. To develop a 24-hour transportation network and emission modelling system for Halifax.

2. To estimate vehicular emission and examine spatio-temporal variations specifically in relation to polluting power and pollution experienced.

3. To evaluate alternative transit infrastructure projects in Halifax using the modeling system.

1.3 Organization of the Thesis

This thesis is presented in 5 chapters. The contents of this thesis are arranged in the following sequence:

Chapter 2 describes the steps of development of the transportation network model.

Chapter 3 presents the estimation of the emissions in Halifax illustrating spatial and temporal variation.

Chapters 4 presents the evaluation of alternate transit infrastructure project for Halifax-Bedford corridor using the transportation network and emissions modeling with respect to network performance and GHG emissions.

Chapter 5 summarizes the conclusion of the research, contributions and recommendations for future work.

CHAPTER 2

TRANSPORTATION NETWORK MODEL DEVELOPMENT

2.1 Chapter Overview

This chapter deals with the development of a regional transportation network model for Halifax, Nova scotia, Canada. This was done by using a four stage travel demand forecasting modeling framework which includes trip generation, trip distribution, modal split and traffic assignment. To represent the 24 hour temporal variation, a time of the day model was also incorporated in the modeling system. The model was developed for base year of 2011 and then Halifax regional observed growth parameters were used to forecast for 2016 and 2021.

The model validation was performed with existing traffic data in Halifax. Network performance were evaluated based on the following metrics: travel time, traffic volume and speed of 24 hours for the total network. Screen line analysis were performed at specific locations and between O-D pairs to characterize network performance in Halifax.

This chapter is organized as follows: first, a brief introduction of description of traffic analysis zone and road network of Halifax followed by the four stage model development, validation and forecasting. Analysis of the transportation network performance measures were presented with discussion of the model results.

2.2 Introduction

Travel is a derived demand for activity participation. In transportation modeling, this demand is defined by number of trips between origin-destination. Trip-based methods are widely used in regional transportation network modeling. Four stage modeling approach holds a significant and useful contribution in the history of demand modeling research. Travel demand forecasting models have been playing a crucial role in transportation planning particularly for the evaluation of transport and land use policies, programs and projects.

The availability of travel demand forecasting models has provided planners with powerful and flexible tools for transport studies. Kriger et al. (*2007)* reviews travel demand forecasting models of Canada's nine largest urban areas: Québec City, Montréal, Ottawa-Gatineau, Toronto, Hamilton, Winnipeg, Calgary, Edmonton and Vancouver. Their finding suggested that well-developed travel demand forecasting models available in each of the nine urban areas which provided a unique opportunity for local authorities to use the models in policy decisions.

Across North America various cities use travel demand forecasting model for transportation planning purpose. For example, Anderson et al. (*2006*) developed the direct demand forecasting model which generates traffic volumes for roadways through the development of a functional relationship between roadway characteristics and socioeconomic influences. The direct demand travel forecasting model has been developed and applied, with a small urban area as a case study community. Proussaloglou et al. (*2007*) developed and validated statewide demand forecasting model for Wisconsin to understand and quantify both passenger and freight flows to support statewide level transportation. A number of different policies including the impact of different land use scenarios, transportation projects on highway traffic, the diversion of traffic along key corridors, and the ridership potential of enhanced intercity bus service were tested in this model. Xiao et al. (*2010*) implemented Intelligent Transportation System (ITS) evaluation as part of the Florida Standard Urban Transportation Model Structure. It represents a formal set of modeling steps, procedures, software, file formats, and guidelines established by the Florida Department of Transportation for use in travel demand forecasting throughout the state of Florida. Kuppam et al. (*2011*) developed special events model which is being designed as a regional model. It will be able to serve as a forecasting and scenario testing tool for special events. The model is a stand-alone forecasting procedure, but it can be integrated within a weekday trip-based modeling framework. Jansuwan et al. (*2012)* developed a simplified planning tool with planning applications like four stage travel demand forecasting model specifically targeted at small cities like Utah and demonstrates how the tool can be implemented in practice.

Unlike those examples, Halifax has a limited research history in the development of travel demand forecasting model. Yan and Habib (*2011*) built a transit network for Halifax.

Rahman and Habib (*2014*) developed a transportation network model using four stage modeling approach and by further developing the existing transit network. This study further extend the modeling system by validating with existing data, forecasting for 2021 and estimating emission. In this way, this study aims to contribute in the sequential development of a transportation network model for Halifax.

The first objective of this study is to develop a 24 hour transport network model. Stages of that model and their developments are described in the following sections.

2.3 Four Stage Travel Demand Forecasting Model

The National Cooperative Highway Research Program (NCHRP) report on Travel Demand Forecasting: Parameters and Techniques (*2012*) provides outline and guidelines on travel demand forecasting procedures and their application for solving common transportation problems. The classical four stage travel demand forecasting model consists of the following four stages:

1. Trip Generation
2. Trip Distribution
3. Modal Split
4. Traffic Assignment.

The purpose of trip generation is to estimate the number of trips of each type in an area. In most models, trips are aggregated to a specific unit of geography (e.g., a traffic analysis zone). The estimated number of daily trips is either vehicle trips or person trips in motorized modes or all modes including motorized and nonmotorized (walking, bicycling) modes.Trip generation models require specific explanatory variables that are related to trip-making behavior and key functions that estimate the number of trips based on these explanatory variables. Typical variables include household characteristics such as number of persons, number of workers, vehicle availability, income level and employment by type. Trip generation stage provides trip productions and attractions by traffic analysis zone and by purpose as output.

The trip distribution stage of the model addresses the question of how many trips travel between units of geography (e.g., traffic analysis zones). It links the trip productions and attractions from the trip generation step. Trip distribution requires explanatory variables that are related to the cost (including time and distance) of travel between zones, as well as the amount of trip-making activity (such as employment) in both the origin zone and the destination zone. Production-attraction zonal trip tables by purpose are the outputs of trip distribution.

Mode choice is the third stage in the four-stage process. In this stage, it is determined which travel modes are being used by the trip makers. The modes can be generally grouped into automobile, transit, and nonmotorized modes. Individual travel behavior is determined in choice models analyzing their sociodemographic chracteristics and relative attractiveness of the mode. The outputs of the mode choice process include person trip matrix by mode and purpose.

The final stage of the process is traffic assignment. This step consists of separate automobile and transit assignment processes. During the assignment process route choice decisions are made and trips are assigned to the route from origin to destination along the transportation network, resulting in traffic volumes on network links by time of day. Speed and travel time estimates, which reflect the levels of congestion indicated by link volumes, are also output of this stage.

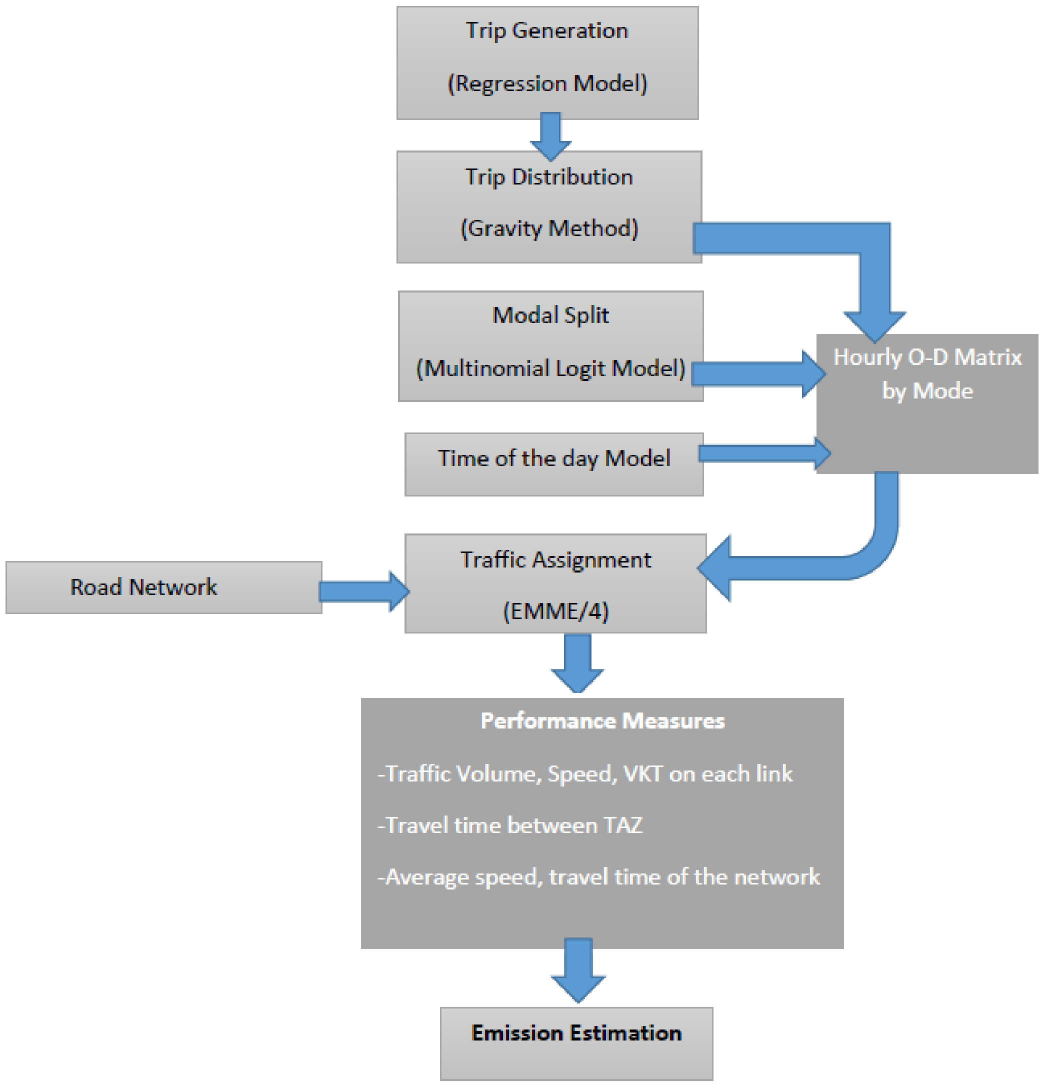


Figure 2-1 Travel demand forecasting model framework considered in this study

The modeling framework used in this study is shown in figure 2-1. Here a regional transportation network model for Halifax is developed using four stage travel demand forecasting methodology. In addition to that, to incorporate 24 hour temporal distribution, a time of the day model was used. The model is further extended to estimate emission.

2.4 Study Area: Traffic Analysis Zone

Halifax Regional Municipality is the study area of this thesis. The first step of network modeling is to develop a zonal system. Yan and Habib (*2011)* developed a zonal system for Halifax with 206 traffic analysis zones. This study extends the zonal system and divided Halifax into 219 traffic analysis zones out of which 91 urban core, 91 suburban and 37 rural zones.

During TAZ development, considerations were taken to ensure compatibility with census tract boundaries, major road network and land use. TAZ were also created to correspond population density, new growth and employment concentration.

Figure 2-2 shows the traffic analysis zones in Halifax map. Here, urban areas are concentrated around downtown Halifax and has a mix of commercial and residential use. Suburban areas are around the periphery of urban areas and mostly residential areas. Rural areas are further outspreaded from the Halifax peninsula.

Location of Traffic analysis zone details can be found in Appendix A-1. Additionally Appendix A-2 lists demographic and socio economic characteristics such as population, household characteristics, employment, income etc.

Figure 2-2 Traffic Analysis Zones (TAZ) of Halifax

2.5 Transportation Network of Halifax

Transportation network model requires network coding of existing roads with their physical and operational characteristics. Halifax has a road network of 2140.3 kilometers. In this study, Road network of Halifax is coded in EMME/4.The roads of transportation network in the model are classified as Highways, Arterial, Major Collector, Minor Collector and Local roads. In this network model, the road network of Halifax is represented by 219 zone centroids, 2249 regular nodes, 5232 directional links, which includes 339.76 km of highway, 551.63 km of arterial road, 395.41 km of major collector, 212.25 km of minor collector and 452.13 km of local roads. Total 1956.45km of road is represented in the network model. The network covers total length of highway, arterial and major collector as well as most of minor collector and some local roads. The road network characteristics with free flow speed and capacity of each road type, considered in this study is represented in table 2-1.

Table 2-1 Road Network Characteristics

Sl No.	Type of Road	Length (km)	Number of Road segment	Free flow speed (km/hr)	Capacity (veh/hr)
1	Highway	339.76	585	100	4400
2	Arterial	556.90	2148	70	3200
3	Major Collector	395.41	1341	50	2200
4	Minor Collector	212.25	387	40	1900
5	Local	452.13	750	30	1600

Figure 2-3 shows the road network of Halifax which is coded in EMME/4 classified with road types. Figure 2-4 highlights the road network of Halifax core area.

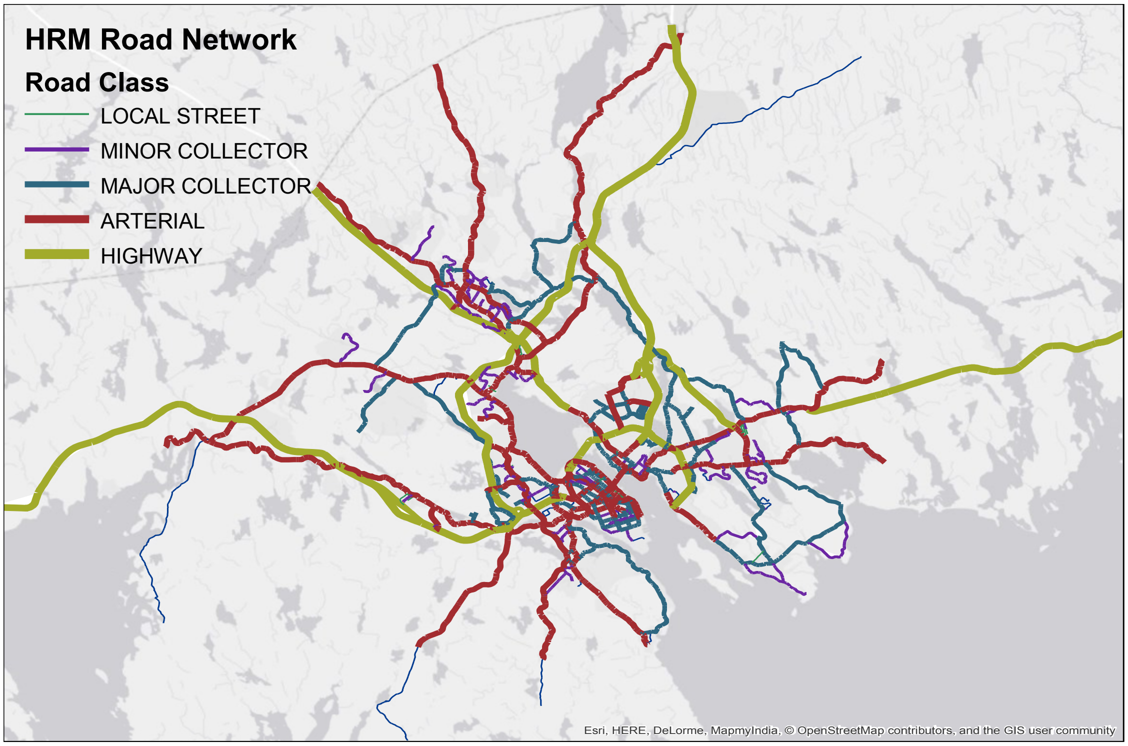


Figure 2-3 Halifax Road Network in the model

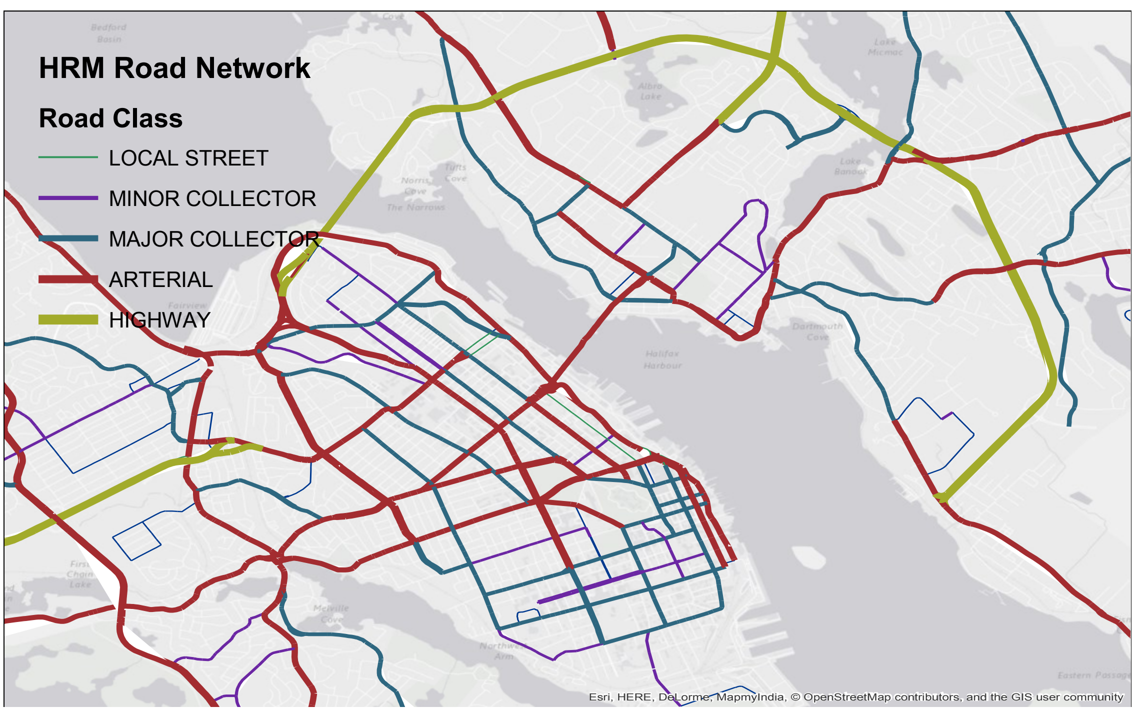


Figure 2-4 Road Network in Halifax core in the model

The transit network is also developed with the existing transit routes for Halifax. Transit services in Halifax are delivered by Metro Transit. The organization operates 63 bus routes as well as two ferries that connect Woodside and Downtown Dartmouth to Downtown Halifax across Halifax Harbor. Figure 2-5 shows the transit network in EMME/4. List of all the transit routes and their headways are provided in Appendix B-3

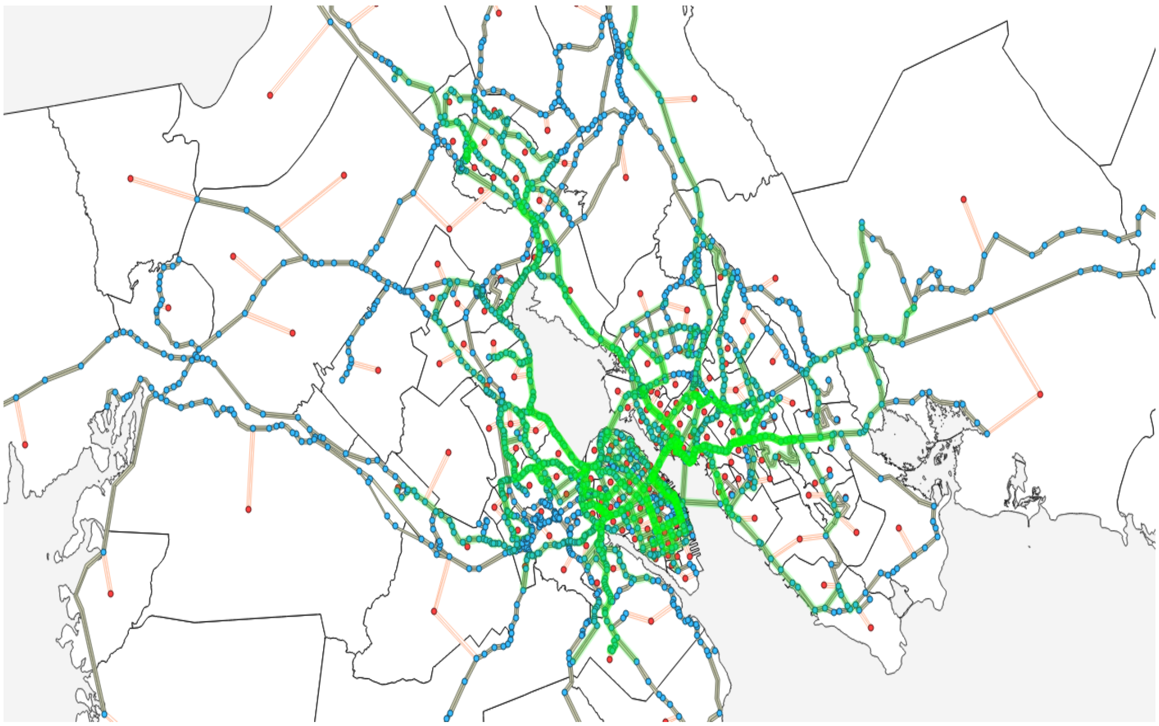


Figure 2-5 Transit Network in the Model

Additional alternate transit route of Bus Rapid transit (BRT), Commuter rail and ferry between Halifax and Bedford are added to the network for transit infrastructure evaluation which is described in chapter 4.

2.6 Trip Generation

Trip generation is the first stage of demand forecasting model. This stage estimates the number of trips produced and attracted in each traffic analysis zone. Generally trip generation model consists of two models such as trip production model and trip attraction model. Several techniques have been proposed to develop these models. Most methods attempt to predict the number of trips produced (or attracted) by household or zone as a function of (generally linear) relations to be defined from available data. (*Ortuzar and Williumsen, 2011*). All of those techniques can be broadly classified in the following three groups:

1. Growth factor method
2. Cross-classification analysis
3. Regression analysis

In this study, zone based multiple regression method is used in trip production model which attempt is made to find a linear relationship between the number of trips produced by zone considering average socioeconomic characteristics of the households in each zone. If the trips per household in a zone is Y and X_1, X_2 ….X_k are demographic and socioeconomic characteristics such as household size, employment, income, vehicle ownership then the regression model would be:

$$Y_i = \theta_0 + \theta_1 X_{1i} + \theta_2 X_{2i} + \ldots + \theta_k X_{ki} \quad \text{.......} \textit{(1)}$$

Whereas θ_0 is the constant parameter and θ_1, θ_2….. θ_k are the parameter value corresponds to variable X_1, X_2 ….X_k. The regression model is run using Minitab software. R-square value is used to measure the model fit.

National Household Survey (NHS) 2011 provides population, household size, employment and income and number of work trips data at 87 Census Tract (CT) level of Halifax. Those data are processed and converted into 219 TAZ data by using weighted average of the area of the individual TAZ. Zone based regression model was developed for the Halifax network model. Trips per household is the dependent variable in this model. Among the independent variables, employment per household, average household size are used as continuous variable and neighborhood characteristics and average income groups were used as binary variables.

Table 2-2 Trip Production Regression Model Results

Variables	Parameter	T- stat
Constant	-1.3294	-11.65
Household Characteristics		
Employment rate	2.0765	41.25
Average Household Size	0.5145	37.02
Neighborhood characteristics		
Urban Core	.0017	.10
Sub Urban	.0292	2.12
Average individual income		
$15000-$30,000	.0613	1.04
$30,000-$45000	.1009	1.71
$45000-$60,000	0.0798	1.34
$60,000-$75000	0.0211	0.35
$75,000 and above	-0.0170	-0.23
Adjusted R –Sq .8731		

The results of the regression model is shown in table 2-2 which is used to calculate the work trips for each zone. Model result suggests that the higher the employment rate in the zone, the higher the trip production. Suburban areas produce more trip per household than other area. Zones with average individual income $30,000-$45,000 produce more trip than other income group. It also concludes that, with income of more than $75,000 trip per household decreases.

Trip attraction is calculated by using point of interest data for business establishment at Decimation Area (DA) level from NHS 2011. The points which has employment potential such as commercial, industrial, service sector, educational institute, and hospital are considered for this purpose. Those are then spatially joined into TAZ level to estimate trip attractions in each zone. Figure 2.6 shows zonal trip productions and attractions in the network model.

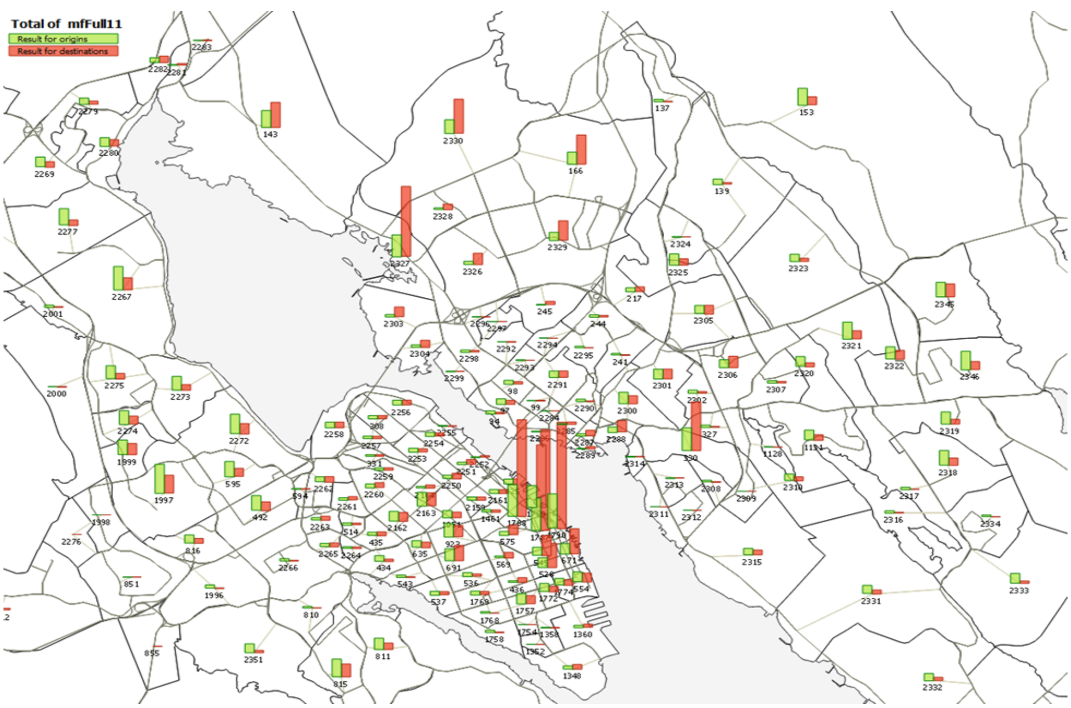


Figure 2-6 Trip Production and Attraction in Traffic Analysis Zone (TAZ) level

Total trip attractions are then matched with total trip generations as by default, that the total number of trips originating (the origins Oi) for all zones will be equal to the total number of trips attracted (the destinations Dj) to them,

Table 2-3 Trip Production and Attraction Summary for Work Trip

	Location	TAZ group	Work Trip Production	Work Trip Attraction
Urban core	Halifax Core (South End)	U-1	6475	4915
	Halifax Core (Citadel-Downtown)	U-2	6099	57361
	Halifax Core (University-Residential)	U-3	7014	5286
	Halifax Core (Chebucto)	U-4	7204	7716
	Halifax Core (North End)	U-5	5833	7276
	Dartmouth Core (Dartmouth North)	U-6	6329	6720
	Dartmouth Core (Dartmouth South)	U-7	6886	13537
	Total Urban		**45840**	**102811**
Suburban	Halifax (Armdale)	S-1	12139	5053
	Halifax (Fairview Clayton park)	S-2	20827	8824
	St Margaret's Bay	S-3	3700	1835
	Bedford Core	S-4	10603	5595
	Bedford	S-5	1468	1006
	Sackville	S-6	14662	8200
	Dartmouth North	S-7	11655	27857
	Dartmouth South	S-8	12437	6614
	Cole Harbor Eastern Passage	S-9	14495	3627
	Total Suburban		**101986**	**68611**
Rural	Prospect	R-1	7692	5279
	St. Margarets Bay	R-2	5075	2434
	Sackvile	R-3	17276	6929
	Waverley-fall River	R-4	2820	2667
	Portar's Lake-Lawraencetown	R-5	9652	5132
	Musquo-doboit Harbour	R-6	5496	2457
	Sheet Harbour	R-7	1521	1037
	Total Rural		**49532**	**25935**

The summary results of work trip generations and attractions by zones are shown in table 2-3. It reveals that the total work trip produced in Halifax in a day is 197,358. Most of the trips are produced from suburban areas represents 51.67% of total trips, whereas rural and urban areas produce 25.10% and 23.23% respectively. On the other hand, 52.09% of total trips are attracted to urban areas and suburban and rural areas attract 34.76% and 13.14% respectively. This reflects that most of the work trips are produced from suburban areas to urban areas.

2.7 Trip Distribution

The objective of the second stage of the process is to recombine trip ends from trip generation into trips. This step matches trip makers' origins and destinations to develop a "trip table", a matrix that displays the number of trips going from each origin to each destination.

This is essentially a two-dimensional array of cells where rows and columns represent each of the z zones in the study area. The cells of each row i contain the trips originating in that zone which have as destinations the zones in the corresponding columns.. Therefore: T_{ij} is the number of trips between origin i and destination j; the total array is $\{T_{ij}\}$ or **T**; O_i is the total number of trips originating in zone i, and D_j is the total number of trips attracted to zone j. P_i is the number of trips produced or generated in a zone i and Q_j those attracted to zone j. A sample Origin-Destination trip matrix is shown in table 2-4.

Traditionally, three methods are used for trip distribution.

1. Growth factor method

2. Gravity model

3. Entropy maximizing approach

Table 2-4 A sample Origin Destination trip matrix

	Destinations					
Origins	1	2	3	$\dots j$	$\dots z$	$\sum_i T_{ij}$
1	T_{11}	T_{12}	T_{13}	$\dots T_{1j}$	$\dots T_{1z}$	O_1
2	T_{21}	T_{22}	T_{23}	$\dots T_{2j}$	$\dots T_{2z}$	O_2
3	T_{31}	T_{32}	T_{33}	$\dots T_{3j}$	$\dots T_{3z}$	O_3
$\vdots$						
I	T_{i1}	T_{i2}	T_{i3}	$\dots T_{ij}$	$\dots T_{iz}$	O_i
$\vdots$						
Z	T_{z1}	T_{z2}	T_{z3}	$\dots T_{zj}$	$\dots T_{zz}$	O_z
$\sum_i T_{ij}$	D_1	D_2	D_3	$\dots D_j$	$\dots D_z$	$\sum_{ij} T_{ij} = T$

In this study a doubly-constrained gravity model is used to develop the trip matrix. Mathematically, the gravity model takes the form:

$$T_{ij} = \frac{A_j F_{ij} K_{ij}}{\sum_{n=1}^{m} A_j F_{ij} K_{ij}} \times P_i \dots\dots\dots\dots(2)$$

Where:

T_{ij} = trips produced from zone *i* and attracted to zone *j*

P_i= total trip production from zone *i*

A_j= total trip attraction to zone *j*

K_{ij} = a socioeconomic adjustment factor

F_{ij} = friction factor or travel time factor $F_{ij} = \frac{1}{(t_{ij})^C}$

t_{ij}=travel time between zone i and j

C = calibration factor for the friction factor

Here t is doubly constrained, in the sense that for any i the total number of trips from i predicted by the model always equals the real total number of trips from i. In our model, distance between centroids of each pair of TAZ are considered as friction factor in absence of actual travel time data.

For a medium sized city with population between 200, 000 to 500, 000 the calibration factors were found 1.95 to 2.1 (*NCHRP report 716*) in this study calibration factor C was taken as 2.0.Socioeconomic adjustment factor K for the Greater golden Horseshoe (GGH) model of Toronto were found 0.667 to 1.487 for different occupation trip. (*IBI Group, 2009*).In this study K was taken as 1.0 for all O-D pair zones. Thus variation of socioeconomic adjustment is not considered across trips in this stage as it was incorporated in trip generation stage. Thus this stage results into a 219×219 work O-D trip matrix for Halifax.

2.8 Time of The Day model

Development of 24-hour model requires determination of daily trips in each hour. Time of the day modeling is used to divide the daily trips into trips for various time periods, such as morning and afternoon peak periods, mid-day, and evening. Most four-step models that include the time-of-day step use fixed factors applied to daily trips by purpose.

For time of the day model, the General Social Survey (GSS) data of 2009 was used. Total 3605 trips were reported from Nova Scotia. Start time of those trips are identified to classify into hourly trips. Travel activity throughout the day was classified into Home Based Work (HBW) trips, Home Based Other (HBO) trips and Non Home Based (NHB) trips.

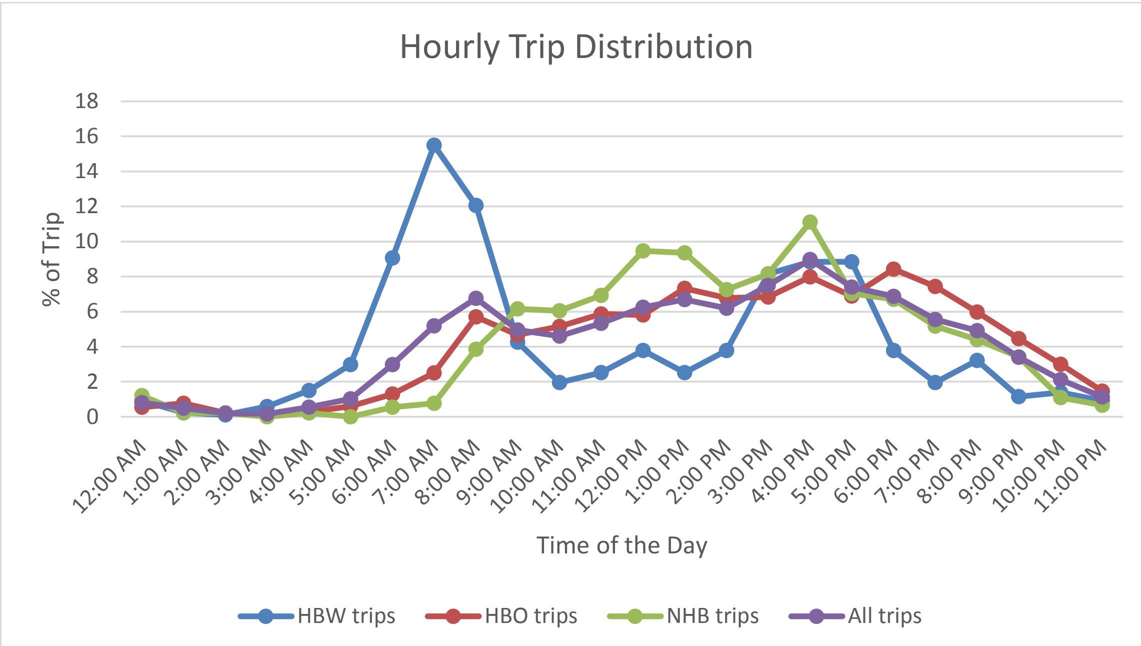


Figure 2-7 Distribution of hourly Trips

Figure 2-7 represents the distribution of HBW, HBO, NHB and all trips throughout 24 hour period. It shows morning peak period is dominated by HBW trips. Afternoon peak consists of HBW, HBO and NHB trips in fair amount.

HBW trips were further identified by observing the location of the start point of trip into trip to work and trip back from work. Figure 2-8 shows the % of home based trips of each hour into trip to work and trip back from work. It found that during morning peak hours most of the work trips starts from home. In the afternoon peaks most work trips are trip to home. At night almost all the trips are trip to home. Hourly trip factors were calculated for trip to and from work. Trip factors by purpose were calculated for 24-hour periods and used to calculate an hourly trip matrix for all purposes.

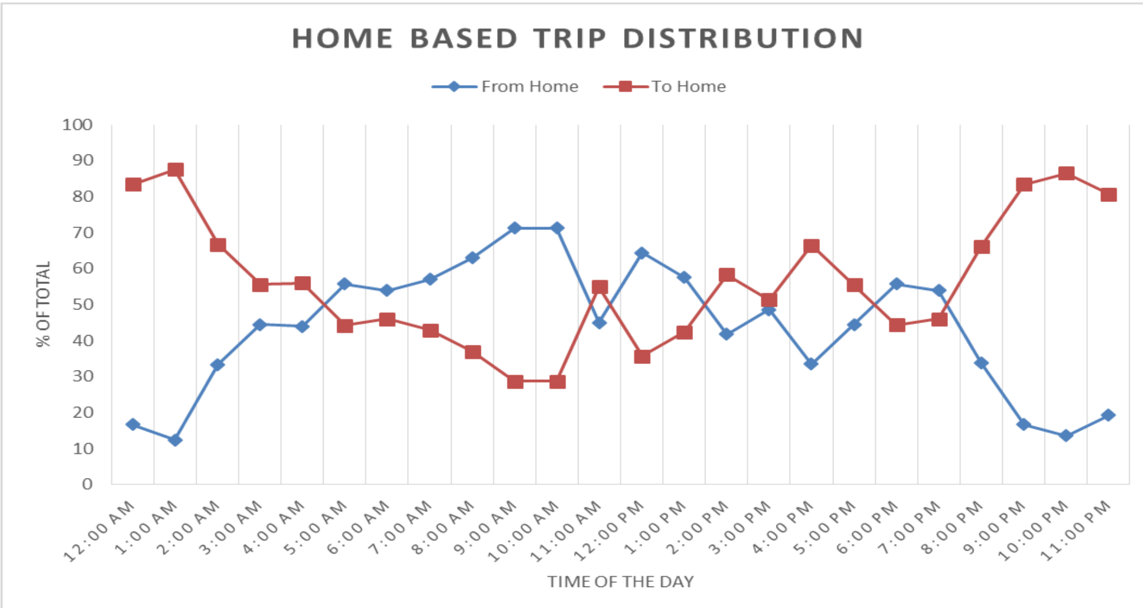


Figure 2-8 24 Hour Distribution of Home Based Trip

HBW trips for 8.00AM is used as reference in this case (appendix). These factors are used to calculate to 24 hour trip matrix for all-purpose. This model also provide opportunity to include HBO and NHB trips in the model in addition to work trips.

2.9 Modal Split Model

Mode choice analysis is the third step in the conventional four-step transportation forecasting model. Mode choice analysis allows the modeler to determine what mode of transport will be used, and what modal share results. There are different types of mode choice model such as

1. Synthetic model

2. Direct demand model
3. Discrete choice model

Multinomial logit model is a discrete choice model. The general equation of a multinomial logit model is given by the equation below (*McFadden 1978*):

$$P_{ijm} = \frac{\exp(V_{ijm})}{\sum_{m \in C_t} \exp(V_{ijm})} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Where,

P_{ijm} is the probability that mode m is chosen for a trip from zone *i* to zone *j*

V_{ijm} is the utility of using mode m for a trip from zone *i* to zone *j*,

$= \beta\, X_{ijm}$

β is vector of utility function parameters

X_{ijm} is vector of explanatory variables for jone *i,j* and mode m

C_t is the choice set of available modes for a trip from zone *i* to zone *j*

MNL model estimate utility by the maximization using Log likelihood procedure. In this study NLOGIT 5.0, which is an econometric and statistical software package was used for the estimation.

The mode choice modeling utilizes data from Household Mobility and Travel Survey (HMTS) which was conducted in Halifax, Nova Scotia in 2012-2013. HMTS yielded 289 complete responses. Five mode choices were considered including auto driver, auto passenger, transit, bike and walk. Location of the trip and distance of the trip was used along with travel time as explanatory variables. The results are shown in table 2-5.

The results of the model shows the probability of choosing auto driver is higher than other modes. In urban areas probability of choosing bike increases. In short distance trips, people are less likely to choose auto drivers.

Table 2-5 Multinomial Logit Model result for Modal Split

Variable	Mode	Parameter	T-stat
Travel Time		-.01345	-1.98
Alternative Specific Constant	Auto Driver	2.24552	4.73
	Auto Passenger	0.75108	1.48
	Transit	1.04173	2.28
	Bike	-0.70205	-1.14
	Walk	Fixed	
Urban Core	Auto Driver	-2.67820	-4.94
	Auto Passenger	-2.67213	-3.55
	Transit	-1.54443	-2.64
	Bike	0.31225	0.44
Trip length <5km	Auto Driver	-1.09797	-2.14
	Auto Passenger	-0.86536	-1.16
	Transit	-0.25680	-0.48
	Bike	-0.24787	-0.45
R square=0.1748			

TAZ specific modal split were derived for each zone using the MNL model results. This stage provides 24-hour trip matrix for each mode choice. The overall modal share of Auto driver, Auto passenger, Transit, Walking and Biking were found 65.88%, 12.08%, 12.81%, 7.46% and 1.77% respectively. Modal share were calculated by both time of the day (table 2-6) and by traffic analysis zones (Table 2-7).

Table 2-6 shows 24-hour modal split. During 12am-6am Transit and bike were not taken as options. Otherwise the modal split is consistent with time and Auto Driver dominates the modal share with a 63-69% modal share during day and with 80-90% in the late-night.

Table 2-6 Modal Split by Time of the Day

Time of the day	Auto Driver	Auto Passenger	Transit	Bike	Walk
12:00 AM	81.09	11.24	0.00	0.00	7.67
1:00 AM	89.05	5.04	0.00	0.00	5.91
2:00 AM	92.55	2.75	0.00	0.00	4.70
3:00 AM	83.95	8.59	0.00	0.00	7.46
4:00 AM	78.95	12.03	0.00	0.00	9.02
5:00 AM	78.69	12.26	0.00	0.00	9.04
6:00 AM	65.85	11.59	13.16	1.85	7.55
7:00 AM	68.10	12.68	11.50	1.83	5.90
8:00 AM	64.66	12.12	13.30	2.08	7.84
9:00 AM	66.24	11.56	13.21	1.63	7.36
10:00 AM	66.50	11.50	13.18	1.55	7.28
11:00 AM	66.19	11.68	13.24	1.57	7.33
12:00 PM	65.26	12.05	13.35	1.82	7.52
1:00 PM	65.41	11.99	13.35	1.79	7.47
2:00 PM	65.60	11.92	13.27	1.77	7.45
3:00 PM	65.24	12.03	13.38	1.80	7.55
4:00 PM	63.46	12.87	13.78	2.13	7.76
5:00 PM	63.75	12.70	13.77	2.09	7.69
6:00 PM	64.62	12.34	13.49	1.93	7.62
7:00 PM	65.16	12.15	13.34	1.85	7.50
8:00 PM	65.40	12.00	13.32	1.84	7.45
9:00 PM	66.71	11.48	13.10	1.54	7.17
10:00 PM	67.94	10.97	12.97	1.22	6.90
11:00 PM	71.06	9.65	12.51	0.67	6.11
Overall	**65.88**	**12.08**	**12.81**	**1.77**	**7.46**

Table 2-7 provided modal split by traffic analysis zones. It reflects that trips from and to urban and urban has high modal share of transit than overall. Auto driver modal share increases in case of rural areas and transit modal share is lowest in trips involving rural areas.

Table 2-7 Modal Split by Traffic Analysis Zone

Trip Origin-Destination	Auto Driver	Auto Passenger	Transit	Bike	Walk
All Zone-All Zone	65.88	12.08	12.81	1.77	7.46
Urban- All Zone	65.16	12.23	14.24	1.19	7.18
Suburban-All Zone	60.18	10.91	16.67	2.50	9.74
Rural- All Zone	80.71	14.46	0.54	1.46	2.83
All Zone-Urban	63.48	11.82	15.18	1.26	8.27
All Zone-Subrban	60.47	10.97	17.06	2.28	9.22
All Zone-Rural	80.48	14.77	0.64	1.46	2.65
Urban- Urban	60.21	12.45	16.69	1.15	9.50
Urban-Suburban	65.55	11.28	15.89	1.24	6.04
Urban- Rural	82.37	13.91	0.81	1.25	1.66
Suburban - Urban	64.03	9.79	16.71	1.68	7.79
Suburban -Suburban	53.02	10.38	21.22	3.12	12.26
Suburban - Rural	81.49	14.10	0.35	1.17	2.89
Rural - Urban	84.94	12.91	0.31	0.89	0.95
Rural -Suburban	82.15	12.98	0.28	1.14	3.46
Rural - Rural	78.59	15.78	0.75	1.81	3.06

2.10 Traffic Assignment

Traffic assignment involves determination of route choices between given O-D pairs.it is the fourth and final stage of demand forecasting model. In this study EMME/4 platform is used for both auto and transit assignment. EMME is a software package which provides travel demand modelling system for urban, regional and national transportation forecasting. It models how people move across a transportation network under a given set of conditions. The assignment algorithm aims at minimizing the total travel time of all the passengers using the network. In this study, strategy based user's equilibrium assignment was performed in the EMME /4 platform in each hour for auto and transit. Volume delay function was used for each type of road.

The Volume delay function equation used in traffic assignment is

$t = t_0[1 + \alpha\ (V/Q)^{\beta}]$……………………………………(4)

t_0 = free flow travel time on the link per unit of time

V = volume of traffic on the link per unit of time

Q = capacity of the link per unit of time

t = is the average travel time for a vehicle on the link

The standard coefficient values for α and β are 0.15 and 4.00 respectively assigned by Bureau of Public roads (BPR).

In this model, the road network with centroids, nodes, and links and with their attributes are developed in EMME/4 platform Demand trip O-D matrix for each hour is used. Volume delay function was for each type of road. Traffic assignment involves iteration of the whole network traffic distribution unless the stopping criteria is satisfied. The network provides results of performance measures which includes Travel time, Traffic volume, and speed of each link and within each O-D pairs. Figure 2-9 shows a sample link volume of an auto assignment. Separate assignment were performed for transit network with transit demand and transit routes in the network. Effective headways, boarding time, wait times are used as parameters. Standard transit assignment provides transit volume, boarding on links and road segments as well as transit time between zones, average number of boarding, transit in vehicle time as outputs. Figure 2-10 shows a sample transit assignment output.

Figure 2-9 Link Volume in Auto assignment

Figure 2-10 Link Volume in Transit assignment

Figure 2-11 Speed on each link of an Auto assignment

Figure 2-11 shows a sample output of average speed on each link of an Auto assignment. Thus each scenario of daily traffic assignment comprise of 24 hourly auto and transit assignments. This step provides total traffic volume, average speed and Vehicle Kilometer Traveled (VKT) of each link of the network, travel time between each O-D pair as well as average speed and travel time of the network. A sample traffic assignment is shown in appendix B-1 as well as transit assignment in appendix B-2.

2.11 Model Validation

A regional transportation network model is required to be validated with existing field or survey data. In this study model validation was done for modal share, traffic volume and transit ridership.

2.11.1 Validation of Modal Share

Modal share results from the transportation network model is validated with observed modal share from different surveys conducted in Halifax. In this study modal share of Auto driver, Auto passenger, Transit, Walking and Biking were found 65.88%, 12.08%, 12.81%, 7.46% and 1.77% respectively. Figure 2.12 shows the comparison of model modal share with Census 2006, NHS 2011, HMTS 2013 (*Salloum and Habib)* and NovaTRAC (*Habib 2015*). The comparison shows the model results are consistent with the survey data.

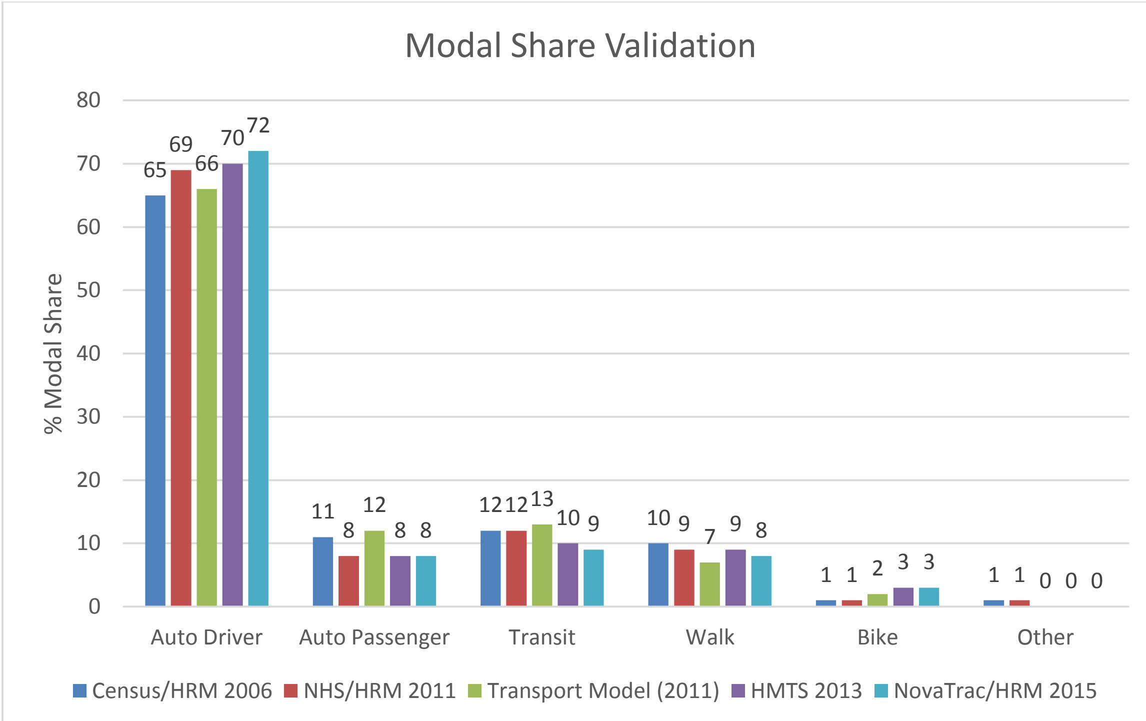


Figure 2-12 Modal share validation

2.11.2 Validation of traffic volume

Traffic volume obtained from the model are validated with Nova Scotia Transportation and Infrastructure Renewal survey data 2011 (Appendix B-4). Screen line validation was used for this purpose. 24 hour traffic volume for 5 different locations are taken for that purpose. Locations are: Victoria Road (Dartmouth), Burnside drive (Dartmouth), Sackville drive, Kearney Lake Road and Herring Cove Road. (Appendix B-7) Those are then plotted against collected average hourly traffic data. Figure 2.13 shows the comparison and R^2 was found to be 0.852.

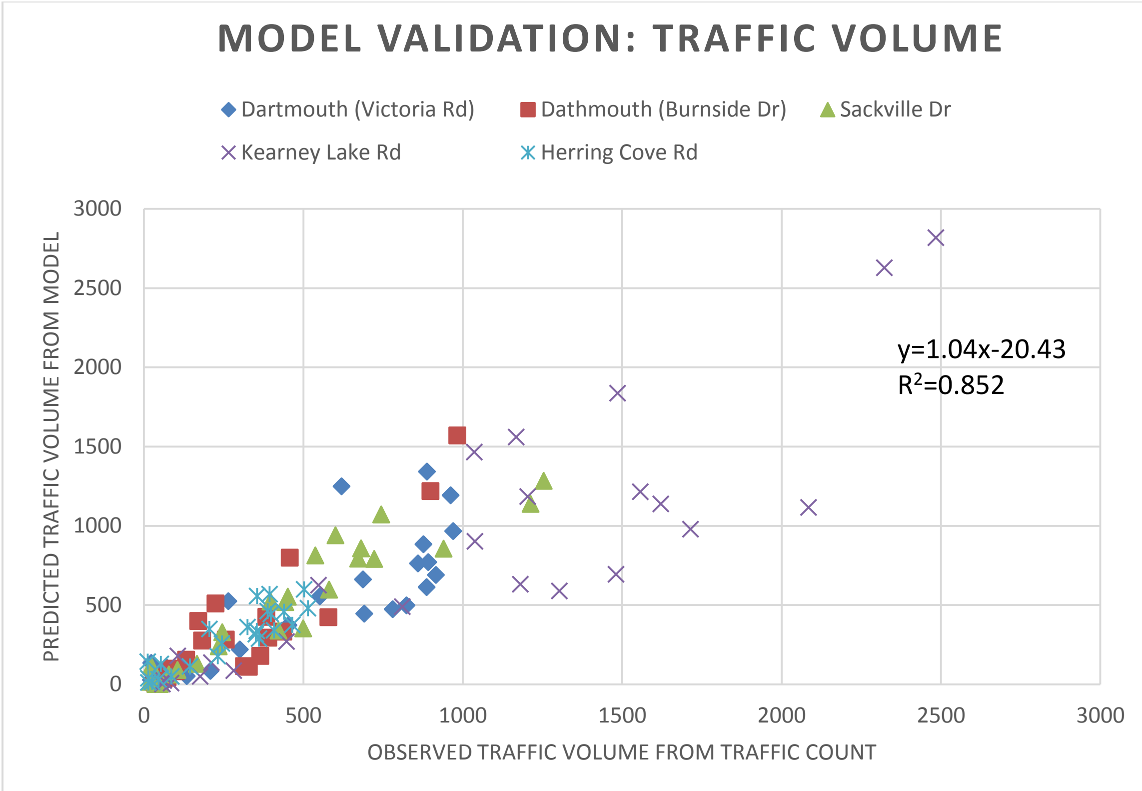


Figure 2-13 Model Validation: Traffic Volume for all five locations

Geoffrey E. Havers (GEH) statistics was used for validation of hourly volume in each location. It is a modified form of chi squared statistic which is used to detect the relative difference between the simulated and field traffic volume. It is expressed by the equation as shown below:

$$GEH = \sqrt{\frac{2(S-F)^2}{S+F}} \quad \text{.....................................(5)}$$

Where, S is the traffic volume obtained from the model and F is the observed traffic volume through the field survey.

The GEH value also determines the goodness of fit of the traffic simulation model. A GEH value smaller than 5 represents a good match between model and field traffic volume. If the GEH value is between 5 and 10, investigation may be required to make the model more representative of the real world. On the other hand, if the GEH value is greater than 10, it represents a bad fit between the model volume and field volume. In that case more investigation and calibration techniques are strongly recommended to improve the accuracy of the model (*Oketch and Carrick, 2005*).

In this study, GEH value was found 3.21, 3.99, 3.53, 5.20 and 5.08 for traffic volume at Victoria Road (Dartmouth), Burnside (Dartmouth), Sackville, Kearney Lake Road and Herring Cove Road respectively. Additionally for A.M. peak (6am-10am) and P.M. peak (2pm-6pm) GEH value was found to be 3.22 and 2.20 respectively. Therefore it can be concluded that the traffic volume obtained from the model can be considered as reasonably good match.

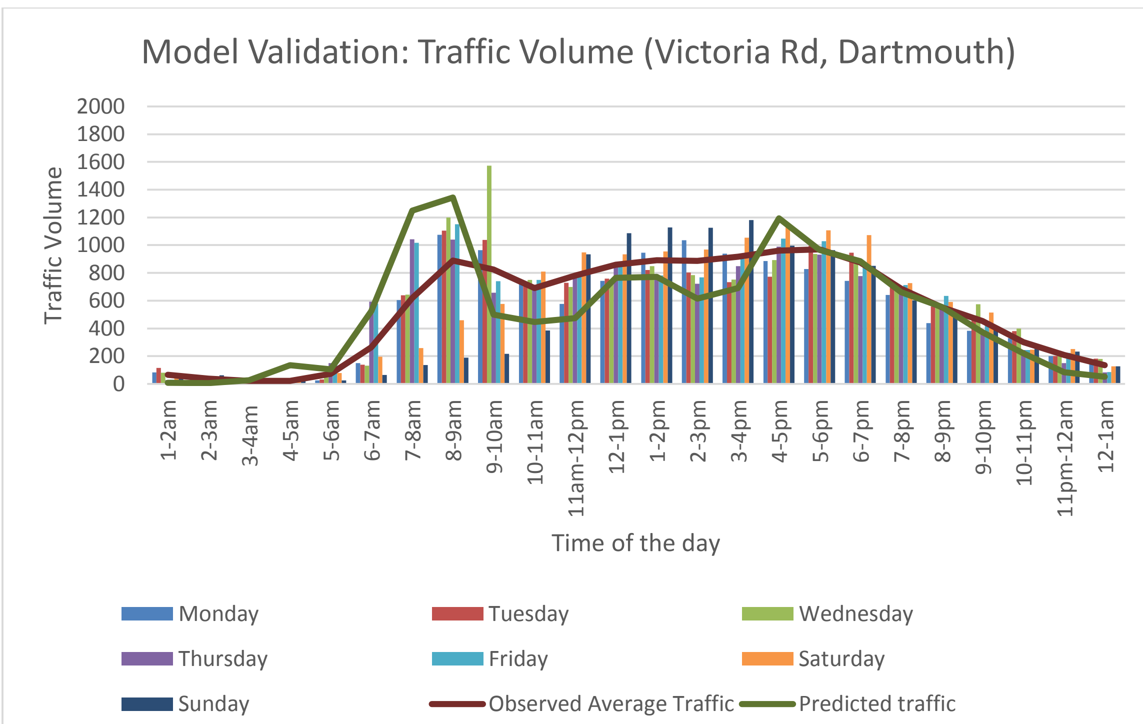


Figure 2-14 Model Validation: Traffic Volume (Victoria Rd, Dartmouth)

Hourly traffic volume obtained from the model for Victoria Road (Dartmouth), Burnside (Dartmouth), Sackville, Kearney Lake Road and Herring Cove Road are plotted with traffic volume observed in each day of the week along with average typical day volume in Figure 2.14 to 2.18. The figures reflects distribution pattern of traffic across the day which is another indicator that shows the model traffic volume is representative of observed traffic volume. In figure 2-14 traffic volume of Victoria Rd. showed morning and afternoon peak and mid-day traffic volume was also significant. Figure 2-15 shows a sharp afternoon peak of traffic volume at Burnside, Dartmouth.

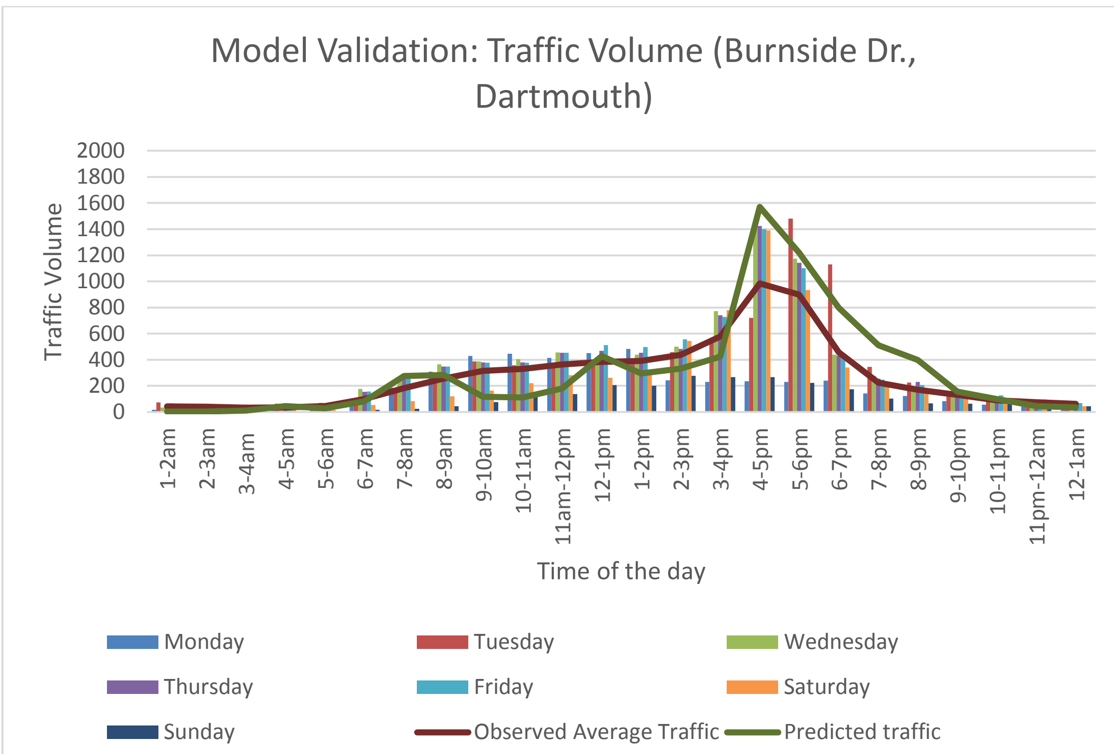


Figure 2-15 Model Validation: Traffic Volume (Burnside, Dartmouth)

In Sackville (figure 2-16) and Kearney lake road (figure 17) afternoon peak traffic volume was prominent and morning and mid-day peak was also observed. In figure 2-18 Herring cove road traffic volume shows morning and afternoon peak.

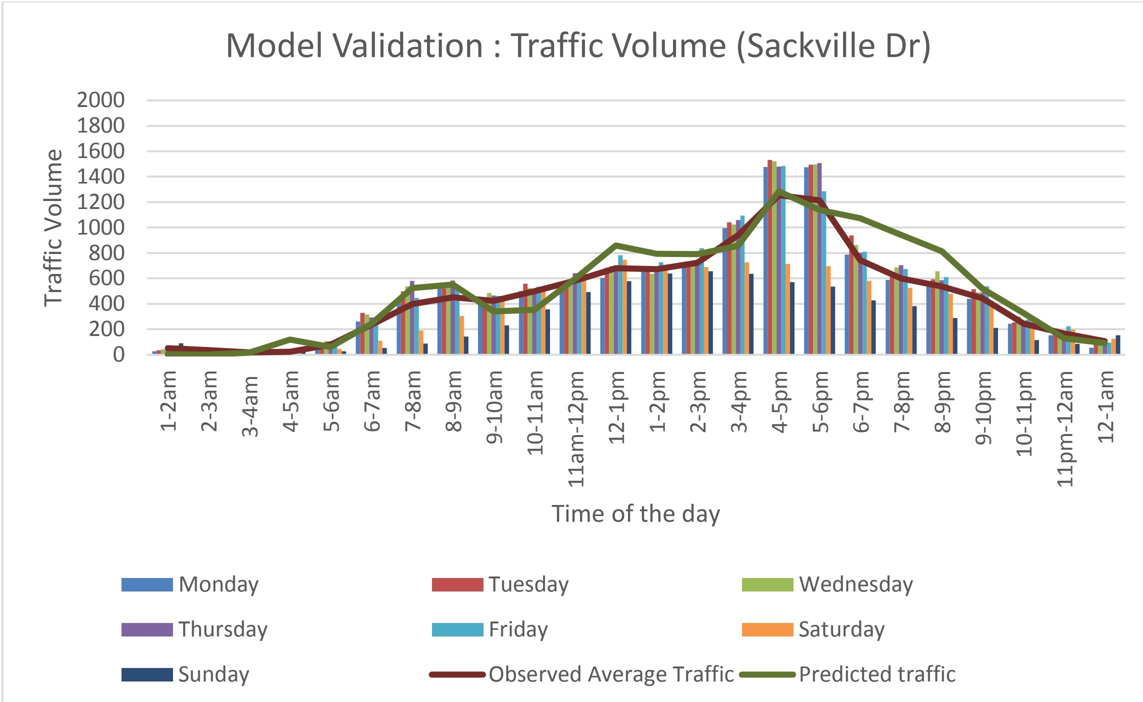


Figure 2-16 Model Validation: Traffic Volume (Sackville)

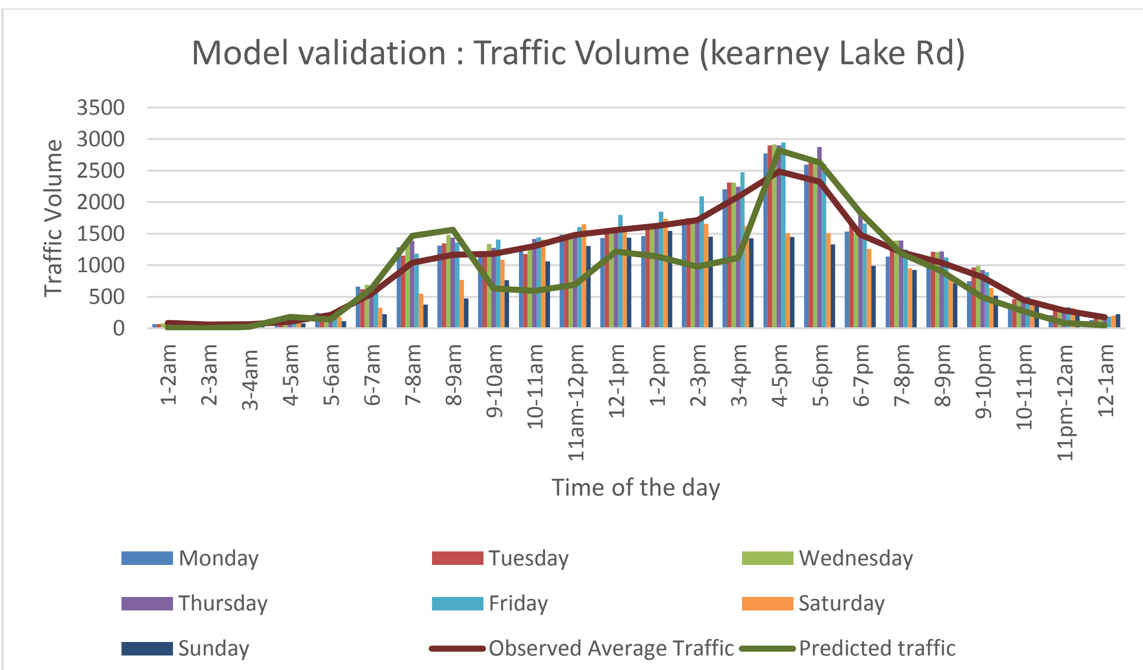


Figure 2-17 Model Validation: Traffic Volume (Kearney Lake Rd)

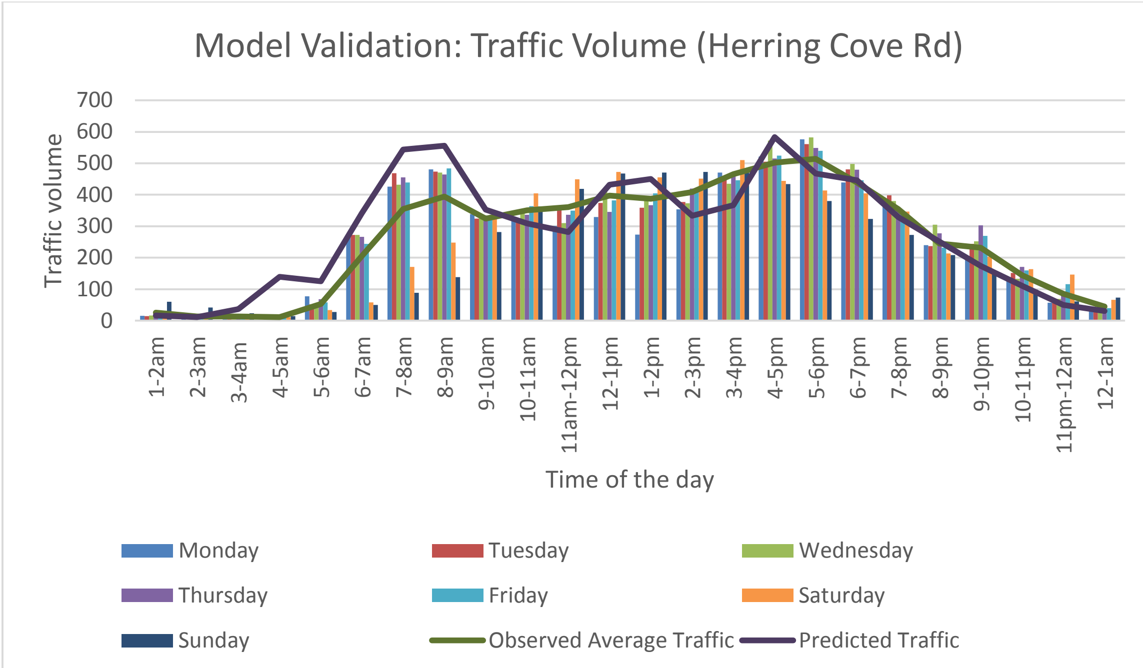


Figure 2-18 Model Validation: Traffic Volume (Herring Cove Rd)

2.11.3 Validation of transit ridership

Transit ridership of all the transit routes are plotted against observed transit ridership data of Halifax transit for 2011. The trend line is shown in figure 2-19 and R^2 was found 0.839. GEH statistics was also performed with transit ridership data and the value is 3.90 which is within a good fit limit.

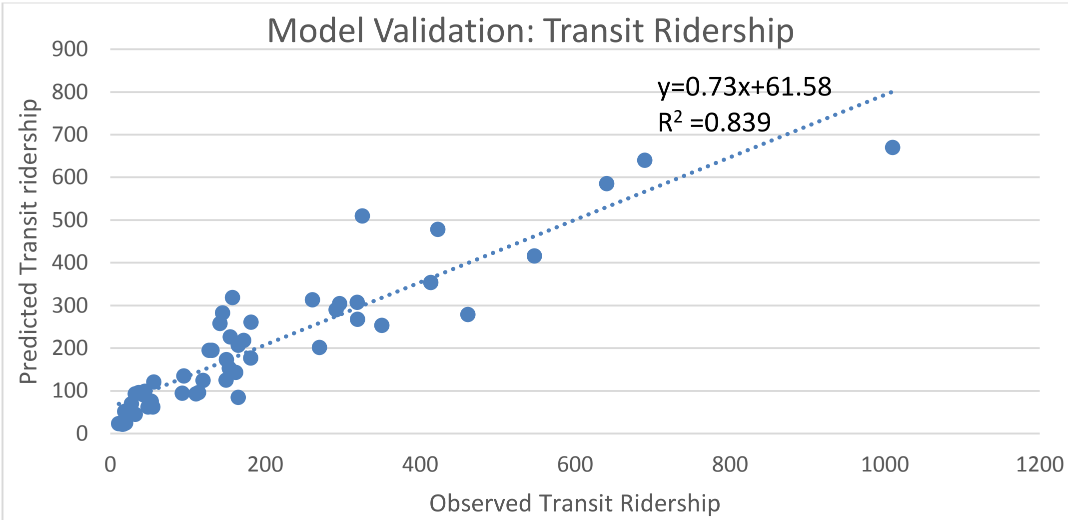


Figure 2-19 Model Validation: Transit ridership

Figure 2-20 shows that transit ridership in each route for observed and predicted data.

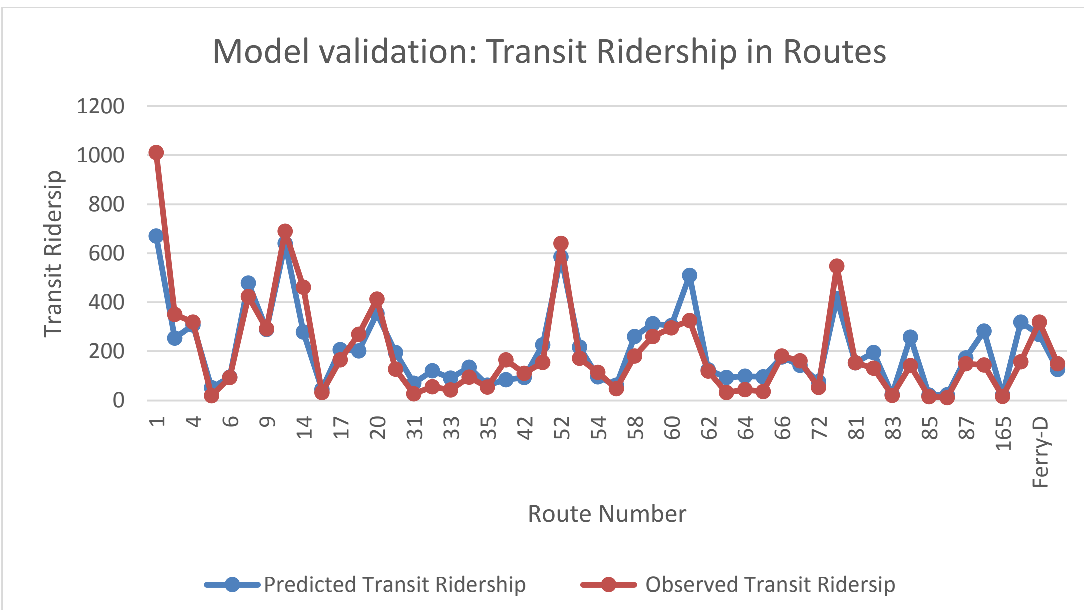


Figure 2-20 Model Validation: Transit ridership in routes

The model results need to be further validated with NovaTRAC survey (*Habib,2015*) when the data become available.

2.12 Future Demand Forecasting for 2016 and 2021

After the development and validation of transportation network model for the base year 2011, the model is used for future forecast. In this study this were done for 2016 and 2021. Table 2-8 and 2-9 shows the key growth scenario projection parameter and distribution of observed growth. According to Regional Municipal Planning Strategy (RMPS) which was adopted in 2006, regional plan growth goals are 25% Regional Centre, 50% Suburban and 25% Rural. But actual observed growth after adoption of regional plan Adoption were 16% Regional Centre, 56% Suburban, and 28% Rural.

Table 2-8 Key Growth Scenario Projection Parameter (*HRM report,2013*)

	2011	2016	2021
Population	392,255	422,730	448,735
Change		30,475	26,005
% Change		7.8%	6.2%
Dwelling Units	165,155	182,730	202,130
Change		17,575	19,400
% Change		10.6%	8.9%
Employed	211,375	233,565	247,040
Change		22,190	13,480
% Change		10.5%	5.8%

Table 2-9 Distribution of Observed Growth (*HRM report,2013*)

	Housing Growth	Employment Growth
Urban Core	16%	31%
Suburban	56%	51%
Rural	28%	18%

To forecast future travel demand for 2016 and 2021, trip generation is revised using this growth of dwelling unit and employment. After preparing the trip generation, all of the other stages trip distribution, modal split and traffic assignment was performed for 24 hours for each hour and each mode with 2016 and 2021 data. Results of those analysis is shown in the following sections.

2.13 Network Model Results

Transportation network model results for 2011, 2016 and 2021 are discussed in this section. Results are represented on the basis of performance measures such as trips and speed of the network in 24 hours. Corridor analysis is performed on the five entrance of Halifax peninsula. Moreover travel times along the in three different O-D pair from suburban areas to Halifax downtown is also analyzed.

2.13.1 Analysis of trips

The time of the day model provides hourly factors which are used to develop hourly trip matrix. Total hourly trips of the network at 2011, 2016 and 2021 are shown in Figure 2-21.

It shows temporal distribution of trips and found that maximum number of hourly trip is 92,455 at 4-5pm for 2011 which is predicted to be 120,508 at the same time period in 2021.

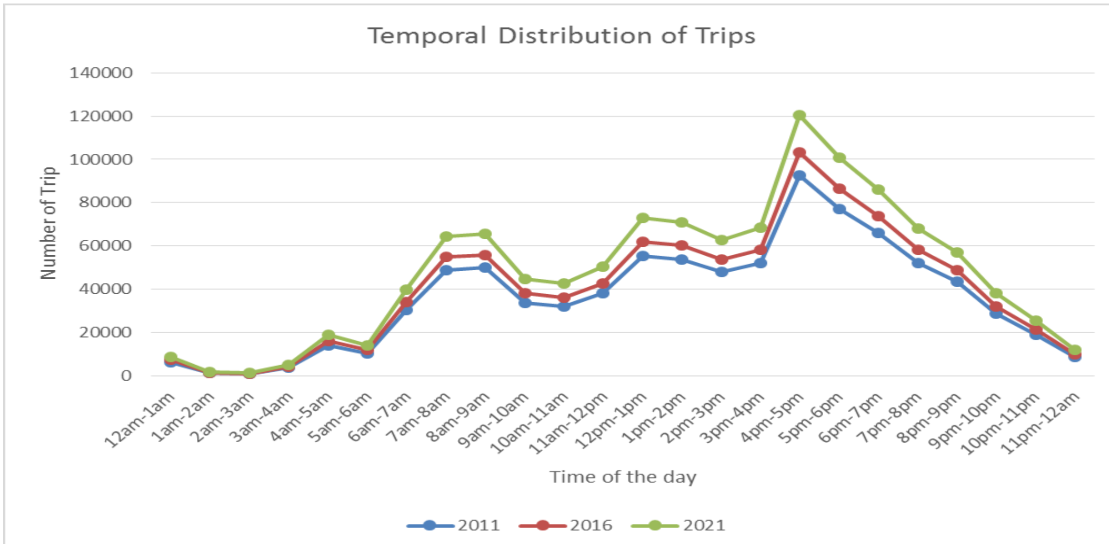


Figure 2-21 Temporal distribution of trip

Table 2-10 shows the average travel time and average trip length in each hour of the day for 2011, 2016 and 2021. Maximum average travel time for a trip is calculated as 18.06 minute in 4-5pm period which is expected to increase to 19.32 minute in 2016 and 23.18 minute in 2021. Similarly, maximum average trip length is found 15.77km at the same period which is expected to increase to 16.05 and 17.04 km in 2016 and 2021 respectively.

Table 2-10 Average travel time and trip length of the network

	Average travel time (minute)			**Average trip length (km)**		
	2011	**2016**	**2021**	**2011**	**2016**	**2021**
12-1am	12.31	12.54	13.29	13.18	13.43	14.31
1-2am	12.26	12.31	13.24	13.04	13.04	14.13
2-3am	12.21	12.38	13.34	12.99	13.13	14.18
3-4am	12.34	12.43	13.3	13.12	13.20	14.20
4-5am	12.62	12.81	13.62	13.54	13.74	14.71

	Average travel time (minute)			Average trip length (km)		
	2011	**2016**	**2021**	**2011**	**2016**	**2021**
5-6am	12.75	12.93	13.69	13.68	13.87	14.78
6-7am	14.6	14.96	15.85	15.40	15.66	16.50
7-8am	15.38	15.8	17.06	15.69	15.93	16.87
8-9am	15.45	15.88	17.18	15.71	15.95	16.88
9-10am	14.27	14.58	15.55	15.12	15.40	16.32
10-11am	14.17	14.43	15.36	15.14	15.38	16.32
11am-12pm	14.21	14.48	15.41	15.12	15.36	16.23
12-1pm	14.71	15.08	16.24	15.34	15.52	16.43
1-2pm	14.6	14.94	15.99	15.34	15.58	16.43
2-3pm	14.61	14.95	16.03	15.28	15.49	16.37
3-4pm	14.74	15.12	16.25	15.32	15.52	16.41
4-5pm	18.06	19.32	23.18	15.77	16.05	17.04
5-6pm	16.84	17.68	20.43	15.64	15.89	16.82
6-7pm	15.61	16.12	17.69	15.52	15.77	16.64
7-8pm	15.19	15.64	16.85	15.46	15.70	16.56
8-9pm	14.87	15.24	16.44	15.33	15.56	16.44
9-10pm	14.2	14.48	15.39	15.09	15.34	16.23
10-11pm	13.9	14.17	14.98	14.89	15.17	16.08
11pm-12am	13.62	13.85	14.68	14.50	14.77	15.81

2.13.2 Average Speed in the Network

Vehicular speed of transportation network of Halifax is analyzed in this 24 hour transportation network model. Figure 2-22 shows the average speed of the network is stable around 59 km/hr or decrease slightly for most part of the day over the years. Speed of the total network is decreased in peak period which demonstrates congestion in the P.M. peak period. The speed is projected to decrease to around 53.87km/hr in 2021 from 56.64 km/hr in 2011 at 4-5pm.

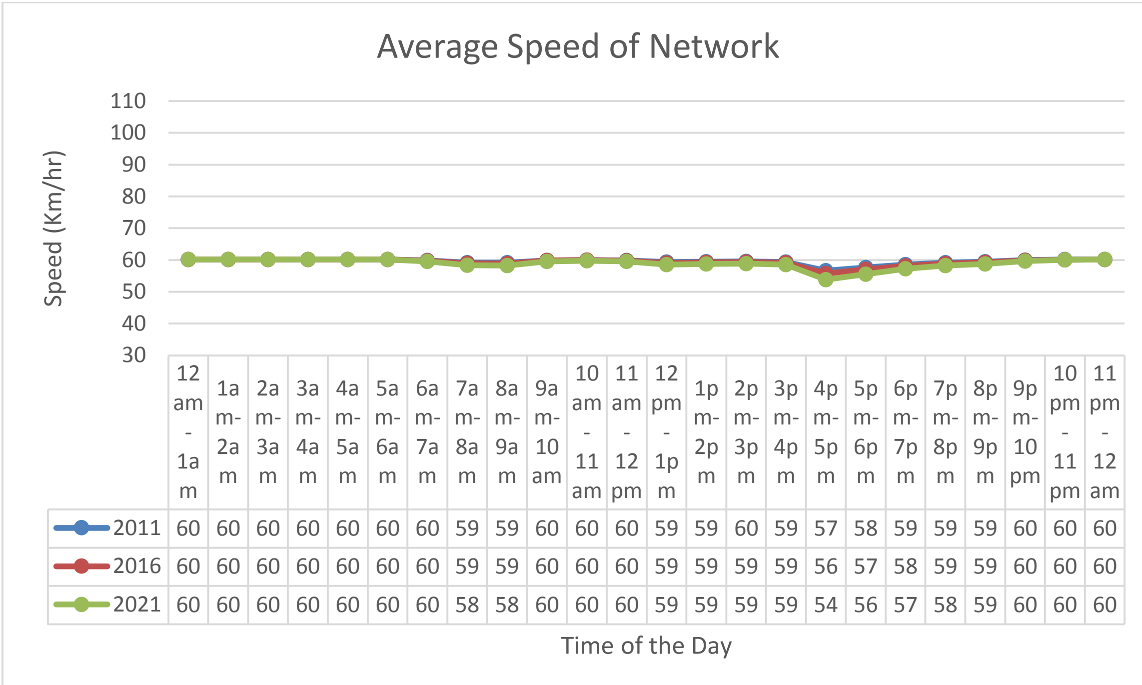
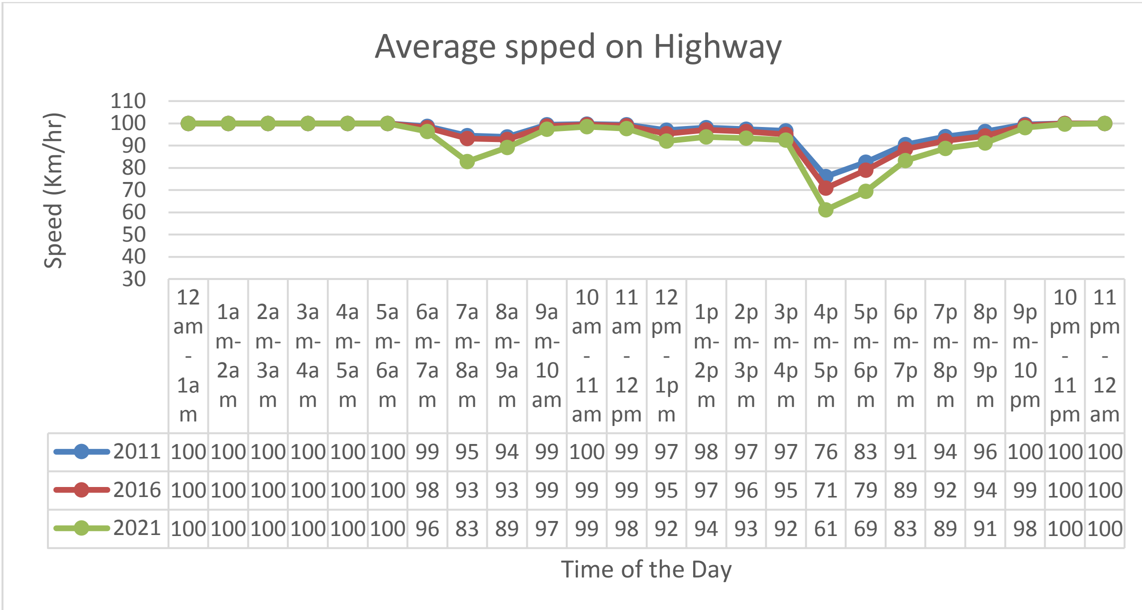


Figure 2-22 Average speed of the network

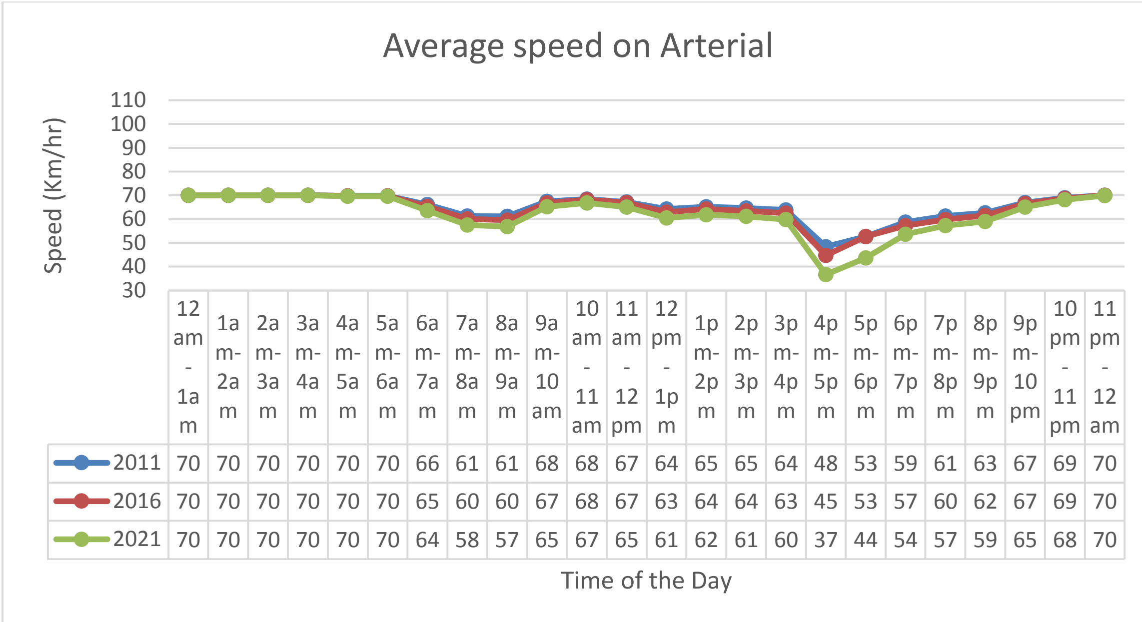
Speed on different types of roads are also analyzed. Figure 2-23, 2-24 and 2-25 shows 24 hour speed variation in Highway, Arterial and major collector roads. The results show stable speed on highway, arterial and major collector in mid days and at night. At the morning peak hour's speed of all types of roads drops but it is more alarming in afternoon peak period where speed drops significantly. Speed comparison between 2011, 2016 and 2021 reveals that speeds are showing similar pattern over the years but in P.M. peak the speed drop increase continues. At 4-5pm Speed on highway, arterial and major collectors are 76 km/hr, 48.4 km/hr and 43.7 km/hr respectively at 2011. In 2021, those speed are predicted to drop to 61.1 km/hr, 36.7 km/hr and 39.2 km/hr. This indicates the speed decrease on highway, arterial and major collector from 2011 to 2021 are 19.60%, 24.17% and 10.30% respectively.



	12 am - 1am	1am-2am	2am-3am	3am-4am	4am-5am	5am-6am	6am-7am	7am-8am	8am-9am	9am-10 am	10 am - 11 am	11 am - 12 pm	12 pm - 1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm	5pm-6pm	6pm-7pm	7pm-8pm	8pm-9pm	9pm-10 pm	10 pm - 11 pm	11 pm - 12 am
2011	100	100	100	100	100	100	99	95	94	99	100	99	97	98	97	97	76	83	91	94	96	100	100	100
2016	100	100	100	100	100	100	98	93	93	99	99	99	95	97	96	95	71	79	89	92	94	99	100	100
2021	100	100	100	100	100	100	96	83	89	97	99	98	92	94	93	92	61	69	83	89	91	98	100	100

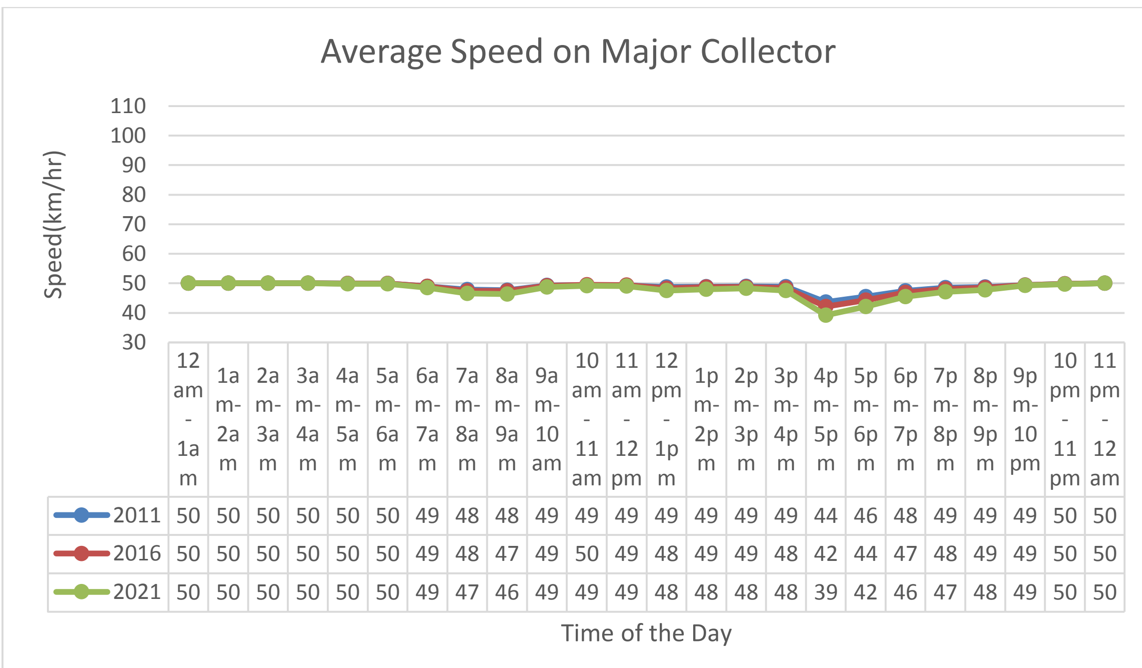
Figure 2-23 Average speed on Highway

The significance of this result is arterial roads are more vulnerable to speed decrease which indicate where more investment is required in coming years to keep up the road network as functional as present.



	12 am - 1am	1am-2am	2am-3am	3am-4am	4am-5am	5am-6am	6am-7am	7am-8am	8am-9am	9am-10 am	10 am - 11 am	11 am - 12 pm	12 pm - 1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm	5pm-6pm	6pm-7pm	7pm-8pm	8pm-9pm	9pm-10 pm	10 pm - 11 pm	11 pm - 12 am
2011	70	70	70	70	70	70	66	61	61	68	68	67	64	65	65	64	48	53	59	61	63	67	69	70
2016	70	70	70	70	70	70	65	60	60	67	68	67	63	64	64	63	45	53	57	60	62	67	69	70
2021	70	70	70	70	70	70	64	58	57	65	67	65	61	62	61	60	37	44	54	57	59	65	68	70

Figure 2-24 Average speed on Arterial



	12 am - 1am	1am-2am	2am-3am	3am-4am	4am-5am	5am-6am	6am-7am	7am-8am	8am-9am	9am-10 am	10 am - 11 am	11 am - 12 pm	12 pm - 1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm	5pm-6pm	6pm-7pm	7pm-8pm	8pm-9pm	9pm-10 pm	10 pm - 11 pm	11 pm - 12 am
2011	50	50	50	50	50	50	49	48	48	49	49	49	49	49	49	49	44	46	48	49	49	49	50	50
2016	50	50	50	50	50	50	49	48	47	49	50	49	48	49	49	48	42	44	47	48	49	49	50	50
2021	50	50	50	50	50	50	49	47	46	49	49	49	48	48	48	48	39	42	46	47	48	49	50	50

Figure 2-25 Average speed on major Collector

2.13.3 Corridor Analysis of Halifax Peninsula

Halifax downtown peninsula have five major entry/exit points of. Those are Macdonald Bridge, McKay Bridge, Highway 102, Bedford highway and Herring cove road. In this section traffic volume and average speed of those five corridor is analyzed for 24 hours in 2016.

Figure 2-26 shows the inbound traffic volume that enters the peninsula and the average speed of those traffics are shown is figure 2-27. Halifax inbound traffic analysis shows that at all the corridor traffic volume is maximum in morning peak hours. MacDonald Bridge carries the maximum traffic for A.M. peak which is 3857 at 7-8am. In the afternoon peak McKay Bridge carries maximum traffic which is 3326 at 4-5pm.

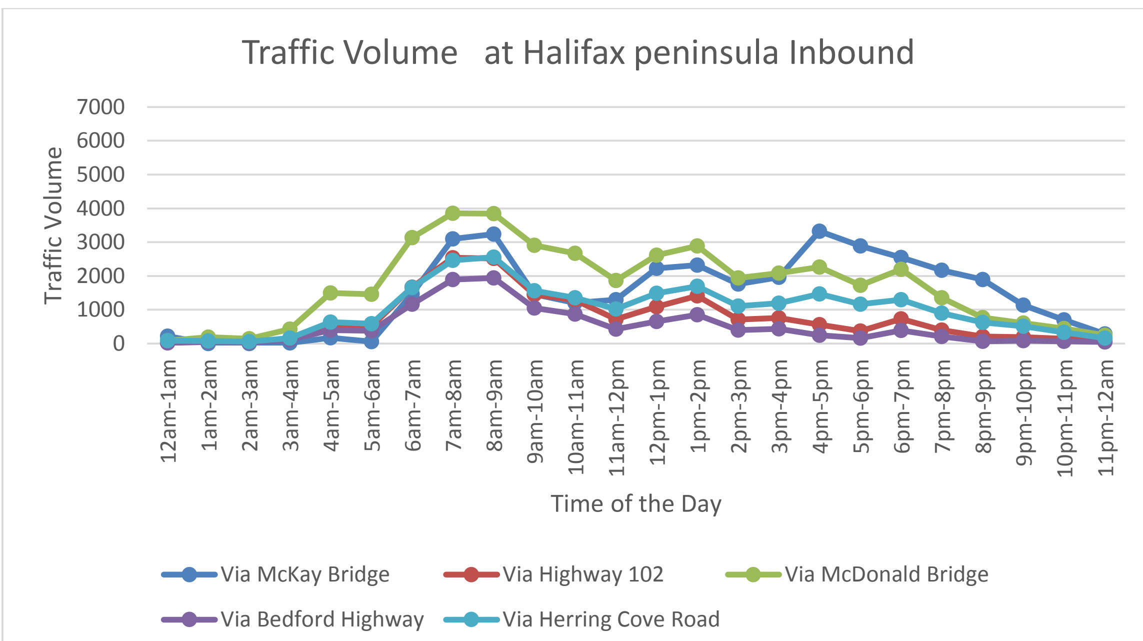


Figure 2-26 Traffic volume at Halifax peninsula inbound

Average speed of vehicle drops at all corridor in the morning peak period. Maximum drop is experience at MacDonald Bridge which is 22.5km/hr from 70km/hr.

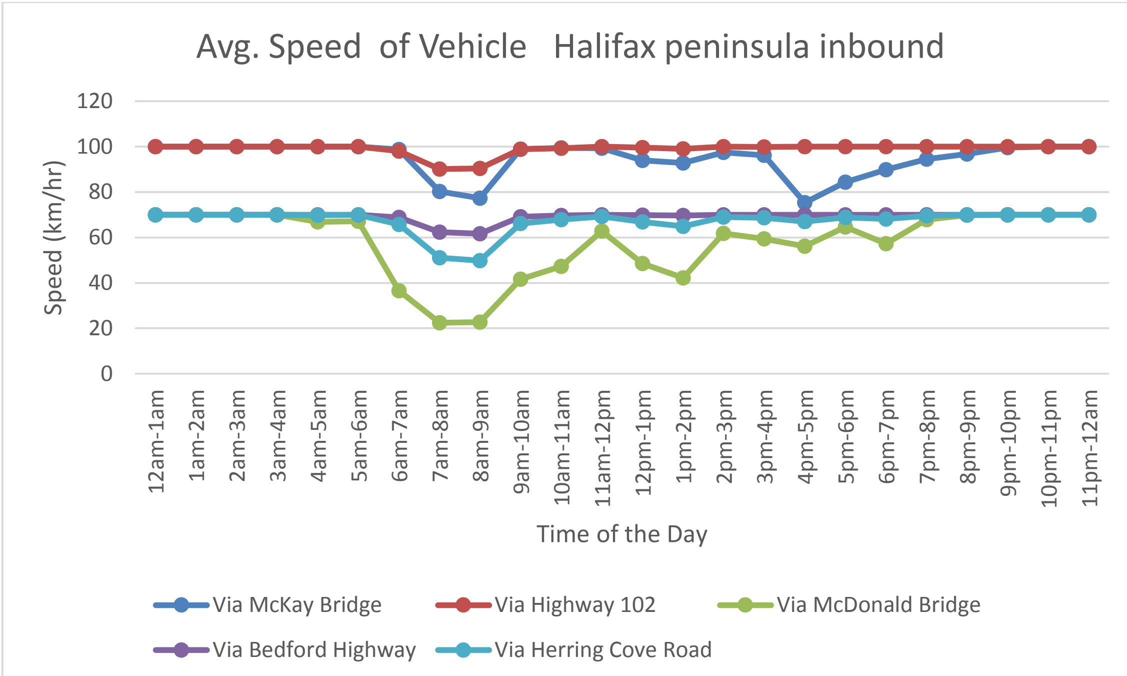


Figure 2-27 Average speed of vehicle at Halifax peninsula inbound

Outbound traffic volume that leaves the peninsula and the average speed of those traffics are shown is figure 2-28 and 2-29. Traffic volume reaches its maximum in all corridors in afternoon peak period. For P.M. peak, McKay Bridge carries the maximum traffic which is 5880, and Macdonald carries 5319 at 4-5pm.

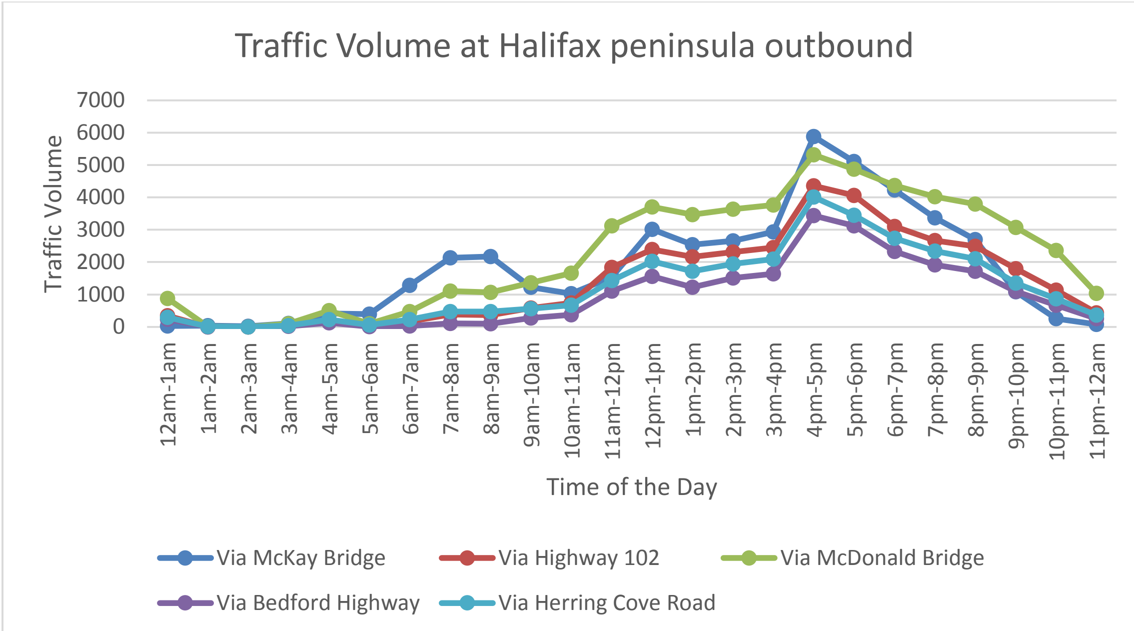


Figure 2-28 Traffic volume at Halifax peninsula outbound

All the corridors experiences sharp speed drop at afternoon peak period. Average speed drops from 100km/hr to 23.87 km/hr at McKay Bridge and from 70km/hr to 8.11km/hr at McDonald Bridge.

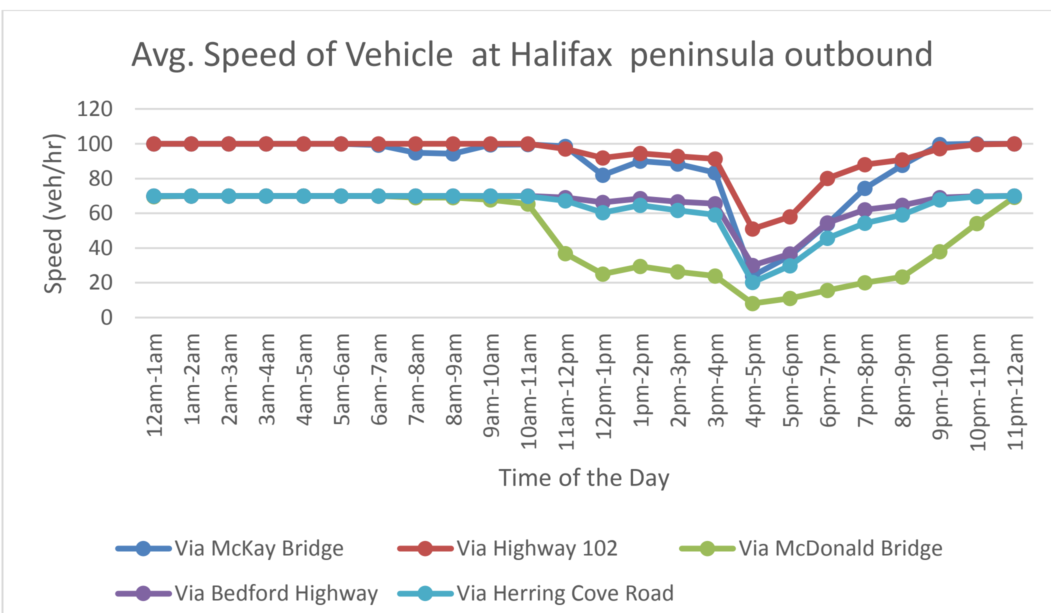


Figure 2-29 Average speed of vehicle at Halifax peninsula outbound

These results provide important traffic volume and speed information about exit/entry point of Halifax peninsula which can be useful for traffic management and future transportation policy decision.

2.13.4 Travel Time Analysis between Origin-Destination Zones

24 hour transportation network model developed in the study also provides travel time between any O-D pair in each hour. In this section, travel time between Halifax downtown to three suburban areas Portland, Spry field and Bedford are presented and change in travel time along the day is observed for 2011, 2016 and 2021. In Figure 2-30, 2-31, 2-32 travel times between Halifax downtown to Portland, Spry field and Bedford west are shown.

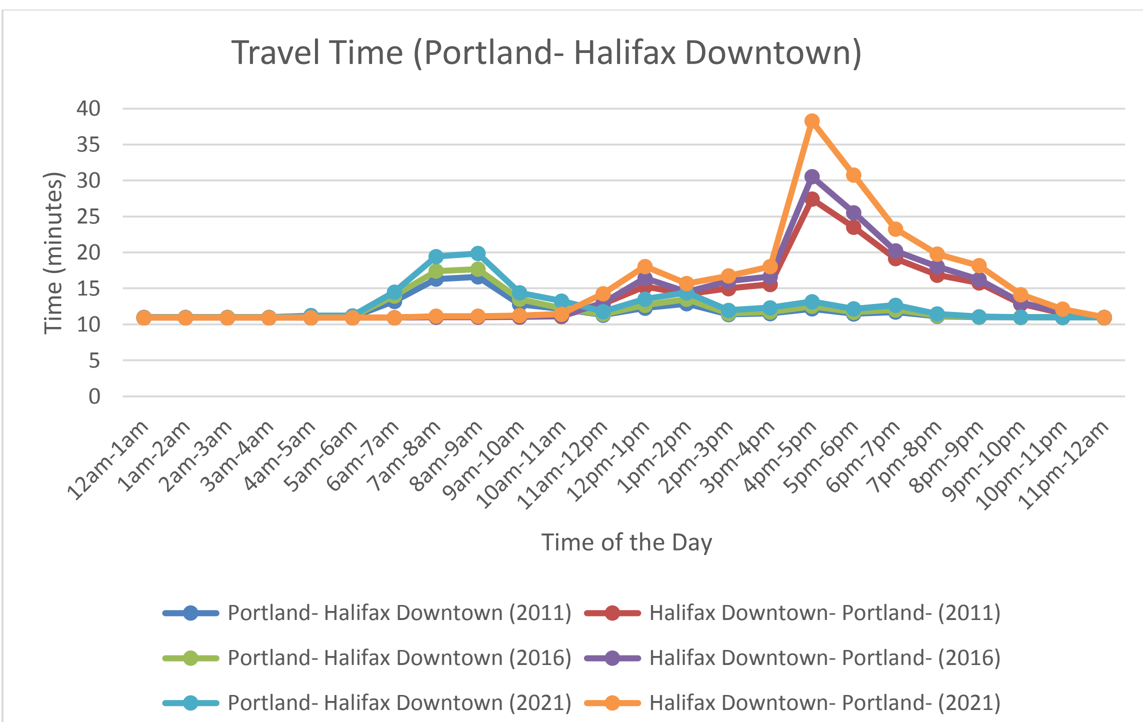


Figure 2-30 Travel time (Portland-Halifax downtown)

Travel time analysis shows that traffic from Portland, spry field and Bedford west towards Halifax downtown experiences increased travel time during morning peak hours. In the afternoon peak travel time for traffic from Halifax downtown towards Portland, Spry field and Bedford west increases significantly.

The model also predict travel time between this zones in 2016 and 2021. It shows travel time would further increase in future. For example, during 4-5pm, travel time between Halifax downtown-Portland, Halifax Downtown-Spry field and Halifax Downtown-Bedford West are 27.43minutes, 16.33 minutes and 22.48 minutes respectively in 2011. The model forecasts that in the same route travel time would be 38.28 minutes, 24.78minutes and 29.58 minutes respectively in 2021. Which means the travel time would increase by 39.56%, 51.74% and 31.58% respectively between 2011and 2021.

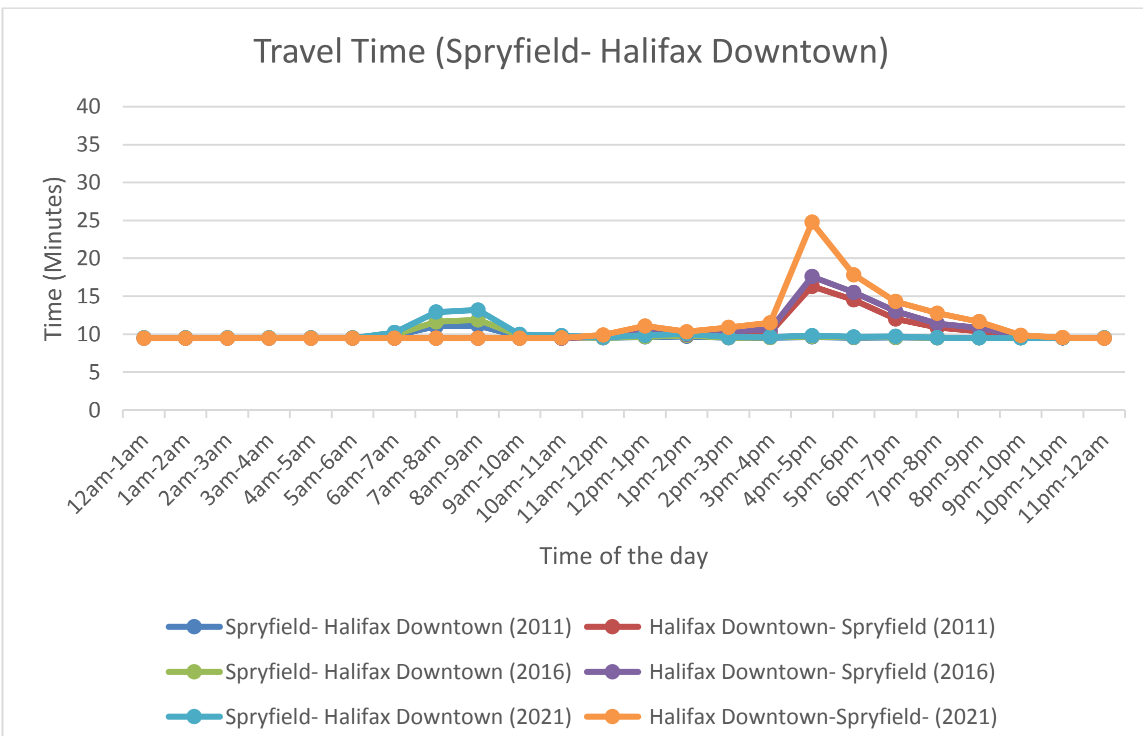


Figure 2-31 Travel time (Spry field -Halifax downtown)

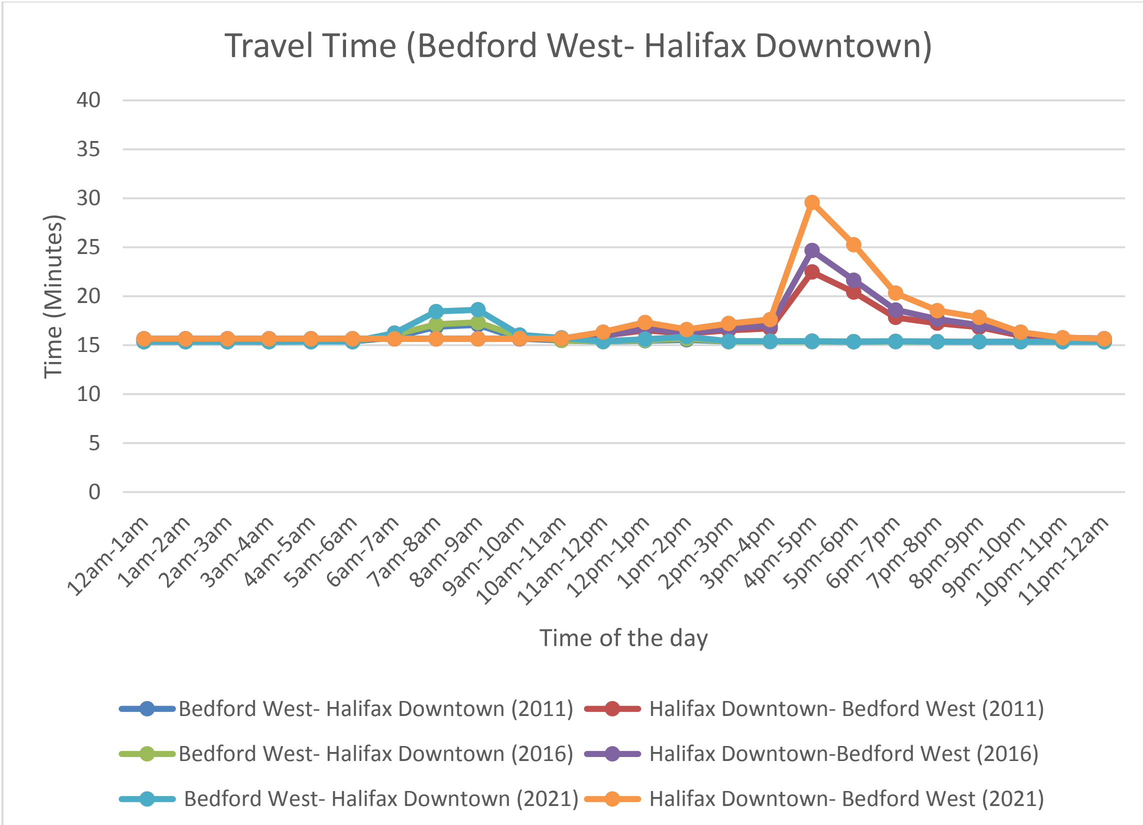


Figure 2-32 Travel time (Bedford west-Halifax downtown)

These results shows that transportation network in Halifax is about to face great challenge of mobility in coming future especially in afternoon peak hours. Transportation planners and policy makers should consider suitable transport demand management measures like peak hour road pricing, adjustment of work hour and lane reallocation for peak hour etc.to address this serious issue.

2.14 Conclusion

A regional 24 hour transportation network model was developed with base year of 2011. The model was developed by using four stage demand forecasting modeling framework which includes trip generation, trip distribution, modal split and traffic assignment.

The model results provide trip production and attraction of each zone. Most of the trips are produced from suburban areas which is 51.67% of total trips, whereas, 52.09% of total trips are attracted to urban areas. It revealed that the modal share of Auto driver, Auto passenger, Transit, Walking and Biking are 65.88%, 12.08%, 12.81%, 7.46% and 1.77% respectively. It also developed hourly O-D matrix for 24 hours with all of those five modes.

The model result for 2011 is validated with existing NSTIR and Halifax transit data. The results obtained from the model for 2016 can be used for further validation by NovaTRAC 2016.

The model provides results of travel time, traffic volume and speed of the network in 24 hours. Result indicates the speed decrease on highway, arterial and major collector from 2011 to 2021 are 19.60%, 24.17% and 10.30% respectively. This indicates arterial roads need more investment in coming years to keep up the road network as functional as present. Corridor analysis was done on the five entrances of Halifax peninsula which were Macdonald Bridge, McKay Bridge, Highway 102, Bedford highway and Herring Cove Road. Results shows that McDonald bridge experience more traffic on AM peak and McKay Bridge at PM peak.

Travel times along three different O-D pairs from suburban areas such as Bedford West, Portland and Spry field to Halifax downtown is also analyzed. It reveals that travel time would increase by 39.56%, 51.74% and 31.58% respectively at afternoon peak period within those O-D pairs between 2011and 2021. Transportation planners and policy makers should take proactive measure to overcome this potential mobility challenge.

CHAPTER 3

EMISSION ESTIMATION

3.1 Chapter Overview

This chapter represents an emission estimation framework for passenger transportation in Halifax, Canada. A regional transportation network model is developed for Halifax which is described in the previous chapter. This study follows a disaggregate accounting approach at the TAZ level for estimating emissions. It uses VKT, speed, traffic volume and other outputs from the 24 hour transportation network model from both auto and transit assignment models. Pollutants considered include: GHG, CO, NOx, THC, VOC, PM_{10}, and $PM_{2.5}$.

Emission estimate of Polluting power and pollution experienced, often identified as in the existing literature, were performed. A unique approach was taken in this study to observe who generates emission and who experienced in highlighting urban-rural divide. Policy scenarios were created to estimate the potential impact of modal shift from auto to transit. This chapter is organized as follows: first, a brief introduction with a review of the literature, discussion on the model and scenario development for the study, followed by a discussion of the model results. The chapter concludes by providing a summary of contributions and future research directions.

3.2 Background

Greenhouse Gas (GHG) and other vehicular emissions contributed by the transportation sector is a growing concern in North American cities. The inventory of GHG includes carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), per fluorocarbons (PFCs), hydro fluorocarbons (HFCs), sulphur hexafluoride (SF6), and nitrogen trifluoride (NF3). In 2014, Canada's total GHG emissions were estimated at 732 megatons of carbon dioxide equivalent emissions (Mt CO_2 eq.) The government of Canada is committed to reduce GHG emissions to 17% below 2005 emission levels by 2020, and 30% below 2005 emission levels by 2030. However, the reality is that Canada has only seen a 2% decrease of emissions from 2005 to 2014. (*Environment and Climate Change Canada, 2016*).

Even though overall emissions decreased during this period, the emissions produced by the transportation sector has increased 4% from 2005 to 2014. In 2014, transportation was responsible for 23% of GHG emission in Canada, which is 171 Mt CO_2 eq. Emissions from light-duty and heavy-duty vehicles increased 42 Mt between 1990 and 2014. Canada produced approximately only 1.6% of total global GHG emissions in 2012. But it has one of the highest per capita emission rate which was 20.6 ton CO_2 eq. in 2014.(*Environment and Climate Change Canada, 2016*). According to the Canadian vehicle survey 2009, 96.3% of vehicles on the road are light vehicles which is the main contributor to this increase. (*National Resources, Canada, 2011*).

Nova Scotia has an annual GHG emission of 17 Mt CO_2 eq in 2014 which had decreased from 20 Mt CO_2 eq in 1990 .The Halifax Regional Municipality (HRM) council adopted a new reduction target of 30% below 2008 levels by 2020 for HRM's greenhouse gas (GHG) emissions (*Halifax Regional Municipality,2012*). In order to meet the emission reduction target it is vital for HRM to track progress in mobile source emission. Many recent studies focused on developing models for tracking progress (TRB *Special Report, 2009; Hankey and Marshall, 2010; Niemeier et al., 2011*) and testing policy scenarios to identify countermeasures for emission reduction. (*Norman et al., 2006; Gouge et al., 2010; Alam et al., 2014*)

In addition, it is also equally important to understand the "polluting power" and "pollution experienced" for proper representation of spatial dimension of emission. Polluting power is the level of emissions generated in any area and the level of emissions that actually occur in that area is termed as pollution experienced by the area.

3.3 Literature Review

GHG emission in passenger transportation is one of the primary focus of emission modeling in recent years. Considerable research have been recently conducted to investigate emissions in many states or cities such as Washington, Toronto, Leeds, Northern Virginia (*Frank et al., 2000; Hatzopoulou et al., 2007; Namdeo and Mitchell, 2008; Ahn and Rakha, 2008)*.Table 3-1 summarizes the findings of some available literature in this aspect.

Table 3-1 Summary of Literature Review

	Study area	Data used	Emissions calculation method	Pollutant Considered	Traffic Mode	Temporal Consideration	Scenario design
Frank et al. (2000)	Puget Sound, Washington, USA	Puget Sound Household Travel Survey 1999	Speed sensitive emission rates of MOBILE for every link of every trip	CO, VOC, NO_x	Auto	Not considered	N/A
Norman et al. (2006)	Toronto, Canada	NRTEE (2003) University of Toronto (2003)	Calculated using emission rate from data used and previous studies	GHG	Auto Transit	Not considered	Two scenario: high density development & low density development
Namadeo & Mitchell (2007)	Leeds, UK	TEMMS, LEEDS (2002)	Calculate link based emissions using ROADFAC	CO_2, CO, NO_x, SO_2, PM_{10}, Benzene, Butadiene	Auto	AM peak only, (correction factor used to get 24-hour emission)	Six scenarios: base scenario, two scenarios with inner orbital cordon and double cordon, three scenarios with distance charges
Hatzopoulou et al. (2007)	Toronto, Canada	GTA travel data generated by TASHA	Calculated VKT from EMME assignment and emission from MOBILE	VOC, CO, NO_x, HC	Auto	24 hour	N/A
Ahn & Rakha (2008)	Northern Virginia, USA	GPS Commute data	Calculated using three models: Mobile6, CMEM and VT micro model	HC, CO, NO_x, CO_2,	Auto	AM peak only	User Equilibrium and System Optimum assignments for high emitting, low emitting vehicles

	Study area	Data used	Emissions calculation method	Pollutant Considered	Traffic Mode	Temporal Consideration	Scenario design
Stone et al. (2009)	11 areas in 6 Midwestern states: IL, IN, MI, MN, OH, WI	US Census 2000	Calculated based on VMT (NPTS) Tract level CO2 calculated by EPA 2011 mission rate: 8887*VMT/MPG	CO2	Auto	Not considered	Three scenarios: Business-as-usual (BAU), Smart-growth 1 (SG1): same growth, new population reallocated to suburban & urban, Smart-growth 2 (SG2): larger population growth, new population reallocated to suburban & urban
TRB Special Report 298 (2009)	USA Nationwide	US census 2000, NHTS 2001, NPTS 1990,	Calculated based on VMT EPA 2005 emission rate: 19.4 lb CO2 per gallon gasoline	CO_2	Auto	Not considered	Three scenarios: base scenario: 1.4% VMT increase; scenario 1: 25% compact growth with 12% VMT reduction; scenario 2: 75% compact growth with 25% VMT reduction
Hankey & Marshall (2010)	142 US cities	US Census 2000	Monte Carlo statistical distribution for future scenario, emission calculated based on VKT and depends on scenario	CO_2	Auto	Not considered	Six scenarios: three bounding scenarios: infill only, constant density, suburban nation; three historical decadal growth: with small (S1), average (S2), large rates (S3);

	Study area	Data used	Emissions calculation method	Pollutant Considered	Traffic Mode	Temporal Consideration	Scenario design
Gouge et al. (2010)	Vancouver, BC, Canada	GPS data	MOBILE	CO, NO_x, HC	Transit	Not considered	Corridor scenario and spatial distribution
Niemeier et al. (2011)	Eight counties of the San Joaquin Valley region, USA	660,000 population growth between 2000 and 2030	UPlan for land use; four-step travel demand forecast; UC Drive & MOBLIE6 model for emissions calculation	CO_2	Auto	Not considered	Four scenarios: Baseline growth (BG): follow current trend; Controlled growth (CG): compact growth; Uncontrolled growth (UG): (very) low density, roadway expansion with little transit; As planned (AP): new road, high speed rail, and medium density
Hennessy & Tynan (2012)	South Carolina, USA	US Census 1990, US Census 2000, South Carolina Population report	Using VMT relationship with GHG emissions	CO_2	Auto	Not considered	Five scenarios: Current trend: 5:1 “growth ratio” (land growth /population growth) 4 Compact dev. ratios: 4:1, 3:1, 2:1, 1:1 “growth ratio”
Sider et al. (2013)	Montreal, Canada	Origin Destination Trip data, Montreal, 2008	Customized MOVES model	NO_x	Auto	A.M. and P. M peak	No additional scenario

	Study area	Data used	Emissions calculation method	Pollutant Considered	Traffic Mode	Temporal Consideration	Scenario design
Mathez et al. (2013)	Montreal, Canada	McGill Travel Survey 2010	MOVES for Auto STM for Transit	GHG	Auto Transit	A.M. Peak	Six scenario: base scenario; 5 scenario of switching mode depending on conditions
Wang et al. (2013)	Virginia, USA	Virginia Add-on survey of NHTS 2009, CENSUS 2010, LEHD 2009	Equation from EPA using VMT	CO_2	Auto	Not considered	No additional scenario
Alam et al. (2014)	Montreal, Canada	Transit Data collection	MOVES model	GHG	Transit	A.M. peak and P.M. peak	Corridor level scenario created for regular and reserved lane for both regular and express buses
Megenbir & Habib (2015)	Halifax, Canada	Dalhousie commuter Survey, 2011-2013	Accounting method using emission factors	GHG, VOC, THC, NO_x, CO, $PM_{2.5}$, PM_{10}	Auto, Transit	Not considered	No additional scenario
Matute & Chester (2015)	California, USA	N/A	Life cycle assessment	GHG	Transit	Not considered	Four scenario of cost allocation technique for High speed rail project
Rahman et al. (2016)	Kelowna, BC, Canada	Okanagan Travel Survey, 2013	Using emission factors with VKT	GHG	Auto Transit	Not considered	No additional scenario

Frank et al. (*2000*) found that auto emissions are positively associated with vehicle mile travelled, vehicle per household, people per household and income in Puget Sound, Washington. Stone et al. (*2009*) showed that smart growth can reduce emissions from auto in six Midwestern states in United States up to 16.7%. Norman et al. (*2006*) reveals that in Toronto, low density suburban development is more GHG intensive than high density urban core development by a factor of 2.0-2.5.Wang et al. (*2013*) estimated that CO_2 emissions are lower for households in mixed land use neighborhood with denser road network and better network connection in Virginia. Hennessy and Tynan (*2010*) concluded that with 1:1 growth ratio CO_2 emission will be reduced by 11% in South Carolina. Megenbir and Habib (*2015*) proposed a disaggregate accounting approach to estimate vehicle emissions using emission factors from the Urban Transportation Emission Calculator (UTEC) and the Environmental Protection Agency (EPA) which were used to estimate emissions from carbon monoxide (CO), volatile organic compounds (VOC), Nitrogen Oxides (NOx), particulate matter under 10 (PM_{10}), total hydrocarbons (THC), particulate matter under 2.5 ($PM_{2.5}$), along with GHG. As there are public health implications of PM_{10} , $PM_{2.5}$ and other pollutants, comprehensive review of all of those pollutant is required.

To capture temporal variation, some studies used the time period of A.M. peak or P.M peak. Namadeo and Mitchell (*2008*) found that emission reduced with implementation of inner cordon charges in Leeds in the morning peak period. Hatzopoulou et al. (*2007*) quantified vehicle emissions in the Greater Toronto Area (GTA) by exploiting travel information provided by activity-based, 24-hour models. Alam et al. (*2014*) estimated corridor level transit emission to explore the impact of transit reserved lane in Montreal. Matute and Chester (*2015)* conducted life cycle emission assessment of a high speed rail project which shows net reduction of GHG emission. It would have been interesting to see the relative impact of shift of modal share from auto to transit which has not been explored extensively.

Emission modeling results generally represents emission of a city or state at aggregate level. The studies by Norman et al. (*2006*) found in Toronto, annual per capita GHG emission from transportation is 5.18 ton CO_2 eq, for low density and 1.42 ton CO_2 eq, for high density area. Mathez et al. (*2013*) estimated that McGill commuters emit 31.13 tons CO_2 eq in a typical winter day. Rahman and Idris (*2016*) estimated 374,344 ton CO_2 eq total annual GHG emission from transportation in Kelowna for 2007. Sider et al. (*2013*) estimated NOx emission polluting power and pollution experienced for Montreal and found that there is much higher pollution along the main highway corridors and in the downtown areas. They also found the emissions are very low for zones on the region's periphery. Aggregate level emission reporting don't reflect actual nature of emission in a city with urban-rural divide. It fails to capture the spatial diversity within the city or state. In a city like Halifax where there are urban, suburban and rural areas within its boundary, spatial distribution of emissions is necessary to explain their relative contribution and exposure to emissions. It is very important to understand how much they pollute and how much they experiences pollution.

There is a clear gap in literature for understanding who generate emission and who experiences where the debate of urban-rural divide exists. Emission analysis with polluting power and pollution experienced in disaggregate level can fulfil the objectives by providing the pollution generation and exposure to pollution of each area. This study addresses above mentioned literature gap and provides the framework to quantify the spatial and temporal emission modelling by estimating polluting power and pollution experienced of each area. Furthermore it also shows the impact of transit modal shift on GHG emission in urban-rural divide context.

3.4 Emission Model Development

This study first developed a regional transportation network model for Halifax. The process diagram of transport network and emission modeling is shown in Figure 3-1.

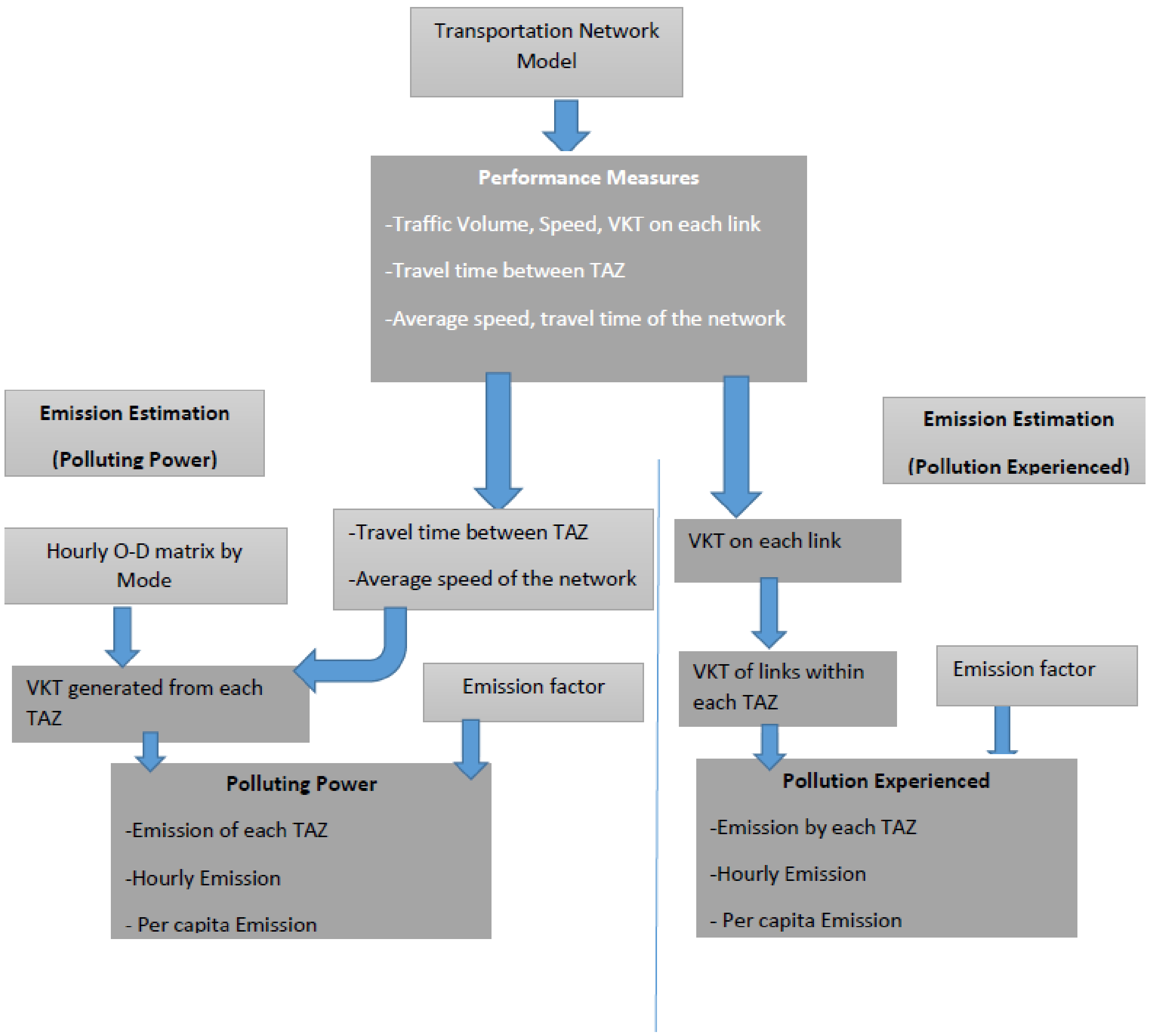


Figure 3-1 Modelling Framework for Emission estimation

Emission modelling comprises of two parts: polluting power and pollution experienced. To estimate polluting power VKT generation is calculated using hourly O-D matrix by mode, travel time between TAZ and average speed of the network. Using emission factors with the VKT polluting power of each TAZ is calculated. Pollution experienced within the TAZ was calculated by using VKT of the links within the zone with the same emission factors. For both cases Megenbir and Habib (*2015)* proposed approach was followed. In that study, we have estimated emissions of GHG, CO, THC, VOC, NOx, PM_{10} and $PM_{2.5}$. The scenarios are described in the following section. (Appendix C-1)

3.5 Scenario Preparation

The Transportation network and emission model used 2011 as base year and forecasted for 2016 and 2021 for different scenarios to calculate emissions for the same time period. As explained in the last chapter, HRM growth scenario projection for household and employment were considered to forecast trip generation for 2016 and 2021.

Additional scenarios were created with 2.5% and 5% modal shift from Auto to transit. This is developed to evaluate the potential impact of transit modal shift in 2016 and 2021. Halifax transit has adopted a plan to increase transit ridership by 5% within next 5 years (*Halifax Transit, 2013*). Scenarios were created in this study to understand what would have been the effect on GHG emission if it were possible to reach the target fully or partially within 2016 or 2021. Table 3-2 shows the household number, employment and state of modal share used in each scenario.

Table 3-2 Scenario Description

Scenarios	Year	No. of Households	Employment	Modal share of auto and transit
2011: Base Scenario	2011	165,155	211,375	no change in modal share
2016: Scenario 01	2016	182,730	233,565	no change in modal share
2016: Scenario 02	2016	182,730	233,565	2.5% modal shift from auto to transit
2016: Scenario 03	2016	182,730	233,565	5% modal shift from auto to transit
2021: Scenario 01	2021	202,130	247,040	no change in modal share
2021: Scenario 02	2021	202,130	247,040	2.5% modal shift from auto to transit
2021: Scenario 03	2021	202,130	247,040	5% modal shift from auto to transit

To incorporate modal shift from auto to transit, modal split was completed in each TAZ level and a 24-hour mode specific O-D matrix was established for each scenario. For these seven scenarios 24-hour auto and transit models are discussed in the following section.

3.6 Results and Discussions of Aggregate Emission

The results generated from the emission model gives aggregate level transportation emissions of Halifax as well as addressing the urban-rural divide. Table 3-3 shows the number of trips, VKT and GHG emissions of auto and transit at different times of the day for 2011.

Auto trips comprise 87.18% of total trips, constitute more than 99.62% of the VKT and are responsible for 97.73% of the GHG emissions. Whereas, transit trips are 12.18% of total trips, the VKT of transit is 0.38% and it generates 2.27% of the GHG emissions. This indicates that the emissions contribution of auto is not proportional but higher than its modal share, which is true for each time segment of the day. The maximum GHG emission for Auto occurred during Afternoon peak which is 1018.71 ton.

Table 3-3 Number of trips, VKT and GHG emission in the base year 2011

		Morning Peak (6AM - 10AM)	Mid-Day (10AM - 2PM)	Afternoon Peak (2PM - 6PM)	Evening (6 PM - 12PM)	Early Morning (12AM - 6 AM)	Daily Total
Number of Trips	Auto	182,726	201,487	301,563	244,224	41,624	971,624
	%	87.19%	86.76%	86.32%	86.68%	100%	87.18%
	Transit	26,847	30,739	47,783	37,528	0	142,893
	%	12.81%	13.23%	13.68%	13.32%	0%	12.18%
VKT	Auto	2,529,936	2,736,126	4,193,235	3,332,456	490,001	13,281,754
	%	99.34%	99.66%	99.64%	99.73%	100%	99.62%
	Transit	16,848	9,429	15,075	9,020	0	50,372
	%	0.66%	0.34%	0.36%	0.27%	0%	0.38%
GHG emissions (ton)	Auto	614.63	664.72	1018.71	809.59	119.04	3,226.69
	%	96.08%	97.93%	97.84%	98.37%	100%	97.73%
	Transit	25.08	14.03	22.44	13.43	0	74.98
	%	3.92%	2.07%	2.16%	1.63%	0%	2.27%

The estimation of the seven scenarios shows that household and employment growth over time would increase annual per capita emissions in table 3-4.The impact of modal shift towards transit during the same time period is found to decrease per capita emission. In 2011, annual per capita GHG emission was found to be 3.09 ton. The projected emission for household and employment growth is found to be 3.16 ton in 2016 and 3.41 ton in 2021.

However, a modal shift towards transit can help reduce emission. For a 5% modal share shift from auto to transit the emission would be 3.05 ton in 2016 and 3.28 ton in 2021. Annual per capita emission from GHG, CO, THC, VOC, NOx, PM_{10} and $PM_{2.5}$ for 2021 is expected to be 3.41 to, 86.57 kg, 9.89kg, 9.34kg, and 6.89kg, 39.55gm and 42.95 gm respectively. Similarly, an increase for growth and a decrease for transit modal shift is observed for all emissions such as CO, THC, VOC, NOx, PM_{10} and $PM_{2.5}$.

Table 3-4 Annual Per Capita Emission

	2011	2016			2021		
Emissions	**Base Year**	**Scenario 1 (no change in modal share)**	**Scenario: 2 (2.5% modal shift from auto to transit)**	**Scenario: 3 (5% modal shift from auto to transit)**	**Scenario: 1 (no change in modal share)**	**Scenario: 2 (2.5% modal shift from auto to transit)**	**Scenario: 3 (5% modal shift from auto to transit)**
GHG (ton)	3.09	3.16	3.16	3.05	3.41	3.37	3.28
CO (kg)	77.92	80.05	79.86	77.03	86.57	85.51	83.22
THC (kg)	8.90	9.15	9.12	8.80	9.89	9.77	9.51
VOC(kg)	8.41	8.64	8.62	8.31	9.34	9.22	8.98
NOx(kg)	6.33	6.45	6.43	6.22	6.89	6.81	6.64
PM_{10}(gm)	35.82	36.70	36.62	35.34	39.55	39.07	38.04
$PM_{2.5}$ (gm)	41.18	41.22	41.14	39.96	42.95	42.50	41.55

Temporal distribution of emissions throughout the 24-hour period is estimated from the model which is shown in Figure 3-2. Passenger transportation emissions were estimated throughout the day in Halifax for all the prepared scenarios. GHG emissions reach the maximum during P.M. peak between 4pm - 5pm of 354.28 ton/hour in 2011, 402.83 ton/hour in 2016 and 498.90 ton/hour in 2021. The model also forecast that the impact of modal shift towards transit would decrease the hourly emissions throughout the day, but its contribution is more significant in the P.M. peak. Calculating a 5% modal shift from auto to transit, the P.M. peak hourly emission would be 387.20 ton/hour in 2016 and 478.18 ton/hour in 2021.

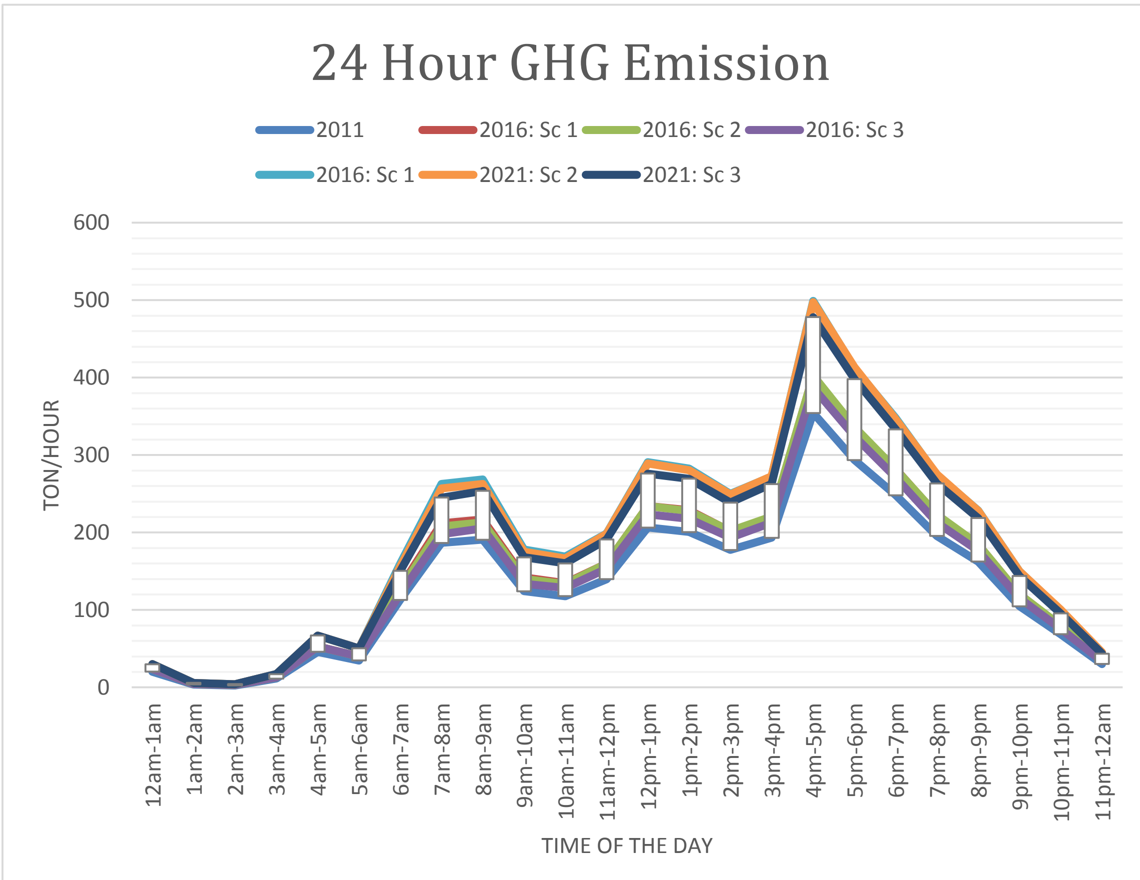


Figure 3-2 24-hour GHG emission

Thus 24-hour emission estimation provides the understanding of the quantity of emission occurred in different time of the day and indicates about the vulnerable time so that policies can be developed accordingly to address those variation.

3.7 Polluting Power and Pollution Experienced

GHG polluting power and pollution experienced is estimated in each zone following the modeling framework described at section 3.4 the results are then accumulated for urban, suburban and rural zones. Table 3-5 shows the GHG emissions per capita for urban, suburban and rural areas. In 2011, the annual GHG per capita was 3.09 ton. The urban area per capita polluting power was 4.16 ton, which is significantly higher than the 2.53 ton of per capita pollution experienced by the urban area. However, both in suburban and rural areas polluting power is less than pollution experienced. This implies that emissions generated from vehicles in the urban areas are adding to the emission experienced at suburban and rural areas.

It also shows the polluting power and pollution experienced in rural areas is higher than overall per capita GHG emission, due to low population density. Polluting power and pollution experienced of suburban areas is lower than overall per capita GHG emissions, reflecting a higher population density in suburban areas. Even though urban areas have the highest population density the per capita polluting power is higher than the overall per capita GHG emission. On the contrary, per capita pollution experienced in urban area is lower than overall per capita GHG emission. This is because the urban areas generate the maximum emissions.

There is also a gradual increase in emissions within 2016 and 2021 when household and employment growth are considered. Pollution experienced is expected to increase 13.54% in urban and 11.67% in suburban areas and 1.51% in rural areas between 2011 and 2021. Polluting power is predicted to increase 25.10% in urban, 15.83% in suburban and 0.02%

in rural areas during the same period. This indicates urban and suburban areas are expected to experience much higher emission increase than in rural areas.

Table 3-5 Annual GHG emission per capita

		2011		2016			2021	
		Base Year	Scenario: 1 (no modal shift)	Scenario: 2 (2.5% modal shift from auto to transit)	Scenario: 3 (5% modal shift from auto to transit)	Scenario: 1 (no modal shift)	Scenario: 2 (2.5% modal shift from auto to transit)	Scenario: 3 (5% modal shift from auto to transit)
GHG per capita	Total	3.09	3.16	3.16	3.05	3.41	3.37	3.28
	% increase from 2011		2.47%			10.40%		
	% change from no modal shift			-0.24%	-3.71%		-1.21%	-3.81%
GHG per capita (Pollution experienced)	Urban	2.53	2.59	2.55	2.47	2.87	2.81	2.74
	% increase from 2011		2.54%			13.54%		
	% change from no modal shift			-1.57%	-5.00%		-2.16%	-4.73%
	Suburban	2.25	2.30	2.30	2.22	2.52	2.50	2.42
	% increase from 2011		2.18%			11.67%		
	% change from no modal shift			0.06%	-3.75%		-0.75%	-3.78%
	Rural	5.24	5.33	5.33	5.16	5.32	5.25	5.13
	% increase from 2011		1.76%			1.51%		
	% change from no modal shift			0.06%	-3.15%		-1.22%	-3.49%
GHG per capita (Polluting power)	Urban	4.16	4.29	4.04	3.83	5.21	4.87	4.61
	% increase from 2011		3.18%			25.10%		
	% change from no modal shift			-5.85%	-10.78%		-6.36%	-11.36%
	Suburban	1.87	1.94	1.91	1.84	2.16	2.13	2.04
	% increase from 2011		4.06%			15.83%		
	% change from no modal shift			-1.58%	-5.60%		-1.78%	-5.87%
	Rural	5.00	5.05	5.08	4.88	5.00	5.00	4.81
	% increase from 2011		1.16%			.02%		
	% change from no modal shift			0.57%	-3.38%		0.05%	-3.79%

In those same years, the change of modal shift towards transit reduce GHG emissions. For a 5% modal shift to transit, the decrease per capita emissions is found 3.71% in 2016 and 3.81% in 2021 for a 5% change in modal shift from Auto to transit.. This shift would decrease polluting power of 11.36% in urban areas, 5.87% in suburban areas and 3.79% in rural areas for 2021. This shows modal shift towards auto has more potential to emission reduction in urban and suburban areas.

Table 3-6 Annual GHG emission per unit area

		2011		2016			2021	
		Base Year	Scenario: 1 (no change in modal share)	Scenario: 2 (2.5% modal shift from auto to transit)	Scenario: 3 (5% modal shift from auto to transit)	Scenario: 1 (no change in modal share)	Scenario: 2 (2.5% modal shift from auto to transit)	Scenari o: 3 (5% modal shift from auto to transit)
GHG per Sq KM	Total	220.50	250.59	249.99	241.30	309.85	306.10	298.03
	% increase from 2011		13.64%			40.52%		
GHG per Sq KM (Pollution experienced)	Urban	6744.15	7352.35	7236.63	6984.56	8675.33	8487.51	8264.90
	% increase from 2011		9.02%			28.63%		
	Suburban	1723.78	1970.23	1971.35	1896.33	2405.17	2387.12	2314.16
	% increase from 2011		14.30%			39.53%		
	Rural	102.17	117.55	117.61	113.85	149.60	147.78	144.38
	% increase from 2011		15.05%			46.43%		
GHG per Sq KM (Polluting power)	Urban	11089.67	12165.25	11453.11	10853.96	15717.02	14717.3	13930.80
	% increase from 2011		9.70%			41.73%		
	Suburban	1429.97	1664.47	1638.25	1571.30	2069.58	2032.70	1948.00
	% increase from 2011		16.40%			44.73%		
	Rural	97.47	111.48	112.12	107.72	140.64	140.71	135.31
	% increase from 2011		14.38%			44.29%		

GHG emissions per unit area is estimated for both polluting power and pollution experienced. (Table 3-6) In 2011, the GHG emissions were 220.50 ton/km^2. The polluting power of urban, suburban and rural areas were found to be 11,089.67 ton/km^2, 1429.97 ton/km^2 and 97.47 ton/km^2, respectively. On the other hand, pollution experienced in urban, suburban and rural area were found to be 6744.15 ton/km^2, 1723.78 ton/km^2 and 102.17 ton/km^2. These affirms that suburban and rural areas experience more pollution than they generate, but for the urban area polluting power and experienced are significantly higher than the average GHG emissions in Halifax.

Emission forecasting shows that polluting power per sq km at suburban areas are expected to generate highest increase which is 16.40% in 2016 and 44.73% in 2021 from the base year 2011. This indicates emission per unit arear in suburban area has potential to increase at higher rate than urban and rural in future.

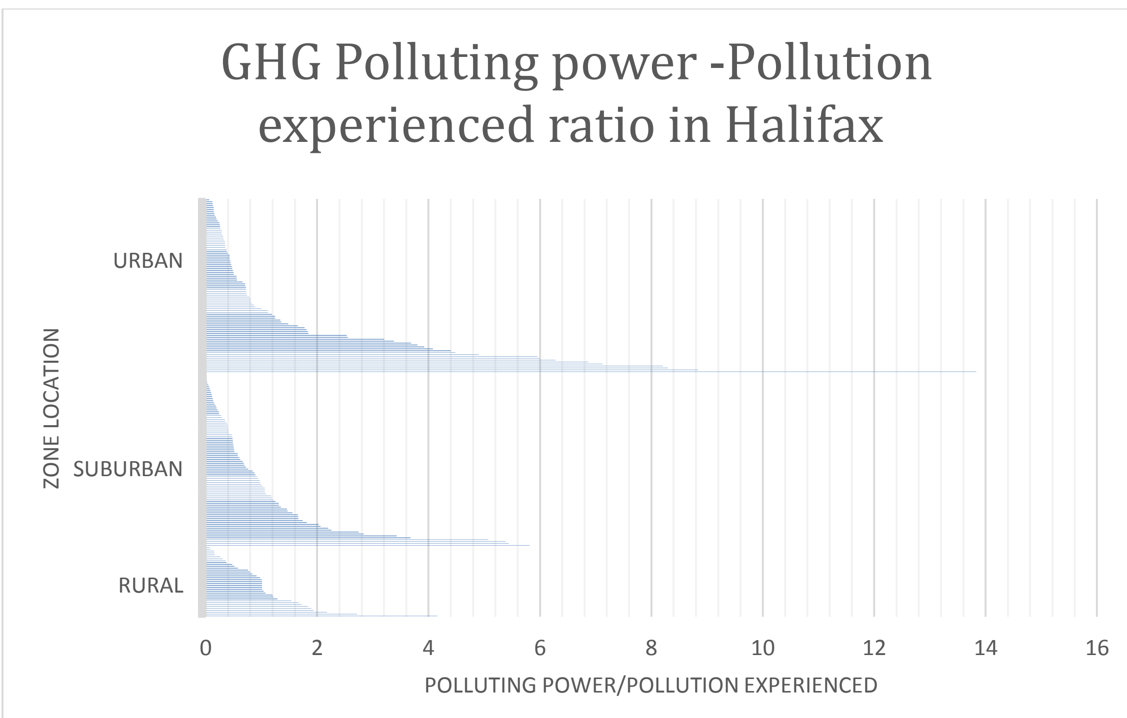


Figure 3-3 GHG polluting power-pollution experienced ratio in Halifax

Figure 3-3 shows who is generating emission and who is experiencing it. Polluting power-pollution experienced ratio of urban area is 1.68 which means urban areas generating 68% more than they are experiencing. 20 out of 91 urban TAZ has a Polluting power-pollution experienced ratio over 2.0 and maximum being 13.83 in Halifax south end. The same for suburban and rural areas are 0.82 and 0.95 which implies suburban and rural areas experience more emission than they generate.

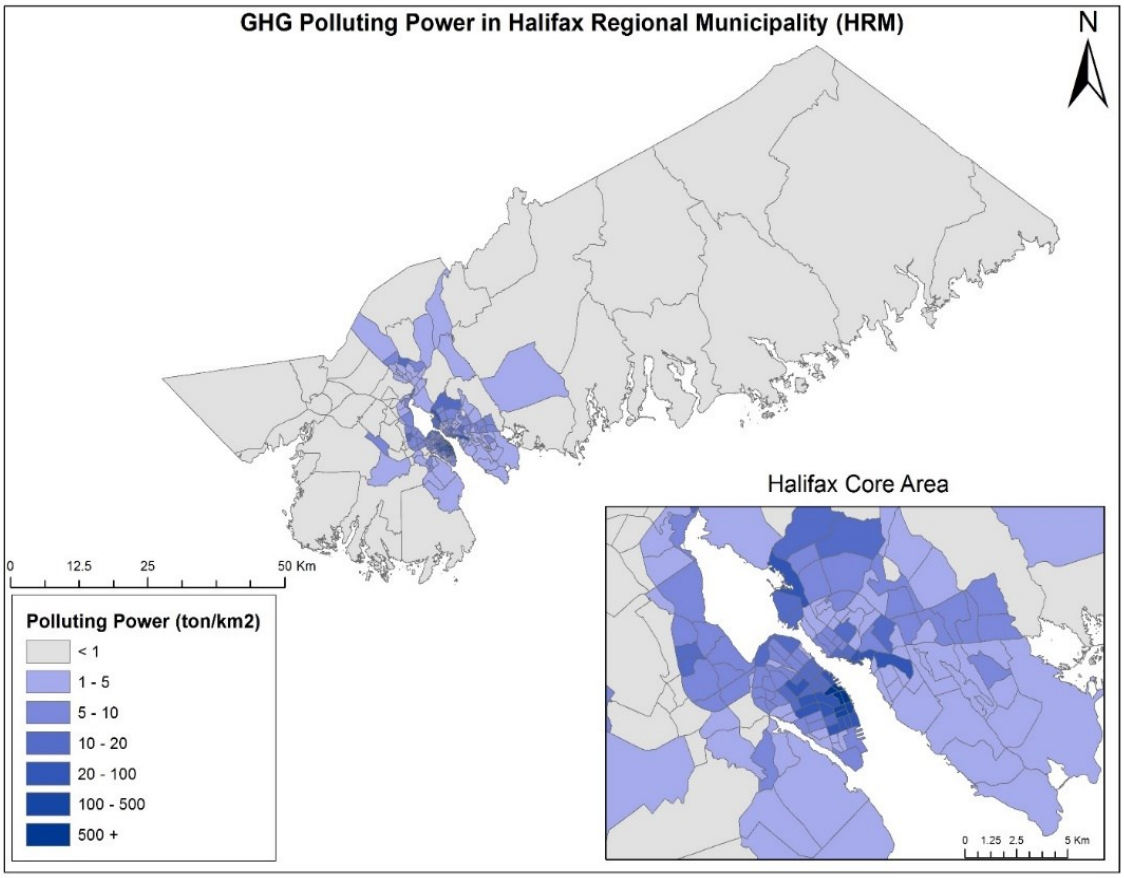


Figure 3-4 Daily GHG Polluting Power Map of Halifax (2016)

GHG emissions were also analyzed at the TAZ level, and a polluting power map and pollution experienced map were produced (Figure 3-4 and 3-5). These maps show the spatial distribution of emissions. Figure 3-4 represents the daily GHG polluting power map of Halifax Regional Municipality (HRM) for 2016. The map shows that the GHG emissions generation from the urban areas are significantly higher than other areas. The maximum GHG polluting power was found to be 862.29 ton/km^2 in the downtown area. Four TAZ values around downtown have a polluting power more than 500 ton/km^2.

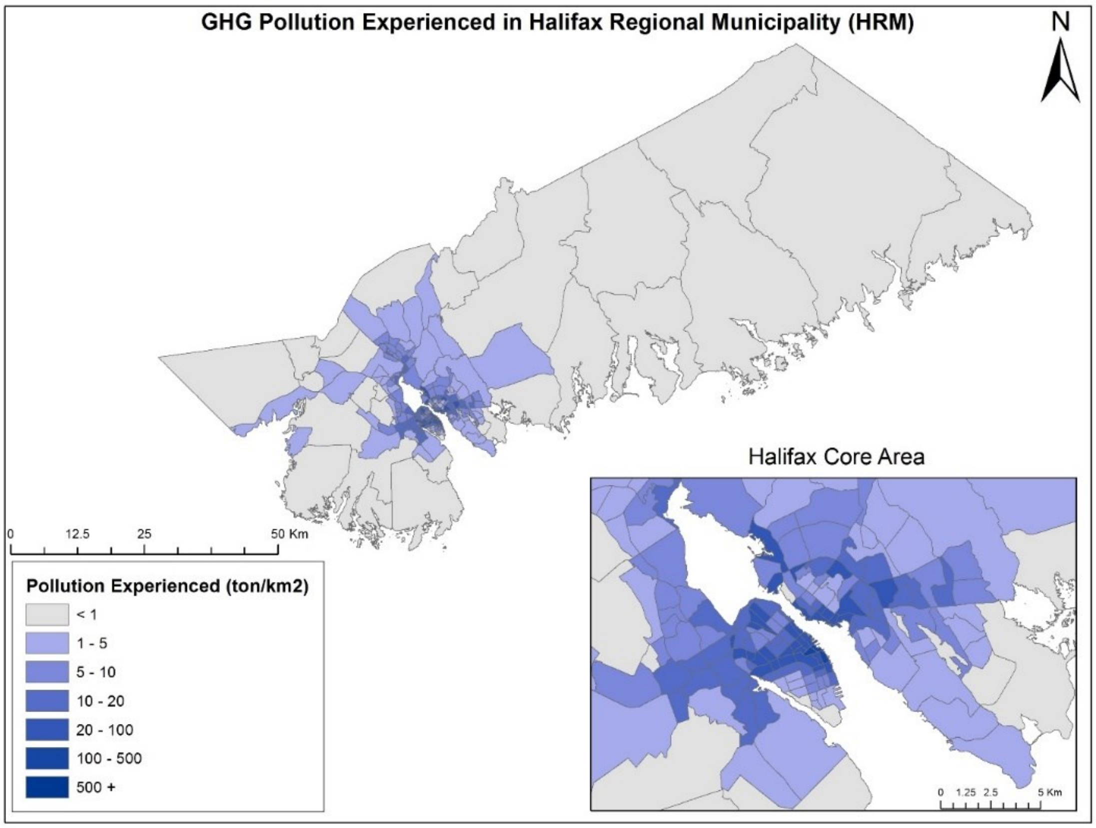


Figure 3-5 Daily GHG Pollution Experienced Map of Halifax (2016)

Figure 3-5 represents the daily GHG pollution experienced in Halifax Regional Municipality for 2016. The maximum GHG polluting power of 118.89 ton/km^2 was found in the downtown area. Three TAZ values around the downtown experienced pollution of more than 100 ton/km^2. Pollution experienced in the downtown is higher than suburban and rural areas

3.8 Conclusion

The results showed that the emission contribution of auto is higher than its modal share, where 87.18% of total trips contribute 97.73 % of GHG emissions. GHG emissions reached the maximum during P.M. peak between 4pm - 5pm of 354.28 ton/hour in 2011, 402.83 ton/hour in 2016 and 498.90 ton/hour in 2021. The model forecasts the increase of annual per capita emissions from 3.09 in 2011 to 3.16 in 2016 and 3.41 in 2021. A 5% shift in modal share from auto to transit translates to a decrease of GHG pollution in 2016 and 2021 which shows the values of 3.05 in 2016 and 3.28 in 2021 The results also indicates that the impact of modal shift towards transit would decrease the hourly emissions throughout the day, but its contribution is more significant in the P.M. peak. This shift would decrease polluting power of urban areas 11.36% and 5.87% in suburban areas whereas the same in rural areas 3.79% in 2021. This shows modal shift from Auto has more potential to emission reduction in urban and suburban areas. Therefore, there is potential that if more transit and active transportation options are offered in urban and suburban areas by transportation planners, that would help to reduce emission contribution from Auto.

The results also reflect the polluting power of urban areas was significantly higher than the pollution experienced in the same areas. This implies that the emissions generated from vehicles in urban areas are adding to the emissions experienced at suburban and rural areas.

Urban areas are generating 68% more emission they generate and suburban and rural areas experience more emission than they generate.

Emission forecasting shows that pollution experienced is expected to increase 13.54% in urban,11.67% in suburban areas and only 1.51% in rural areas between 2011 and 2021.Polluting power is predicted to increase 25.10% in urban,15.83% in suburban and 0.02% in rural areas during the same period. This indicates the prospective increase of emission in coming years at urban and suburban areas is much higher than in rural areas. The pollution map dictates that the downtown areas are responsible for maximum pollution and experienced pollution. It reveals that maximum emissions are generated and experienced at urban downtown areas which is 862.29 ton/km^2 and 118.89 ton/km^2 respectively. Emission forecasting also shows that polluting power at suburban areas are expected to generate highest increase which is 16.40% in 2016 and 44.73% in 2021 from the base year 2011. This indicates emission per unit area in suburban area has potential to increase at higher rate than urban and rural in future

The findings of emission polluting power and pollution experienced can be used as a basis for a decision making strategy in a urban-rural divide context particularly how to reduce pollution in one hand and how to reduce exposure on the other hand. It also shows the impact of GHG emission reduction for a modal shift to transit in urban and suburban areas are significant which can be useful for making transit investment and policy decisions. More investment in transit for urban and suburban areas will not only be beneficial for urban and sub urban, but would help rural areas to experience less pollution.

CHAPTER 4

ALTERNATIVE TRANSIT INFRASTRUCTURE PROJECT EVALUATION

4.1 Chapter Overview

The chapter investigates the impact of transit infrastructure projects on network performance and emission by using the transport network and emission modelling system. Halifax Regional Municipality (HRM) is considering three alternative transit infrastructure projects such as BRT, rail and ferry between Halifax Downtown-Bedford corridors to enhance the transit service. This study creates four different scenarios including three proposed alternative modes: Bus rapid transit (BRT), commuter rail and ferry along with business as usual regular transit. Prediction of transit users, network performance indicators and greenhouse gas (GHG) emissions were considered as evaluation criteria.

This study implemented a unique approach by using of stated preference survey to create future origin-destination matrix for the network model. The scenarios thus reflect alternative futures, with the interaction of external conditions and as a result of choices.

This chapter is organized as follows: first, a brief introduction with a review of the literature, then background of alternative transit plans for Halifax-Bedford. Use of stated preference survey is discussed followed by evaluation of projects by network performance and GHG emissions results.

4.2 Background

Public transit is a vital component of an integrated sustainable transportation system for an urban area. Transit agencies in different cities around the world, are aiming for improving their quality of service and introducing new alternative transit infrastructure projects in order to increase transit ridership and attract passengers from other modes, especially passenger car.

Any transportation project evaluation process involve predicting future ridership. But as it is an unobserved future and hypothetical in nature, modelling future ridership is challenging. Stated preference survey is an effective tool which is very useful in this type of evaluation. Transport network modeling is the best possible way to conduct network evaluation. Greenhouse gas (GHG) emissions contributed by the transportation sector is a growing concern in recent years in North American cities, which should be taken into consideration in any transportation infrastructure project. Nowadays, GHG emissions is one of the most important criteria to use when evaluating between alternate public transportation projects.

Different alternatives of public transportation have evolved around the world for small or medium sized cities. Bus Rapid Transit (BRT) is a popular option in some cities, and commuter rail is a viable option for cities that are equipped with railway track infrastructure. Similarly, cities that have a proximal water body or harbor have the advantage of considering fast ferry service as an option. Halifax, which is the capital of

Nova Scotia, Canada has all of these options are available for consideration. This is why Halifax can be a perfect case study to investigate those three transit alternative infrastructure projects.

4.3 Literature Review

Transit infrastructure projects are of large investment, therefore, there are always attempts to analyze the potential impact of the project as precisely as possible.

Future potential ridership is one of the important indicator for evaluating transit infrastructure. Henao et al. (*2015*) concluded that transportation infrastructure investments such as improving mode choices through new infrastructure and services in Boulder, Colorado from 1990 to 2009, are associated with an increase in transit mode share and a decrease in single occupancy vehicle mode share. Allen et al. (*2006*) analyzed a transit database from 1985 to 2003 and reported that the Dallas Area Rapid Transit system in Texas experienced significant ridership changes as it transitioned from an all-bus system to a bus-and-rail system. It is very important to forecast potential ridership of transit infrastructure as close as possible. Jones et al. (*2014*) pointed out that CBA overestimates traffic forecast by 20%-60%. Therefore to address unobserved future is a challenge for transit modal shift forecasting. Stated preference survey can be used to serve the purpose very effectively to address these future hypothetical scenarios.

Stated preference (SP) methods were introduced to transportation in the early 1970s and become popular among researchers during early to mid-1980s, when SP surveys were used to investigate travelers' behavior. Loo (*2002*) reviewed studies conducted in different parts of the world in stated preference (SP) surveys and suggested that SP techniques can be used with the traditional four-stage transportation planning model. Stated preference surveys are popular in modal choice and other decision choice studies. Roman et al. (*2010*) analyzed a mixed revealed preference data set to study Madrid–Zaragoza and Madrid–Barcelona routes, in which high speed rail could attract more traffic than competing modes. In this study, a stated preference survey results were used as a tool for hypothetical future investments.

Recently, the impact of GHG emissions is a growing concern which also has been used as an evaluation tool for projects. Euritt et al. (*1996*) concludes if greenhouse gas emissions are to be held at 1990 levels or reduced below that in Texas, very dramatic policies in the are needed that include modal shift to high occupancy vehicles including high speed rail. Puchalsky's (*2005*) analysis shows that whenever equal levels of technology are compared, Light rail transit (LRT) consistently performs better to reduce emission than BRT despite recent advances in the BRT mode. The analysis also shows that both modes are cleaner now than in the past. Brisson et al. (*2012*) examined GHG reduction strategy for San Francisco and found that although investments in transit alone may not produce substantial GHG reductions, they are necessary to accommodate the mode shift of other strategies and can be paired strategically with road pricing strategies which were found to have the largest potential to reduce GHG emissions.

This study extends the regional transport network and emission modelling system to evaluate future alternative transit infrastructure projects in Halifax

4.4 Transit alternative plans for Halifax-Bedford

Halifax is the capital of the province of Nova Scotia, Canada. The proportion of commuters in Halifax using public transit to get to work has continued to rise in recent years. In the HRM, 11.9% commuters used public transit in 2006 compared to 9.9% in 2001. (*Halifax Transit, 2013*).

Meanwhile, in 2009 the HRM emphasized its potential growth of transit users in the 5-year strategic plan. They have adopted a transportation strategy, which further emphasizes the need for increased reliance on transit. To accommodate a greater portion of transportation trips, the HRM strives to increase to as high as 26% of overall trips by 2031 and 18% within next five years. The HRM addresses this issue with greater emphasis on public transit and the ability to handle a major portion of the future growth of transportation (*Halifax Transit, 2013*).

For more than a decade, the HRM has been investigating the possibility of enhancing commuter service between Bedford and the Halifax Peninsula, and has considered a BRT system, a commuter rail service, and a ferry service. According to the Regional Municipal Planning Strategy (RMPS) adopted by the HRM in 2006, the suburban communities of Bedford West and Bedford South are each expecting a population increase of over 15,000 people in the next twenty years (*Delphi-MRC, 2010*). In order to accommodate the large increase in the number of commuters to the Halifax Peninsula and reduce automobile congestion along major commuter corridors, the current public transit system needs to be improved. Therefore, the study has great significance in present context of Halifax. Figure 4-1 shows the proposed BRT, rail and ferry routes in Halifax.

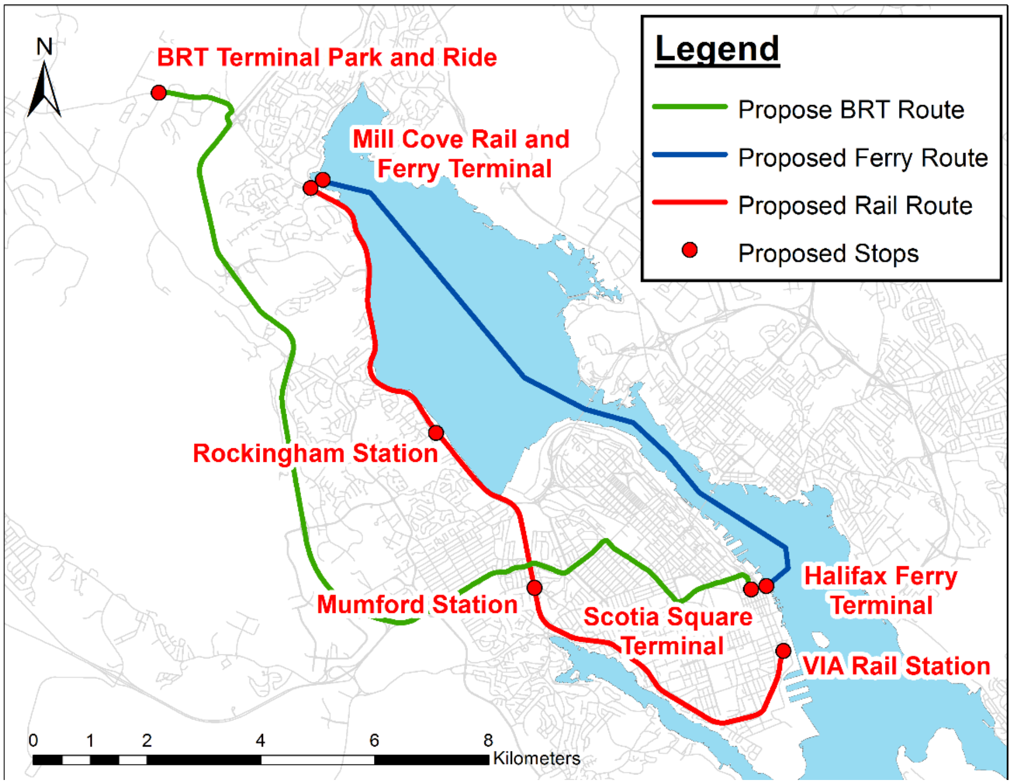


Figure 4-1 Proposed BRT, Ferry and Rail Route

The proposed BRT line starts at from the Park and Ride facility in Bedford and ends at Scotia Square in Downtown Halifax. The proposed ferry route is from Mill Cove, Bedford to Halifax ferry terminal. Meanwhile the proposed commuter rail stats at Mill cove and runs through Rockingham to a VIA rail station.

4.5 Modelling framework

A regional transportation model is developed for Halifax in this study which is described in Chapter 2. The model was validated with existing data and forecasted for 2016 and 2021. Emission estimation is incorporated in the modelling framework to quantify emissions for

Halifax which is described in Chapter 3. This transportation network and emission modelling system is used to evaluate alternate transit infrastructures in Halifax.

Four different scenarios were created for 2016 with one being business as usual and the other three including BRT, rail and ferry with the current transit network of Halifax. For each scenario, an A.M. peak (6 am-10am) and a P. M. peak (2pm-6pm) model were performed using 2016 hourly auto and transit origin-destination trip matrix. These two time periods are used to investigate the impact of a transit infrastructure project of BRT, rail or ferry in this study. Eight traffic analysis zones from downtown Halifax and eight traffic analysis zones from Bedford are considered to show the response of implementing the transit infrastructure options with BRT, rail or ferry in this study. (Appendix D-1)

Richardson and Habib (*2011*) performed a stated preference survey to investigate user preferences for three proposed transit alternatives, bus rapid transit, commuter rail and ferry connecting Bedford and Halifax. The survey design used for the study considers three attributes. Those are: travel time, travel cost, and service frequency for each transit alternative. A fractional factorial design is considered for the SP survey, which generates 12 choice scenarios. A multinomial logit (MNL) model was developed using SP survey data with random utility-based discrete choice modelling techniques. Results of that Multinomial model which is based on SP survey data for BRT, rail and ferry is are shown in Table 4-1. Results indicates increase in travel cost and travel time for a mode would decrease the probability of choosing that mode. On the other hand increase in service frequency of a mode would increase the probability of choosing that mode.

Table 4-1 MNL Model Results Based on the SP Survey Results

Attribute	Coefficient	t-stat
Travel time	-.0554	-17.103
Travel Cost	-.3929	-23.445
Service Frequency	.0231	4.118
ASC Ferry	-.8292	-4.715
ASC Train	-.3957	-2.535
ASC Bus	-.9004	-7.318
Model Fit (Adjusted Rho-square) = 0.11		

(*Richardson and Habib , 2011*)

The Modeling framework for alternative transit infrastructure evaluation is shown in figure 4-2. This study uses the above mentioned MNL model results to calculate the future modal share of Auto, existing transit and proposed alternate transit. This provides the forecast of transit users of all three transit alternatives which is the first evaluation criteria.

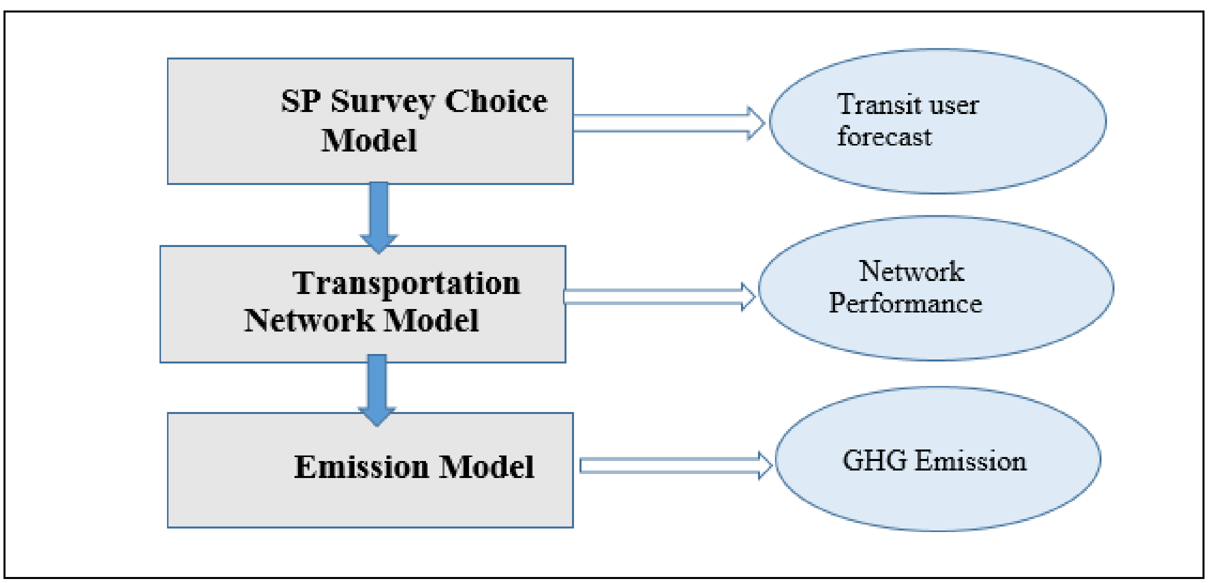


Figure 4-2 Modeling framework for alternative transit evaluation

Transportation network model is used to evaluate network performance. Transit and Auto assignments are run for the created four scenarios. To represent unobserved future, modal share of the 16 zones were updated by using the MNL model results. Thus SP survey provide the hypothetical future choices to the transportation network modeling framework. Travel time, trip length of overall network is observed for all the scenario. Transit-Auto travel time ratio for each O-D pair was calculated which gives the performance measure of the each transit alternatives.

GHG emission of the network for each scenario were also estimated using the emission estimation procedure described in chapter 3. Per capita GHG emission and emission experienced in each zone were estimated. This provides the relative impact of all those transit alternative on increasing or decreasing GHG emission.

4.6 Evaluation based of network performance

Network performance indicators those are used in this study are change in modal share, network characteristics like travel time and trip length and transit-auto travel time ratio.

4.6.1 Change in Modal Share

The model result suggest that, current modal share between auto and transit is expected to change with inclusion of an alternate transit like BRT, rail or ferry. Figure 4-3 shows modal share of auto will be dropped 84.94% to 80.59% at AM peak and from 79.87% to 74.38% at PM peak for rail. It would attract more rider than other two options as 7.16% in PM peak and 5.73% in AM peak. Among these shift 5.49% in PM peak and 4.35% in AM peak are from auto and rest are from existing transit. Among the other two options BRT is attracting more rider in AM peak which is 2.36% compare to ferry's 2.04%. But shift to ferry in PM peak is 4.25%, which is higher than 2.82% of BRT. Thus all the options shows modal shift from auto to transit and rail has the maximum potential to shift Auto users to transit.

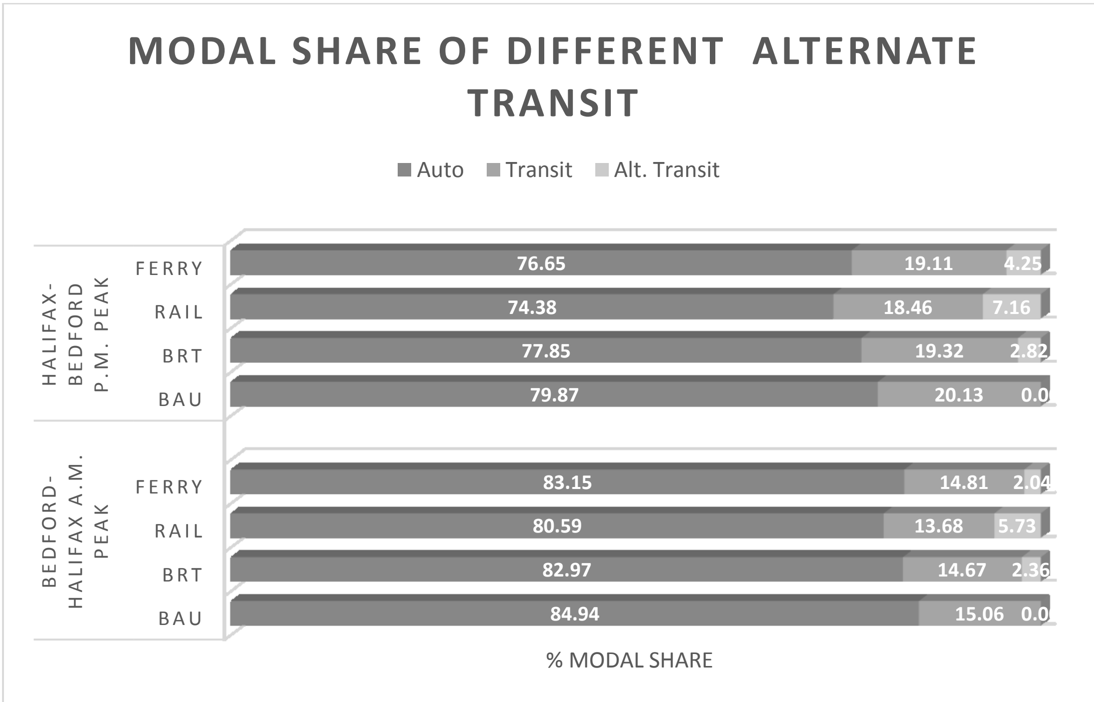


Figure 4-3 Modal share of different alternative transit

4.6.2 Network Characteristics

The model also evaluates the overall transit system performance of the HRM with respect to the proposed inclusion of BRT, rail and ferries in the system. Table 4-2 shows the average distance traveled for transit per trip and the average transit travel time per trip for both AM peak and PM peak periods. Although this improvement is proposed for one corridor of the city, it shows some impact of overall transit performance of the city. For a business as usual scenario, the average distance traveled in transit per trip is 5.31 km in AM peak and 5.55 km in PM peak. All three options would decrease the distance whereas BRT would do the maximum. Introduction of BRT decreases average distance traveled in transit per trip to 0.32% in AM peak and 0.33% at PM peak.

Average transit travel time per trip was found to be 11.65 minute for AM peak and 12.21 for PM peak. In this case, BRT shows a 1.65% and 1.70% decrease, whereas rail and ferry indicate some increase of travel time. Overall, the inclusion of BRT is showing better network performance than other options.

Table 4-2 Network Characteristics of Alternative Transit Scenarios

AM Peak period				
	BAU	BRT	Rail	Ferry
Distance traveled in transit per trip (km)	5.311	5.295	5.307	5.310
% Change from BAU		-0.32	-0.09	-0.03
Average transit travel time per trip (minute)	11.652	11.459	11.668	11.658
% Change from BAU		-1.65	0.14	0.05

PM Peak Period				
	BAU	BRT	Rail	Ferry
Distance traveled in transit per trip (km)	5.550	5.532	5.544	5.547
% Change from BAU		-0.33	-0.11	-0.07
Average transit travel time per trip (minute)	12.209	12.001	12.227	12.220
% Change from BAU		-1.70	0.15	0.09

4.6.3 Transit-Auto Travel Time Ratio between O-D Zones

Transit–auto travel time ratio is a service quality measure which indicates the relative effectiveness of a transit system with respect to Auto travel time. In this study, the transit-auto travel time ratio is calculated with each origin destination zone between Bedford-Halifax downtown in PM peak period for all the scenarios. In the business as usual case, transit-auto travel time varies from 1.428 between the Downtown Core-Mill Cove to 2.655 between Downtown Citadel-Kerney Lake areas. For most of the cases including BRT is better in terms of transit-auto travel time ratio. Out of the 64 origin destination pair for BRT transit-auto travel time ratio is lower than business as usual for 62 cases. Rail and ferry showed a similar advantage for 26 and 28 O-D pair respectively. Table 4-3 shows the relative comparison of transit-auto travel time ratio.

Table 4-3 Transit-Auto Travel Time Ratio

		Destination Zones							
Origin Zones		**Larry Uteck**	**Kearney Lake Rd**	**Kearney Lake**	**Hamond Plains Rd**	**Bedfod West**	**Bedfod South**	**Mill Cove**	**Bedfod Core**
Downtown -Pier 21	BAU	2.153	2.075	2.471	1.902	2.260	1.954	1.689	1.826
	BRT	**2.092**	**1.994**	**2.398**	**1.836**	**2.099**	**1.879**	**1.628**	**1.755**
	Rail	2.156	**2.069**	**2.465**	**1.897**	**2.254**	**1.949**	1.691	**1.822**
	Ferry	2.153	**2.069**	**2.464**	**1.897**	**2.254**	**1.949**	1.689	**1.822**
Downtown -Lower Water Street	BAU	1.998	1.892	2.313	1.751	2.089	1.784	1.529	1.661
	BRT	**1.935**	**1.813**	**2.241**	**1.687**	**1.929**	**1.711**	**1.466**	**1.591**
	Rail	2.001	**1.890**	**2.311**	**1.750**	**2.087**	**1.783**	1.532	**1.660**
	Ferry	2.004	**1.892**	**2.313**	**1.751**	2.090	1.785	1.534	**1.661**
Downtown -Citadel	BAU	2.339	2.253	2.655	2.033	2.442	2.107	1.834	1.966
	BRT	**2.282**	**2.176**	**2.586**	**1.972**	**2.279**	**2.037**	**1.776**	**1.898**
	Rail	2.351	2.260	2.663	2.038	2.450	2.113	1.844	1.971
	Ferry	2.348	2.255	2.657	2.034	2.444	2.109	1.841	1.967

Origin Zones		Larry Uteck	Kearney Lake Rd	Kearney Lake	Hamond Plains Rd	Bedfod West	Bedfod South	Mill Cove	Bedfod Core
Downtown Core	BAU	1.901	1.786	2.225	1.663	1.992	1.686	1.428	1.563
	BRT	**1.846**	**1.715**	**2.161**	**1.606**	**1.838**	**1.620**	**1.372**	**1.500**
	Rail	1.912	1.793	2.233	1.668	1.999	1.691	1.436	1.569
	Ferry	1.910	1.790	2.229	1.666	1.996	1.689	1.434	1.566
Downtown -Upper Water street	BAU	1.912	1.801	2.227	1.678	2.000	1.701	1.450	1.582
	BRT	**1.849**	**1.722**	**2.156**	**1.614**	**1.842**	**1.629**	**1.387**	**1.512**
	Rail	1.921	1.806	2.233	1.681	2.006	1.706	1.457	1.586
	Ferry	1.918	1.802	2.229	1.679	2.002	1.703	1.455	1.583
Downtown -Casino NS	BAU	1.971	1.843	2.278	1.709	2.046	1.737	1.490	1.607
	BRT	**1.921**	**1.775**	**2.215**	**1.654**	**1.895**	**1.674**	**1.440**	**1.553**
	Rail	1.972	**1.843**	**2.278**	**1.708**	**2.046**	**1.737**	**1.490**	**1.607**
	Ferry	1.975	**1.839**	**2.273**	**1.706**	**2.042**	**1.734**	1.492	**1.604**
Downtown -Cogswell	BAU	2.080	1.974	2.408	1.810	2.178	1.853	1.584	1.721
	BRT	**2.072**	**1.952**	**2.387**	**1.793**	**2.067**	**1.833**	**1.575**	**1.702**
	Rail	2.090	1.979	2.413	1.814	2.183	1.858	1.591	1.725
	Ferry	2.087	**1.970**	**2.403**	**1.807**	**2.174**	**1.850**	1.589	**1.718**
Downtown - North St	BAU	2.136	2.016	2.441	1.845	2.216	1.892	1.638	1.751
	BRT	2.142	**2.004**	**2.428**	**1.836**	**2.113**	**1.881**	1.642	**1.742**
	Rail	2.138	**2.016**	**2.441**	**1.844**	**2.216**	**1.892**	**1.639**	**1.751**
	Ferry	2.140	**2.011**	**2.436**	**1.842**	**2.211**	**1.889**	1.641	**1.748**

4.7 Evaluation based on GHG Emission

GHG emission analysis provides per capita emissions of downtown Halifax and Bedford area in AM peak and PM peak period for all the scenarios (Table 4-4). In Halifax, per capita emission is 1.692 kg at AM peak and 3.029 kg in PM peak. On the other hand, in Bedford, per capita emission is 1.002 kg at AM peak and 1.89 kg in PM peak. Results also show a decrease of per capita emission for BRT during all period, with the highest being 0.19% in PM peak at Halifax. For rail and ferry in Halifax, AM peak pollution increased slightly.

All other instances show a decrease of emission. In Bedford, AM peak rail per capita emission decreases the most which is 0.30%. For ferry its 0.26% during Halifax PM period.

Table 4-4 Per Capita GHG Emissions

	Per capita GHG Emissions (Kg)			
	BAU	BRT	Rail	Ferry
Halifax (AM Peak)	1.692	1.692	1.693	1.693
% Change from BAU		-0.03	0.01	0.03
Halifax (PM Peak)	3.029	3.023	3.022	3.021
% Change from BAU		-0.19	-0.23	-0.26
Bedford (AM Peak)	1.002	1.001	0.999	1.001
% Change from BAU		-0.09	-0.30	-0.11
Bedford (PM Peak)	1.895	1.893	1.892	1.893
% Change from BAU		-0.13	-0.17	-0.11

Comparing GHG emission reduction in Halifax and Bedford with the total network is shown in Figure 4-4. There is a very small increase in emission in total network but decrease in Halifax and Bedford except PM peak period in Halifax. This reflects that only one route might not have a significant impact on GHG emission but it may have the potential to decrease GHG emissions if the total network is of BRT or rail can be established.

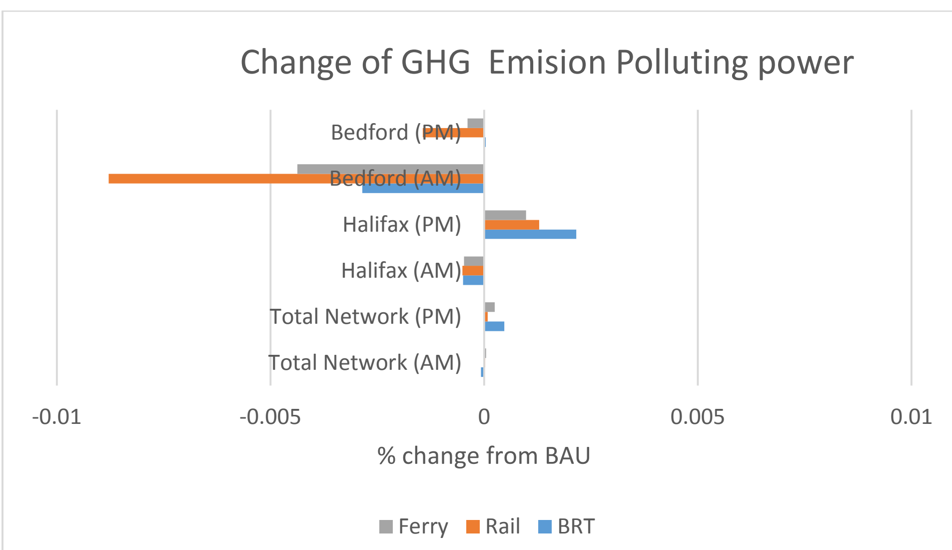


Figure 4-4 Change of GHG emissions

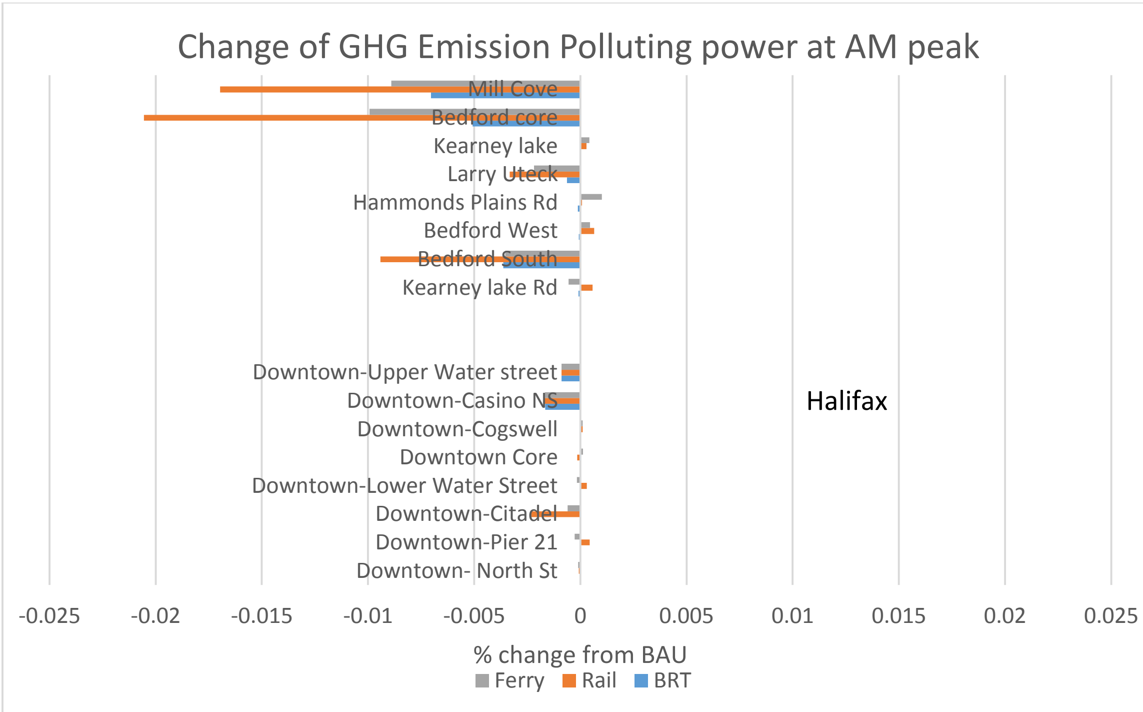


Figure 4-5 Change of AM peak GHG emissions polluting power

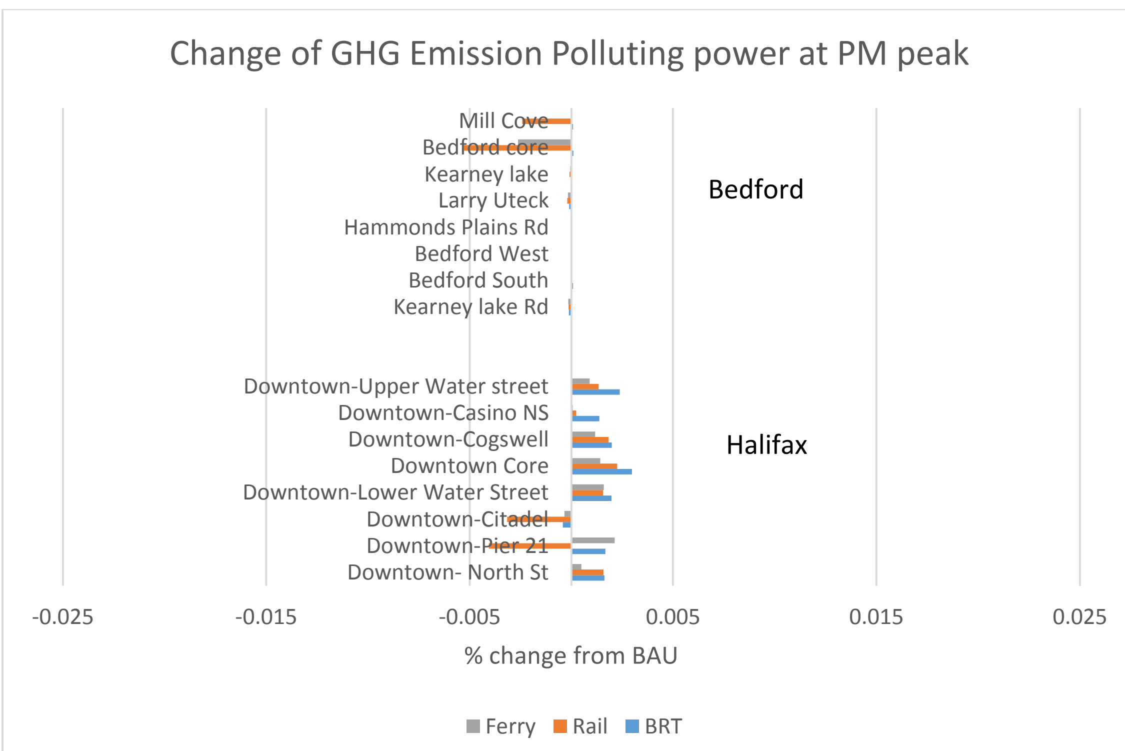


Figure 4-6 Change of PM peak GHG emissions polluting power

GHG emission polluting power in each zone of Halifax and Bedford during AM peak period is shown in Figure 4-5. It shows most of the zone is polluting power is decreasing in Halifax and Bedford zones. Figure 4-6 shows polluting power of PM peak period which reflects decrease of emission in Bedford zones but small increase of emissions in most Halifax zones. Emission experienced for all zones were also estimated (Appendix D-2) Though overall change in GHG emission is not significant reduction emission, but there may be potential of substantial emission reduction if a network of Rail of BRT can be established. This also states any of the transit infrastructure projects can help to reduce emissions. Further study is required in this regard to reach a definite conclusion.

4.8 Conclusion

This study evaluate three alternative transit infrastructure projects between Halifax-Bedford using transport network and emission modeling system. It is evident from the model results that rail showed better results in terms of modal shift from Auto. On the other hand, BRT has advantage in terms of reducing travel time. In the case of GHG emission reductions, BRT, ferry and rail have impacts on the local level, whereas overall GHG reduction is not that significant. It reflects that implementation of an infrastructure project in one route might not have a significant impact on GHG emissions but has potential to decrease GHG emissions if the total network of BRT or rail can be established. The findings of this study have important policy implications. This study sheds light on possible options to be prioritized by decision makers.

CHAPTER 5

CONCLUSION

5.1 Summary

The first objective of this study was to develop a 24 hour transportation network model for Halifax. A regional transportation network model was developed using four stage demand forecasting modeling framework with base year of 2011. Time of the day model was incorporated into it to have the 24 hour temporal variation. By using the observed growth, the model forecasted travel demand and other attributes of the transportation system in 2016 and 2021.

The model results provide trip production and attraction of each zone. Most of the trips are produced from suburban areas which is 51.67% of total trips, whereas rural and urban areas produce 25.10% and 23.23% respectively. On the other hand, 52.09% of total trips are attracted to urban areas and suburban and rural areas attract 34.76% and 13.14% respectively. It revealed that the modal share of Auto driver, Auto passenger, Transit, Walking and Biking are 65.88%, 12.08%, 12.81%, 7.46% and 1.77% respectively. It also developed hourly O-D matrix for 24 hours with all of those five modes. The model provides the temporal variation of travel time, traffic volume and speed of the network in 24 hours. Model results indicates that speed decrease on highway, arterial and major collector from 2011 to 2021 are 19.60%, 24.17% and 10.30% respectively. This indicates the necessity of putting more resources such as infrastructure investment on arterial roads in coming years to keep up the road network as functional as present. Corridor analysis was done on the five entry/exit points of Halifax peninsula which were Macdonald Bridge, McKay Bridge, Highway 102, Bedford highway and Herring Cove Road. This analysis found that Macdonald Bridge is having highest traffic volume and experiencing lowest speed among those corridors in morning peak periods. The study on travel times and speed along three different O-D pairs from suburban areas like Bedford West, Portland and Spry field to Halifax downtown concludes that travel time would increase by 39.56%, 51.74% and 31.58% respectively at afternoon peak period within those O-D pairs between 2011and 2021.

The second objective of this study was to estimate vehicular emission by using the modeling system. The scope of this is to characterize the emission in terms of who generates emission and who experiences highlighting urban-rural divide. Scenarios were created to forecast the impact of a potential modal shift from auto to transit and on GHG emissions. The results revealed that whereas Auto is 87.18% of total trips, it contributes 97.73% of GHG emissions. It reached the maximum during P.M. peak of 354.28 ton/hour. The impact of household and employment growth would increase annual per capita emissions from 3.09 in 2011 to 3.16 in 2016 and 3.41 in 2021 in Halifax. The impact of modal shift is found to decrease per capita emissions by 3.71% in 2016 and 3.81% in 2021 for a 5% shift from Auto to transit. This shift would decrease polluting power of urban areas 11.36% and 5.87% in suburban areas whereas the same in rural areas 3.79% in 2021. This shows modal shift from auto has more potential to emission reduction in urban and suburban areas. It can be concluded that more transit and active transportation options should be offered in urban and suburban areas by transportation planners to reduce emission contribution from Auto which would help rural areas also to experience less emission.

This research illustrates the findings of pollution generation and experienced in urban-rural Halifax Nova Scotia. The polluting power and pollution experienced map reveals that maximum emissions are generated and experienced at urban downtown areas which is 862.29 ton/km^2 and 118.89 ton/km^2 respectively. Overall urban areas generates 68% more emission than they are experienced whereas suburban and rural areas experience more emission than they generate. This implies that emissions generated by vehicles from urban areas are adding to the emission experienced in suburban and rural areas in Halifax. Emission forecasting reveals that between 2011 and 2021 Pollution experienced is expected to increase 13.54% in urban , 11.67% in suburban areas and only 1.51% in rural areas. Polluting power is predicted to increase 25.10% in urban, 15.83% in suburban and only 0.02% in rural areas during the same period. This indicates urban and suburban areas are expected to experience much higher emission increase than in rural areas. Emission forecasting also shows that polluting power at suburban areas are expected to generate highest increase which is 16.40% in 2016 and 44.73% in 2021 from the base year 2011. This indicates emission per unit area in suburban area would increase at a higher rate than urban and rural in future.

The third objective of this study was to evaluate alternative transit infrastructure projects in Halifax. It evaluates three alternative transportation options which were BRT, rail and ferry in the Bedford-Halifax corridor. In this study transit ridership and different network performance indicators were used for performance evaluation. Greenhouse gas (GHG) emissions were also considered for the purpose of investigation.

The evaluation of results found that rail showed better results in terms of modal shift from auto which is a maximum of 5.49% modal shift from auto to transit in PM peak period. Whereas BRT has advantage in terms of reducing travel time. 62 out of 64 O-D pair would experience decrease of transit travel time in case of BRT. For GHG emission reductions, BRT, ferry and rail have impacts on the local level, but overall GHG reduction is not significant. It implies that implementation of an infrastructure project in one route might not have a significant impact on GHG emissions but if the total network of BRT or rail can be established that may have potential to decrease GHG emissions substantially.

5.2 Research Contributions

The study has following research contributions:

- ❖ This study contributes by developing a 24 hour transportation network model for Halifax. 24-hour network model is limited in the existing literature. The model evaluate the impact of a policy scenario of modal shift towards transit.
- ❖ Transportation network and emission modeling system is used in this study to estimating emission polluting power and pollution experienced for urban, suburban and rural areas. The study addresses the literature gap by describing the relative contribution of urban, suburban areas rural in generating and experiencing emissions.

❖ This study evaluates three alternative transit infrastructure projects. A unique feature of this evaluation is the use of Stated Preference survey to create future origin-destination matrix. The scenarios thus reflect alternative futures, with the interaction of external conditions and as a result of choices.

5.3 Practical Implications of findings

The study results and findings have practical implications. Some of them are discussed in the following.

- Auto is 87.18% of total trips but it contributes 97.73% of GHG emissions. Therefore any modal shift from Auto to transit or active transportation would reduce emission.
- From 2011 to 2021, that travel time would increase by maximum 51.74% at afternoon peak period from Halifax downtown to suburban areas. Transportation demand management measures need to be implemented in afternoon peak period to ensure stable network performance from Halifax Downtown to suburban areas.
- The study identified that on arterial roads speed would decrease the maximum which is 24.17% from 2011 to 2021. So it is a necessity of putting more resources such as infrastructure investment on arterial roads in coming years to keep up the road network as functional as present.
- The study result suggested that a 5% modal shift from auto to transit would decrease polluting power of urban areas 11.36% and 5.87% in suburban areas

whereas the same in rural areas 3.79% in 2021. More transit and active transportation options should be offered in urban and suburban areas by transportation planners to reduce emission contribution from Auto.

- An interesting finding of the study is that urban areas are generating 68% more emission they generate. On the other hand, suburban and rural areas experiencing emission generated by urban areas. Hence, investment of emission reduction on urban areas would help rural areas also to experience less emission.
- Implementation of an infrastructure project in one route would not have a significant impact on GHG emissions, which can be achieved by establishing network of BRT or rail.

5.4 Limitations and Future Work

The transportation network model developed in this study is a four stage trip based model. Activity-based models could replicate actual traveler decisions and may provide forecasts of future travel patterns. Incorporation of an activity based model into the current transport network can improve the model output. Moreover the typical daily 24 hour model can be upgraded to weekly model considering the weekly variation of travel behavior.

This study focused on emission from passenger transportation. Future work should include freight transportation to present the complete picture of emission from road transportation. In this study, emission was estimated by using emission factors. Emission modeling software platforms such as MOVES offer the opportunity to estimate emissions of a wide range of transportation related air pollutants for different vehicle types considering various vehicle model years, fuel types, meteorology, and road types. Adoption of MOVES platform can offer extensive emission analysis. An emission dispersion model can also be used to measure the intensity of pollutants.

The study area has exogenous land use characteristics. Land use models can predict future changes in land use, socioeconomic and demographic data based on economic theories and social behaviors. Use of a land use model to predict population growth, residential location choice, vehicle ownership etc. under the current modeling framework would be an improvement of the transportation network model.

Finally future work include development of an integrated Transportation, Land-use and Energy (iTLE) model which can simultaneously predict spatial distribution of population and travel patterns.

Nevertheless, this thesis work developed a 24 hour regional transportation network and emission modeling system for Halifax which provides emission estimation and transit infrastructure projects evaluation. The transportation network model developed in this study is the first step towards the integration of the models developed in DalTRAC towards Halifax integrated Transportation, Land-use and Energy (iTLE) model.

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APPENDIX A

Appendix A-1 Traffic Analysis Zone Summary

	Location	Total Number of Zones	Zone Number	TAZ group
Urban core	Halifax Core (South End)	11	1-11	U-1
	Halifax Core (Citadel-Downtown)	14	12-16, 25-33	U-2
	Halifax Core (University-Residential)	8	17-24	U-3
	Halifax Core (Chebucto)	11	34-44	U-4
	Halifax Core (North End)	13	45-57	U-5
	Dartmouth Core (Dartmouth North)	18	58-64,78-88	U-6
	Dartmouth Core (Dartmouth South)	16	65-77, 89-91	U-7
	Total Urban	**91**		
Suburban	Halifax (Arm dale)	9	92-98,103-104	S-1
	Halifax (Fairview Clayton park)	15	99-102,105-115	S-2
	St Margaret's Bay	3	116-118	S-3
	Bedford Core	10	119-121, 128-134	S-4
	Bedford	6	122-127	S-5
	Sackville	12	135-146	S-6
	Dartmouth North	15	147-161	S-7
	Dartmouth South	9	162-170	S-8
	Cole Harbor Eastern Passage	12	171-182	S-9
	Total Suburban	**91**		
Rural	Prospect	5	183-187	R-1
	St. Margaret's Bay	5	188-192	R-2
	Sackville	11	193-203	R-3
	Waverley-fall River	3	204-206	R-4
	Porter's Lake-Lawraencetown	6	207-212	R-5
	Musquo-doboit Harbour	4	213-216	R-6
	Sheet Harbour	3	217-219	R-7
	Total Rural	**37**		
Total		**219**		

Appendix A-2 Demographic and Socio Economic Characteristics of TAZ

TAZ Group	*Pop. (2011)	*Pop. (2006)	Area (km^2)	No. of *HH	*Pop. density (pop./km^2)	*Avg. *HH size	*Empl. rate per HH	*Avg. *Ind. Income
U-1	12902	11914	4.10	6741	3145.81	1.91	0.59	$56,463
U-2	11492	10979	3.14	6490	3659.87	1.77	0.61	$41,221
U-3	12744	12674	2.97	5511	4295.44	2.31	0.63	$44,268
U-4	13947	13404	3.89	6783	3581.18	2.06	0.60	$35,954
U-5	11413	11251	4.72	5550	2418.01	2.06	0.58	$37,237
U-6	12407	12694	7.53	6509	1648.55	1.91	0.59	$35,771
U-7	14138	14164	7.06	6935	2001.41	2.04	0.57	$35,546
Urban	**89042**	**87080**	**33.41**	**44520**	**2664.93**	**2.00**	**0.60**	**$40,869**
S-1	24892	24371	49.64	10969	501.46	2.27	0.55	$38,777
S-2	40270	37823	19.76	18776	2037.97	2.14	0.58	$36,925
S-3	6820	6747	25.79	2490	264.44	2.74	0.61	$40,930
S-4	20836	16759	15.55	8733	1340.10	2.39	0.58	$49,776
S-5	3113	2776	31.97	977	97.36	3.19	0.52	$51,956
S-6	27840	27650	24.21	10590	1149.94	2.63	0.59	$36,505
S-7	23124	23322	41.74	10115	553.96	2.29	0.58	$40,355
S-8	24516	24456	15.76	9642	1555.78	2.54	0.57	$38,491
S-9	29014	26738	37.48	10738	774.04	2.70	0.57	$43,480
Suburban	**200426**	**190643**	**261.90**	**83030**	**765.27**	**2.41**	**0.58**	**$40,339**
R-1	15229	14846	401.74	5861	37.91	2.60	0.58	$38,579
R-2	11101	9978	389.75	4225	28.48	2.63	0.53	$47,312
R-3	34460	30345	352.25	11778	97.83	2.93	0.58	$48,120
R-4	5561	5431	83.82	2130	66.34	2.61	0.59	$44,769
R-5	19142	18437	807.24	7105	23.71	2.69	0.58	$39,742
R-6	11869	12148	1384.96	4891	8.57	2.43	0.53	$34,132
R-7	3478	3936	1749.11	1681	1.99	2.07	0.50	$29,218
Rural	**100840**	**95121**	**5168.87**	**37670**	**19.51**	**2.68**	0.57	$42,517
Total	**390309**	**372844**	**5464.19**	**165220**	**71.43**	**2.36**	**0.58**	**$41,022**

*Pop.=Population , *HH=Household, *Avg.=Average, *Empl.=Employment *Ind.=Individual

Appendix A-3 Hourly and Trip Purpose factor

Time of the day	Hourly factor		Trip Purpose factor		
	Home To Work	Work to Home	HBW	HBO	NHB
12:00 AM	0.002433090	0.01734104	0.076190476	0.032019079	0.071371900
1:00 AM	0.002433090	0.000000000	0.019047619	0.044826710	0.012976709
2:00 AM	0.002433090	0.000000000	0.009523810	0.012807631	0.012976709
3:00 AM	0.009732360	0.002890173	0.047619048	0.003201908	0.000000000
4:00 AM	0.024330900	0.008670520	0.123809524	0.016009539	0.012976709
5:00 AM	0.060827251	0.002890173	0.247619048	0.035220987	0.000000000
6:00 AM	0.184914842	0.005780347	0.752380952	0.076845789	0.032441773
7:00 AM	0.272506083	0.020231214	1.285714286	0.147287762	0.045418482
8:00 AM	0.184914842	0.011560694	1.000000000	0.336200326	0.227092409
9:00 AM	0.055961071	0.017341040	0.352380952	0.275364076	0.363347855
10:00 AM	0.024330900	0.011560694	0.161904762	0.304181247	0.356859500
11:00 AM	0.014598540	0.031791908	0.209523810	0.345806049	0.408766337
12:00 PM	0.026763990	0.054913295	0.314285714	0.342604141	0.557998491
1:00 PM	0.021897810	0.028901734	0.209523810	0.432257562	0.551510137
2:00 PM	0.017031630	0.054913295	0.314285714	0.400238483	0.428231400
3:00 PM	0.03163017	0.101156069	0.676190476	0.403440391	0.480138237
4:00 PM	0.01703163	0.187861272	0.733333333	0.470680456	0.655323810
5:00 PM	0.01216545	0.193641618	0.733333333	0.406642299	0.415254691
6:00 PM	0.01459854	0.072254335	0.314285714	0.496295719	0.395789628
7:00 PM	0.00486618	0.040462428	0.161904762	0.438661377	0.304952664
8:00 PM	0.00243309	0.066473988	0.266666667	0.352209865	0.259534182
9:00 PM	0.00243309	0.023121387	0.095238095	0.262556445	0.201138991
10:00 PM	0.00486618	0.028901734	0.114285714	0.176104933	0.064883545
11:00 PM	0.00486618	0.01734104	0.076190476	0.086451512	0.038930127

Appendix A-4 Travel time Regression model for modal split

	Auto Driver		Auto Passenger		Transit		Bike		Walk	
Variable	Parameter	T-stat	Parameter	T-stat	Parameter	T-stat	Parameter	T-stat	Parameter	T-stat
Constant	22.87	8.45	24.03	8.93	24.3	1.25	4.75	.51	-31.5	-2.83
Distance (KM)	.5645	11.65	.5292	11.34	.737	4.18	1.844	2.7	6.963	7.86
Suburban	-8.36	-3.61	-8.16	-3.55	14.1	.81				
Urban	-11.57	-3.93	-10.47	-2.93	16.8	.91	-1.22	-.4	14.68	2.42
Distance< 5km	-5.35	-2.02	2.20	.52	-17.78	-2.34	4.12	.56	21.64	3.31
Distance5 kmto10km	-.40	-.20	1.01	.48	-8.10	-1.14	4.94	1		
R-Sq (adj)	.7408		.6856		.5669		.5107		.5651	

APPENDIX B

Appendix B-1 : Sample Traffic Assignement Model run in EMME/4

Licence EF87: FAP-DU...none Dalhousie University
Database Title: HRM
Scen. 1(--- A-): Auto Run 9 am
1. U T I L I T I E S
2. N E T W O R K E D I T O R
3. M A T R I X E D I T O R
3.01 Input / modify / output zone groups
3.11 Input matrices using batch entry
3.12 Input / modify matrices interactively
3.13 Plot matrices
3.14 Output matrices
3.16 Plot histogram of matrices
3.21 Matrix calculations
3.22 Matrix balancing
3.23 Triple-index operations
4. F U N C T I O N E D I T O R
5. A S S I G N M E N T P R O C E D U R E S
6. R E S U L T S
9. E N D O F S E S S I O N
Enter: Next module=5.11

Fri Aug 12 03:14:07 20165.11 PREPARE SCENARIO 1 FOR STANDARD TRAFFIC OR TRANSIT ASSIGNMENT

Scenario 1 currently contains:
Standard traffic assignment with fixed demand (5 iterations)

Select: Type of assignment
1= fixed demand traffic assignment
2= fixed demand transit assignment
3= variable demand traffic assignment
4= end
1

A standard traffic assignment has already been performed:
Demand: mf01 : trDist 910am auto OD
Travel times: mf06 : TT910 Traveltime9am10amAuto
Stopping criteria: iter= 100 bgap= 0.1000 %
rgap= 0.0000 ngap= 0.0500
Number of iterations: 5 stopped by: bgap

Select: 1= more iterations on old assignment
2= new assignment
2

Select: 1= single class assignment on auto mode
2= single class assignment with generalized cost
3= multiclass assignment
4= multiclass assignment with generalized cost
5= generalized cost multiclass assignment with class specific volumes
6= generalized cost multiclass assignment with path analysis
1

Select: Source for additional volumes
1= no additional volumes
2= auto equivalent of transit vehicles
3= user data on links and turns
4= transit vehicles and user data
5= assign additional demand (additional options assignment)
1

Demand in persons
Enter: Matrix=mf1
mf01 trDist 910am auto OD (16-05-08 17:30:53)

Vehicle occupancy in persons/veh (optional)
Enter: Matrix=

Additional demand in auto equivalents (optional)
Enter: Matrix=

Matrix to hold travel times (optional)
Enter: Matrix(mf)= mf6
mf06 TT910 Traveltime9am10amAuto (16-05-09 21:55:13)
Change header information?no

Enter: Max. number of iterations (100)=
Enter: Stopping criterion for best relative gap (0.1000 %) [, relative gap (0)]=
Enter: Stopping criterion for normalized gap (excess avg time)
(0.0500 min)=

Fri Aug 12 03:14:32 2016Licence EF87: FAP-DU...none Dalhousie University
Database Title: HRM
Scen. 1(--- R-): Auto Run 9 am
1. U T I L I T I E S
2. N E T W O R K E D I T O R
3. M A T R I X E D I T O R

4. F U N C T I O N E D I T O R
5. A S S I G N M E N T P R O C E D U R E S
5.11 Prepare for standard traffic or transit assignment
5.21 Standard traffic assignment
5.22 Standard traffic assignment (parallel)
5.23 SOLA traffic assignment
5.25 Path-based traffic assignment
5.31 Standard transit assignment
5.32 Extended transit assignment
5.33 Extended transit assignment (parallel)
5.34 Prepare access/egress nodes for individual transit trips
5.35 Analyze / assign individual transit trips
5.36 Deterministic transit assignment
6. R E S U L T S
9. E N D O F S E S S I O N
Enter: Next module=5.21

Fri Aug 12 03:14:37 20165.21 STANDARD TRAFFIC ASSIGNMENT

Select: List device
    1= Terminal
    2= Printer
     1

Fri Aug 12 03:14:39 2016Emme Module: 5.21 Date: 16-08-12 03:14 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Auto Run 9 am
Matrix mf01 trDist 910am auto OD

STANDARD TRAFFIC ASSIGNMENT
****

Scenario: 1: Auto Run 9 am
Network size: 219 centroids 2249 reg. nodes
    5211 road links 0 turn entries

Demand: mf01 : trDist 910am auto OD
Travel time: mf06 : TT910 Traveltime9am10amAuto

Stopping criteria: iter= 100 bgap= 0.1000 %
    rgap= 0.0000 ngap= 0.0500

-------------------------------- Iteration   0 --------------------------------

Number of trips: Total persons: 33810.00
Total automobiles: 33810.00   Additional veh.:   0.00
Total vehicles: 33810.00   Not assigned: 1161.00

Obj. function: Initial value: 0.460984E+09

CPU time: Subproblem: 0.1 (0.1)   Steplength: 0.0 (0.0)
Update: 0.0 (0.0)   Total: 0.1 (0.1)

-------------------------------- Iteration   1 --------------------------------

Number of trips: Total persons: 33810.00
Total automobiles: 33810.00   Additional veh.:   0.00
Total vehicles: 33810.00   Not assigned: 1161.00

-->

Fri Aug 12 03:14:40 2016Emme   Module: 5.21   Date: 16-08-12 03:14   User: EF87/FAP-DU...none
Database Title: HRM
Scenario   1: Auto Run 9 am
Matrix   mf01   trDist   910am auto OD

Search for lambda:L= 0.000000 0.062500 0.125000 0.250000 0.500000 1.000000
G=-.656E+07-0.403E+07-0.182E+07 0.185E+07 0.761E+07 0.245E+08
Appr. optimal lambda:0.182727   Estimated error: 0.000524

Avg trip times: Currently on network:14604.04   On shortest paths: 14403.11

Vol. difference: Average per link: 0.62   Avg absolute diff: 14.63
Minimum difference: -650.87   (on link   427   431)
Maximum difference: 549.46   (on link   407   603)

Obj. function: Absolute gap: 6560250.6880   Normalized gap: 200.932663
Relative gap: 0.01375870
New lower bound: 0.454424E+09   Best lower bound:0.454424E+09
Current value: 0.460422E+09   Best relative gap: 1.3027 %

CPU time: Subproblem: 0.1 (0.2)   Steplength: 0.0 (0.0)
Update: 0.0 (0.0)   Total: 0.5 (0.6)

-------------------------------- Iteration   2 --------------------------------

Number of trips: Total persons: 33810.00
Total automobiles: 33810.00 Additional veh.: 0.00
Total vehicles: 33810.00 Not assigned: 1161.00

Search for lambda:L= 0.000000 0.049280 0.098561 0.197121 0.394242 0.788484
G=-.165E+07-0.145E+07-0.127E+07-0.953E+06-0.422E+06 0.495E+06
Appr. optimal lambda:0.565649 Estimated error: 0.010645

Avg trip times: Currently on network:14373.24 On shortest paths: 14322.72

-->

Fri Aug 12 03:14:41 2016Emme Module: 5.21 Date: 16-08-12 03:14 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Auto Run 9 am
Matrix mf01 trDist 910am auto OD

Vol. difference: Average per link: -1.66 Avg absolute diff: 15.40
Minimum difference: -1186.24 (on link 585 584)
Maximum difference: 1118.39 (on link 562 547)

Obj. function: Absolute gap: 1649309.3460 Normalized gap: 50.516380
Relative gap: 0.00351461
New lower bound: 0.458773E+09 Best lower bound:0.458773E+09
Current value: 0.459997E+09 Best relative gap: .2662 %

CPU time: Subproblem: 0.1 (0.4) Steplength: 0.0 (0.0)
Update: 0.0 (0.0) Total: 0.5 (1.1)

-------------------------------- Iteration 3 --------------------------------

Number of trips: Total persons: 33810.00
Total automobiles: 33810.00 Additional veh.: 0.00
Total vehicles: 33810.00 Not assigned: 1161.00

Search for lambda:L= 0.000000 0.056422 0.112844 0.225689 0.451378 0.902755
G=-.945E+06-0.823E+06-0.708E+06-0.495E+06-0.660E+05 0.141E+07
Appr. optimal lambda:0.478713 Estimated error: 0.003647

Avg trip times: Currently on network:14277.63 On shortest paths: 14248.69

Vol. difference: Average per link: 1.37 Avg absolute diff: 11.72
Minimum difference: -829.72 (on link 2199 794)

```
            Maximum difference:   1137.83   (on link        2206    796)

Obj. function:    Absolute gap:     944821.2462   Normalized gap:     28.938749
            Relative gap:      0.00202686
            New lower bound: 0.459052E+09   Best lower bound:0.459052E+09
            Current value:   0.459771E+09   Best relative gap:    .1563 %

-->


Fri Aug 12 03:14:41 2016Emme   Module:  5.21      Date: 16-08-12 03:14      User: EF87/FAP-
DU...none
Database Title: HRM
Scenario    1:  Auto Run 9 am
Matrix   mf01   trDist        910am auto OD
----------------------------------------------------------------------------------------------



CPU time:        Subproblem:    0.0 (     0.4)   Steplength:    0.0 (     0.0)
            Update:       0.0 (     0.0)   Total:        0.4 (     1.5)

------------------------------- Iteration   4 -------------------------------

Number of trips:  Total persons:       33810.00
            Total automobiles:   33810.00   Additional veh.:        0.00
            Total vehicles:      33810.00   Not assigned:        1161.00

Search for lambda:L= 0.000000  0.057561  0.115122  0.230245  0.460489  0.920979
            G=-.594E+06-0.565E+06-0.536E+06-0.483E+06-0.377E+06-0.896E+05
            Appr. optimal lambda:1.000000   Estimated error:     0.029219

Avg trip times:   Currently on network:14287.86   On shortest paths:   14269.66

Vol. difference:  Average per link:       -1.34   Avg absolute diff:      18.39
            Minimum difference:  -1477.98   (on link        2206    796)
            Maximum difference:   1141.79   (on link         533    544)

Obj. function:    Absolute gap:     594085.0625   Normalized gap:     18.196117
            Relative gap:      0.00127354
            New lower bound: 0.459177E+09   Best lower bound:0.459177E+09
            Current value:   0.459430E+09   Best relative gap:    .0551 %

CPU time:        Subproblem:    0.1 (     0.5)   Steplength:    0.0 (     0.0)
            Update:       0.0 (     0.0)   Total:        0.1 (     1.6)

-->
```

Fri Aug 12 03:14:41 2016Emme Module: 5.21 Date: 16-08-12 03:14 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Auto Run 9 am
Matrix mf01 trDist 910am auto OD

-------------------------------- Iteration 5 --------------------------------

Number of trips: Total persons: 33810.00
Total automobiles: 33810.00 Additional veh.: 0.00
Total vehicles: 33810.00 Not assigned: 1161.00

Search for lambda:L= 0.000000 0.062500 0.125000 0.250000 0.500000 1.000000
G=-.453E+06-0.284E+06-0.139E+06 0.913E+05 0.421E+06 0.142E+07
Appr. optimal lambda:0.197522 Estimated error: -0.001777

Avg trip times: Currently on network:14272.40 On shortest paths: 14258.52

Vol. difference: Average per link: 0.62 Avg absolute diff: 4.35
Minimum difference: -383.59 (on link 2199 794)
Maximum difference: 525.21 (on link 2206 796)

Obj. function: Absolute gap: 453004.2993 Normalized gap: 13.874983
Relative gap: 0.00097215
New lower bound: 0.458977E+09 Best lower bound:0.459177E+09
Current value: 0.459389E+09 Best relative gap: .0462 %

CPU time: Subproblem: 0.4 (0.9) Steplength: 0.0 (0.0)
Update: 0.0 (0.0) Total: 0.4 (2.0)

--------------------------- Stopping criterion: Best Relative Gap -------------

-->

Appendix B-2 : Sample Transit Assignement Model run in EMME/4

Licence EF87: FAP-DU...none Dalhousie University
Database Title: HRM
Scen. 1(--- -A): Transit Run 10am-2pm
1. U T I L I T I E S
2. N E T W O R K E D I T O R
3. M A T R I X E D I T O R
3.01 Input / modify / output zone groups
3.11 Input matrices using batch entry
3.12 Input / modify matrices interactively
3.13 Plot matrices
3.14 Output matrices
3.16 Plot histogram of matrices
3.21 Matrix calculations
3.22 Matrix balancing
3.23 Triple-index operations
4. F U N C T I O N E D I T O R
5. A S S I G N M E N T P R O C E D U R E S
6. R E S U L T S
9. E N D O F S E S S I O N
Enter: Next module=5.21

Fri Aug 12 03:20:07 20165.21 STANDARD TRAFFIC ASSIGNMENT

Scenario 1 not ready for standard traffic assignment!

Fri Aug 12 03:20:08 2016Licence EF87: FAP-DU...none Dalhousie University
Database Title: HRM
Scen. 1(--- -A): Transit Run 10am-2pm
1. U T I L I T I E S
2. N E T W O R K E D I T O R
3. M A T R I X E D I T O R
4. F U N C T I O N E D I T O R
5. A S S I G N M E N T P R O C E D U R E S
5.11 Prepare for standard traffic or transit assignment
5.21 Standard traffic assignment
5.22 Standard traffic assignment (parallel)
5.23 SOLA traffic assignment
5.25 Path-based traffic assignment

5.31 Standard transit assignment
5.32 Extended transit assignment
5.33 Extended transit assignment (parallel)
5.34 Prepare access/egress nodes for individual transit trips
5.35 Analyze / assign individual transit trips
5.36 Deterministic transit assignment
6. R E S U L T S
9. E N D O F S E S S I O N
Enter: Next module=5.11

Fri Aug 12 03:20:13 20165.11 PREPARE SCENARIO 1 FOR STANDARD TRAFFIC OR TRANSIT ASSIGNMENT

Scenario 1 currently contains:
    Standard transit assignment

Select: Type of assignment
    1= fixed demand traffic assignment
    2= fixed demand transit assignment
    3= variable demand traffic assignment
    4= end
    2

A transit assignment has already been performed:
Standard transit assignment: 16-06-14 17:07
Transit demand: mf02 : Tran2 10am-2pm Tansit OD
Transit times: mf06 : tt Transit travel time
Invehicle times: mf07 : invt In vehicle time
Aux. transit times: mf08 : auxtt aux. transit time
Total waiting times: mf09 : Twt total waiting time
Number of boardings: mf10 : Board Number of Boarding
Active modes: bc Subset for trip components: b
Boarding time: 2.50 Wait time factor: .50
Weight factors: wait= 2.00 aux= 2.00 board= 2.00
Spread factor: 1.00

Select: 1= assign more demand on existing transit volumes
    2= new assignment
    2

Transit demand matrix
Enter: Matrix=mf2
mf02 Tran2 10am-2pm Tansit OD (16-06-11 16:06:14)

Matrix to hold transit times (optional)
Enter: Matrix=mf6
mf06 tt Transit travel time (16-06-14 17:07:56)

Change header information?no

Matrix to hold in-vehicle times (optional)
Enter: Matrix=mf7
mf07 invt In vehicle time (16-06-14 17:07:56)
Change header information?no

Matrix to hold auxiliary transit times (optional)
Enter: Matrix=mf8
mf08 auxtt aux. transit time (16-06-14 17:07:56)
Change header information?no

Matrix to hold total waiting times (optional)
Enter: Matrix=mf9
mf09 Twt total waiting time (16-06-14 17:07:56)
Change header information?no

Matrix to hold first waiting times (optional)
Enter: Matrix=

Matrix to hold boarding times (optional)
Enter: Matrix=

Matrix to hold average number of boardings (optional)
Enter: Matrix=mf10
mf10 Board Number of Boarding (16-06-14 17:07:56)
Change header information?no

Active transit and aux. transit modes for assignment

Enter: Mode(s)=bc

Compute auxiliary transit time, in-vehicle time and number of boardings
on a subset of active modes only?y

Modes to be included in trip component matrices

Enter: Mode(s)=b

Select: Source for effective headways
1= actual line headways
2= actual line headways with maximum
3= user defined line attribute
4= user defined segment attribute
1

Select: Source for boarding times
1= same value for entire network

2= node specific boarding times
3= line specific boarding times
4= node and line specific boarding times
1
Enter: Boarding time (mins)=2.5

Select: Source for wait time factors
1= same value for entire network
2= node specific wait time factors
1
Enter: Wait time factor=.5

Enter: Wait time weight [, spread factor]=2

Enter: Auxiliary transit time weight=2

Enter: Boarding time weight=2

Perform additional options assignment?no

Fri Aug 12 03:22:12 2016Licence EF87: FAP-DU...none Dalhousie University
Database Title: HRM
Scen. 1(--- -R): Transit Run 10am-2pm
1. U T I L I T I E S
2. N E T W O R K E D I T O R
3. M A T R I X E D I T O R
4. F U N C T I O N E D I T O R
5. A S S I G N M E N T P R O C E D U R E S
5.11 Prepare for standard traffic or transit assignment
5.21 Standard traffic assignment
5.22 Standard traffic assignment (parallel)
5.23 SOLA traffic assignment
5.25 Path-based traffic assignment
5.31 Standard transit assignment
5.32 Extended transit assignment
5.33 Extended transit assignment (parallel)
5.34 Prepare access/egress nodes for individual transit trips
5.35 Analyze / assign individual transit trips
5.36 Deterministic transit assignment
6. R E S U L T S
9. E N D O F S E S S I O N
Enter: Next module=5.31

Fri Aug 12 03:22:23 20165.31 STANDARD TRANSIT ASSIGNMENT

Select: List device
1= Terminal
2= Printer
1

Fri Aug 12 03:22:25 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 10am-2pm Tansit OD

STANDARD TRANSIT ASSIGNMENT
****

Scenario: 1
Transit demand: mf02 : Tran2 10am-2pm Tansit OD
Transit times: mf06 : tt Transit travel time
Invehicle times: mf07 : invt In vehicle time
Aux. transit times: mf08 : auxtt aux. transit time
Total waiting times: mf09 : Twt total waiting time
Number of boardings: mf10 : Board Number of Boarding
Effective headways: Actual line headways
Boarding time: 2.50 min
Wait time factor: 0.50
Wait time weight: 2.00
Spread factor: 1.00
Aux. transit time weight: 2.00
Boarding time weight: 2.00
Maximum segment time: 12295.3 min (resolution 0.10 used)

Truncated transit times (3276.70) will be used for 22 line segments!
Auxiliary transit mode: c 740 links, speed: 5.00 km/hr (not in aux. tr. time matrix)
Transit mode: b 96 lines 6089 segments

-->

Fri Aug 12 03:22:26 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 /c 10am-2pm Tansit OD

```
destin    total   assigned intrazonal not ass.   aux.tr.   total  lines     pass.    mean     cpu
 zone    demand    demand    demand    demand     only    board.  /pass.    hours    time    time

   67    68.00    59.00    0.00    9.00    0.00    96.00   1.63  27181.1227641.82   0.00
   73   102.00    88.00    0.00   14.00    0.00   216.67   2.46  36335.5224774.22   0.00
   74     2.00     0.00    0.00    2.00    0.00     0.00   0.00     0.00   0.00   0.00
   78     2.00     2.00    0.00    0.00    2.00     0.00   0.00   2543.0076290.10   0.00
   81   234.00   202.00    0.00   32.00    2.00   434.87   2.15 120277.9735726.13   0.00
   83   126.00   117.00    0.00    9.00    0.00   267.00   2.28  55587.7028506.51   0.00
   84   119.00   104.00    0.00   15.00    0.00   205.67   1.98  49399.6528499.80   0.00
   86   100.00    88.00    0.00   12.00    0.00   227.00   2.58  43093.0129381.60   0.00
   94    62.00    62.00    0.00    0.00   24.00   146.00   2.35  13044.5112623.72   0.00
   97   100.00   100.00    0.00    0.00   23.00   174.33   1.74  19905.0411943.02   0.00
   98    86.00    86.00    0.00    0.00    4.00   161.67   1.88  22711.4615845.21   0.00
   99    14.00    14.00    0.00    0.00    4.00    12.00   0.86   2976.0912754.67   0.00
  137    71.00    71.00    0.00    0.00    0.00   340.11   4.79  58857.9649739.12   0.00
  139   131.00   124.00    0.00    7.00    0.00   719.67   5.80 108398.2452450.76   0.00
  143   434.00   389.00    0.00   45.00    0.00   964.14   2.48 196974.3230381.64   0.00
  153     4.00     0.00    0.00    4.00    0.00     0.00   0.00     0.00   0.00   0.00
  156    24.00     0.00    0.00   24.00    0.00     0.00   0.00     0.00   0.00   0.00
  157   310.00   262.00    0.00   48.00    0.00   993.23   3.79 237394.7154365.20   0.00
  166   371.00   339.00    0.00   32.00    0.00  1658.02   4.89 258799.0545805.14   0.00
  217   162.00   156.00    0.00    6.00    0.00   461.17   2.96  79456.3830560.15   0.00
  241    61.00    61.00    0.00    0.00    0.00   137.00   2.25  22774.2322400.88   0.00
  244    80.00    77.00    0.00    3.00    0.00   191.00   2.48  26025.5320279.63   0.00
  245    42.00     0.00    0.00   42.00    0.00     0.00   0.00     0.00   0.00   0.00
  308    84.00    82.00    0.00    2.00   13.00   256.17   3.12  23276.6217031.67   0.00
  327    53.00    53.00    0.00    0.00    0.00    77.00   1.45  17837.8320193.77   0.00
  330   731.00   595.00    0.00  136.00    0.00  1622.46   2.73 310396.2531300.46   0.00

-->


Fri Aug 12 03:22:27 2016Emme   Module:  5.31      Date: 16-08-12 03:22      User: EF87/FAP-
DU...none
Database Title: HRM
Scenario    1:  Transit Run 10am-2pm
Matrix   mf02   Tran2    /c    10am-2pm Tansit OD
------------------------------------------------------------------------------------------------


destin    total   assigned intrazonal not ass.   aux.tr.   total  lines     pass.    mean     cpu
 zone    demand    demand    demand    demand     only    board.  /pass.    hours    time    time
```

331	46.00	46.00	0.00	0.00	0.00	125.21	2.72	10042.04	13098.31	0.00
425	95.00	93.00	0.00	2.00	0.00	231.00	2.48	18552.12	11969.11	0.00
434	119.00	112.00	0.00	7.00	9.00	229.70	2.05	31456.14	16851.51	0.00
435	93.00	88.00	0.00	5.00	28.00	130.39	1.48	24570.14	16752.37	0.00
436	46.00	36.00	0.00	10.00	0.00	77.69	2.16	8584.31	14307.18	0.00
492	380.00	340.00	0.00	40.00	0.00	1132.49	3.33	154578.42	27278.55	0.00
514	54.00	54.00	0.00	0.00	6.00	108.98	2.02	13730.89	15256.54	0.00
528	274.00	209.00	0.00	65.00	0.00	508.01	2.43	62332.82	17894.59	0.00
536	88.00	80.00	0.00	8.00	17.00	171.17	2.14	23078.57	17308.93	0.00
537	96.00	84.00	0.00	12.00	0.00	200.33	2.38	22277.69	15912.63	0.00
543	55.00	52.00	0.00	3.00	0.00	115.00	2.21	14726.23	16991.80	0.00
545	218.00	0.00	0.00	218.00	0.00	0.00	0.00	0.00	0.00	0.00
554	208.00	187.00	0.00	21.00	0.00	539.00	2.88	35235.66	11305.56	0.00
569	60.00	49.00	0.00	11.00	0.00	127.97	2.61	12887.08	15780.10	0.00
575	94.00	81.00	0.00	13.00	0.00	223.14	2.75	25925.83	19204.32	0.00
594	40.00	40.00	0.00	0.00	0.00	99.77	2.49	9985.23	14977.85	0.00
595	385.00	362.00	0.00	23.00	0.00	974.70	2.69	156229.18	25894.34	0.00
635	153.00	142.00	0.00	11.00	0.00	386.75	2.72	35120.72	14839.74	0.00
671	275.00	223.00	0.00	52.00	0.00	805.86	3.61	72708.07	19562.71	0.00
691	282.00	254.00	0.00	28.00	16.00	557.72	2.20	73797.79	17432.55	0.00
810	33.00	26.00	0.00	7.00	0.00	120.33	4.63	8963.52	20685.04	0.00
811	314.00	198.00	0.00	116.00	0.00	796.90	4.02	81060.79	24563.87	0.00
815	472.00	0.00	0.00	472.00	0.00	0.00	0.00	0.00	0.00	0.00
816	213.00	0.00	0.00	213.00	0.00	0.00	0.00	0.00	0.00	0.00
851	9.00	5.00	0.00	4.00	0.00	10.00	2.00	1838.14	22057.70	0.00
855	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

-->

Fri Aug 12 03:22:28 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 /c 10am-2pm Tansit OD

---

destin zone	total demand	assigned demand	intrazonal demand	not ass. demand	aux.tr. only	total board.	lines /pass.	pass. hours	mean time	cpu time
923	305.00	283.00	0.00	22.00	0.00	862.10	3.05	70735.30	14996.88	0.00
1051	149.00	136.00	0.00	13.00	0.00	341.00	2.51	16640.79	7341.53	0.00
1128	27.00	27.00	0.00	0.00	0.00	79.00	2.93	11591.80	25759.55	0.00
1131	257.00	208.00	0.00	49.00	0.00	754.67	3.63	90145.53	26003.52	0.00
1348	86.00	65.00	0.00	21.00	0.00	169.25	2.60	29407.22	27145.13	0.00

1352 1.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00
1358 21.00 18.00 0.00 3.00 0.00 31.75 1.76 5541.0018470.00 0.00
1360 68.00 57.00 0.00 11.00 0.00 122.00 2.14 21620.8722758.81 0.00
1461 59.00 0.00 0.00 59.00 0.00 0.00 0.00 0.00 0.00 0.00
1754 4.00 4.00 0.00 0.00 0.00 8.00 2.00 942.8314142.50 0.00
1757 222.00 200.00 0.00 22.00 0.00 556.42 2.78 53390.7416017.22 0.00
1758 46.00 41.00 0.00 5.00 0.00 151.75 3.70 8774.7512841.10 0.00
1768 35.00 33.00 0.00 2.00 0.00 102.71 3.11 6845.6312446.59 0.00
1769 89.00 78.00 0.00 11.00 0.00 237.33 3.04 15165.4311665.71 0.00
1772 173.00 155.00 0.00 18.00 20.00 306.61 1.98 30342.4811745.48 0.00
1774 139.00 126.00 0.00 13.00 19.00 260.75 2.07 23083.9910992.38 0.00
1775 12.00 0.00 0.00 12.00 0.00 0.00 0.00 0.00 0.00 0.00
1787 1025.00 816.00 0.00 209.00 0.00 2857.89 3.50 292116.0721479.12 0.00
1788 1027.00 835.00 0.00 192.00 0.00 3156.76 3.78 325776.4323409.09 0.00
1789 662.00 554.00 0.00 108.00 0.00 2234.84 4.03 198947.7421546.69 0.00
1790 1103.00 872.00 0.00 231.00 0.00 3325.72 3.81 331756.6022827.29 0.00
1993 132.00 0.00 0.00 132.00 0.00 0.00 0.00 0.00 0.00 0.00
1995 223.00 124.00 0.00 99.00 0.00 548.80 4.43 74784.6836186.14 0.00
1996 62.00 42.00 0.00 20.00 0.00 181.34 4.32 22300.4931857.85 0.00
1997 725.00 633.00 0.00 92.00 0.00 2238.05 3.54 296232.2928078.89 0.00
1998 4.00 4.00 0.00 0.00 0.00 8.00 2.00 985.2614778.90 0.00

-->

Fri Aug 12 03:22:28 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 /c 10am-2pm Tansit OD
----

destin total assigned intrazonal not ass. aux.tr. total lines pass. mean cpu
zone demand demand demand demand only board. /pass. hours time time

1999 427.00 413.00 0.00 14.00 0.00 897.57 2.17 136734.1519864.53 0.00
2000 28.00 0.00 0.00 28.00 0.00 0.00 0.00 0.00 0.00 0.00
2001 67.00 66.00 0.00 1.00 0.00 212.00 3.21 32928.1929934.72 0.00
2159 79.00 71.00 0.00 8.00 0.00 164.00 2.31 13571.5811468.94 0.00
2161 88.00 84.00 0.00 4.00 0.00 189.00 2.25 13077.54 9341.10 0.00
2162 232.00 213.00 0.00 19.00 17.00 568.38 2.67 54732.8215417.70 0.00
2163 310.00 277.00 0.00 33.00 0.00 715.06 2.58 52473.5411366.11 0.00
2164 49.00 45.00 0.00 4.00 0.00 88.17 1.96 8826.7111768.94 0.00
2250 86.00 0.00 0.00 86.00 0.00 0.00 0.00 0.00 0.00 0.00
2251 61.00 45.00 0.00 16.00 10.00 83.67 1.86 8731.0611641.41 0.00

2252	24.00	22.00	0.00	2.00	10.00	27.00	1.23	3103.13	8463.07	0.00
2253	90.00	72.00	0.00	18.00	0.00	204.00	2.83	17251.4014376.17	0.00	
2254	81.00	0.00	0.00	81.00	0.00	0.00	0.00	0.00	0.00	0.00
2255	29.00	19.00	0.00	10.00	0.00	40.00	2.11	3161.08	9982.35	0.00
2256	100.00	95.00	0.00	5.00	0.00	290.54	3.06	26598.7516799.21	0.00	
2257	72.00	72.00	0.00	0.00	13.00	196.60	2.73	16467.0413722.54	0.00	
2258	150.00	147.00	0.00	3.00	0.00	477.28	3.25	52087.0021260.00	0.00	
2259	72.00	72.00	0.00	0.00	0.00	186.16	2.59	14231.6111859.67	0.00	
2260	110.00	104.00	0.00	6.00	7.00	224.38	2.16	31557.3218206.14	0.00	
2261	67.00	66.00	0.00	1.00	7.00	148.29	2.25	19486.4017714.91	0.00	
2262	143.00	134.00	0.00	9.00	0.00	325.54	2.43	43164.8519327.55	0.00	
2263	81.00	71.00	0.00	10.00	0.00	225.51	3.18	18926.1515993.93	0.00	
2264	47.00	44.00	0.00	3.00	0.00	81.33	1.85	9574.7113056.42	0.00	
2265	91.00	74.00	0.00	17.00	0.00	178.37	2.41	22996.3818645.72	0.00	
2266	79.00	0.00	0.00	79.00	0.00	0.00	0.00	0.00	0.00	0.00
2267	460.00	435.00	0.00	25.00	0.00	1475.67	3.39	297007.7940966.59	0.00	

-->

Fri Aug 12 03:22:29 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 /c 10am-2pm Tansit OD
----

destin zone	total demand	assigned demand	intrazonal demand	not ass. demand	aux.tr. only	total board.	lines /pass.	pass. hours	mean time	cpu time
2268	4.00	4.00	0.00	0.00	0.00	10.00	2.50	2642.7139640.68	0.00	
2269	226.00	193.00	0.00	33.00	0.00	595.50	3.09	99150.9630824.13	0.00	
2270	4.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00
2271	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2272	475.00	454.00	0.00	21.00	0.00	1190.35	2.62	197358.3026082.59	0.00	
2273	319.00	309.00	0.00	10.00	0.00	902.07	2.92	166363.1832303.53	0.00	
2274	377.00	366.00	0.00	11.00	0.00	713.25	1.95	162602.3226656.12	0.00	
2275	289.00	272.00	0.00	17.00	0.00	635.50	2.34	154292.7134035.16	0.00	
2276	1.00	1.00	0.00	0.00	0.00	2.00	2.00	444.1626649.40	0.00	
2277	307.00	287.00	0.00	20.00	0.00	918.17	3.20	195803.6640934.56	0.00	
2278	17.00	13.00	0.00	4.00	0.00	33.00	2.54	12254.3656558.58	0.00	
2279	150.00	0.00	0.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00
2280	221.00	169.00	0.00	52.00	0.00	425.50	2.52	66430.8223584.91	0.00	
2281	70.00	13.00	0.00	57.00	0.00	13.00	1.00	2936.9813555.30	0.12	
2282	173.00	0.00	0.00	173.00	0.00	0.00	0.00	0.00	0.00	0.00

2283	32.00	21.00	0.00	11.00	0.00	32.00	1.52	7016.9020048.29		0.00
2284	3.00	3.00	0.00	0.00	0.00	3.00	1.00	597.9611959.10		0.00
2285	25.00	25.00	0.00	0.00	0.00	55.00	2.20	6053.5014528.40		0.00
2286	18.00	18.00	0.00	0.00	0.00	54.00	3.00	3612.7212042.39		0.00
2287	65.00	65.00	0.00	0.00	0.00	133.00	2.05	15284.6914108.95		0.00
2288	148.00	139.00	0.00	9.00	0.00	404.00	2.91	39046.3216854.53		0.00
2289	27.00	27.00	0.00	0.00	0.00	56.00	2.07	3922.12 8715.83		0.00
2290	42.00	42.00	0.00	0.00	0.00	103.33	2.46	14355.6820508.11		0.00
2291	161.00	158.00	0.00	3.00	10.00	381.67	2.42	59183.1822474.63		0.00
2292	7.00	7.00	0.00	0.00	2.00	7.00	1.00	2181.0918695.07		0.00
2293	26.00	26.00	0.00	0.00	7.00	43.00	1.65	7786.6617969.22		0.00

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Fri Aug 12 03:22:29 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 /c 10am-2pm Tansit OD
----

destin zone	total demand	assigned demand	intrazonal demand	not ass. demand	aux.tr. only	total board.	lines /pass.	pass. hours	mean time	cpu time
2294	15.00	12.00	0.00	3.00	3.00	22.67	1.89	4014.6820073.38		0.00
2295	50.00	48.00	0.00	2.00	0.00	145.67	3.03	18006.6222508.27		0.00
2296	4.00	4.00	0.00	0.00	0.00	8.00	2.00	1058.9815884.70		0.12
2297	1.00	1.00	0.00	0.00	0.00	3.00	3.00	304.3718262.40		0.00
2298	59.00	59.00	0.00	0.00	0.00	149.00	2.53	17850.2118152.76		0.00
2299	24.00	24.00	0.00	0.00	0.00	83.67	3.49	7858.7519646.87		0.00
2300	245.00	240.00	0.00	5.00	0.00	602.67	2.51	81518.5620379.64		0.00
2301	246.00	223.00	0.00	23.00	0.00	682.00	3.06	93448.0425142.97		0.00
2302	77.00	75.00	0.00	2.00	0.00	178.67	2.38	25577.3020461.84		0.00
2303	94.00	94.00	0.00	0.00	0.00	224.46	2.39	45941.9229324.63		0.00
2304	87.00	87.00	0.00	0.00	0.00	204.66	2.35	35963.3424802.30		0.00
2305	269.00	229.00	0.00	40.00	0.00	705.44	3.08	122671.8632141.10		0.00
2306	282.00	213.00	0.00	69.00	0.00	786.33	3.69	91442.5825758.47		0.00
2307	83.00	0.00	0.00	83.00	0.00	0.00	0.00	0.00	0.00	0.00
2308	36.00	36.00	0.00	0.00	0.00	88.00	2.44	18079.2230132.03		0.00
2309	20.00	20.00	0.00	0.00	4.00	39.00	1.95	7005.3721016.11		0.00
2310	191.00	168.00	0.00	23.00	8.00	488.12	2.91	103558.2536985.09		0.00
2311	11.00	11.00	0.00	0.00	0.00	30.00	2.73	4154.8822663.00		0.00
2312	10.00	0.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2313	16.00	16.00	0.00	0.00	0.00	43.00	2.69	6996.4026236.48		0.00

```
  2314    21.00    21.00     0.00     0.00     0.00    69.00  3.29  5694.7416270.68    0.00
  2315   118.00   110.00     0.00     8.00     0.00   332.62  3.02  73118.4239882.78    0.00
  2316    69.00    57.00     0.00    12.00     0.00   193.33  3.39  45373.6747761.76    0.00
  2317    66.00    43.00     0.00    23.00     0.00   131.00  3.05  23830.0033251.17    0.00
  2318   314.00     0.00     0.00   314.00     0.00     0.00  0.00     0.00   0.00    0.00
  2319   263.00   125.00     0.00   138.00     0.00   492.40  3.94  61998.2929759.18    0.00
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Fri Aug 12 03:22:30 2016Emme   Module:  5.31      Date: 16-08-12 03:22      User: EF87/FAP-
DU...none
Database Title: HRM
Scenario    1:  Transit Run 10am-2pm
Matrix   mf02   Tran2    /c    10am-2pm Tansit OD
------------------------------------------------------------------------------------------------


destin    total   assigned intrazonal not ass.   aux.tr.   total  lines     pass.    mean     cpu
  zone   demand    demand    demand    demand     only    board.  /pass.    hours    time    time

  2320   239.00     0.00     0.00   239.00     0.00     0.00  0.00     0.00   0.00    0.00
  2321   411.00   217.00     0.00   194.00     0.00   919.33  4.24 136121.8737637.38    0.00
  2322   342.00     0.00     0.00   342.00     0.00     0.00  0.00     0.00   0.00    0.00
  2323   163.00     0.00     0.00   163.00     0.00     0.00  0.00     0.00   0.00    0.00
  2324    20.00    20.00     0.00     0.00     0.00    52.00  2.60  9084.6027253.79    0.00
  2325   326.00   306.00     0.00    20.00     0.00  1111.56  3.63 156945.3030773.59    0.00
  2326   122.00   120.00     0.00     2.00     0.00   339.17  2.83  60099.8630049.93    0.00
  2327   693.00   615.00     0.00    78.00     0.00  1996.33  3.25 298374.9629109.75    0.00
  2328    72.00    72.00     0.00     0.00     0.00   285.80  3.97  28809.1324007.61    0.00
  2329   275.00   251.00     0.00    24.00     0.00  1105.86  4.41 138701.6433155.77    0.00
  2330   394.00    60.00     0.00   334.00     0.00    60.00  1.00  49209.1049209.10    0.00
  2331   154.00   125.00     0.00    29.00     0.00   343.62  2.75 126405.1560674.48    0.00
  2332   118.00     0.00     0.00   118.00     0.00     0.00  0.00     0.00   0.00    0.12
  2333   126.00    95.00     0.00    31.00     0.00   396.83  4.18  96539.8860972.56    0.00
  2334    34.00     0.00     0.00    34.00     0.00     0.00  0.00     0.00   0.00    0.00
  2335     2.00     0.00     0.00     2.00     0.00     0.00  0.00     0.00   0.00    0.00
  2336   134.00    96.00     0.00    38.00     0.00   249.40  2.60  51161.7131976.07    0.00
  2337   206.00     0.00     0.00   206.00     0.00     0.00  0.00     0.00   0.00    0.00
  2338   140.00   106.00     0.00    34.00     0.00   260.20  2.45  55819.6931596.05    0.00
  2339   348.00   301.00     0.00    47.00     0.00   856.67  2.85 169494.4833786.28    0.00
  2340   539.00   450.00     0.00    89.00     0.00  1261.33  2.80 250963.1733461.76    0.00
  2341   399.00   305.00     0.00    94.00     0.00   792.00  2.60 170354.4333512.35    0.00
  2342   187.00     0.00     0.00   187.00     0.00     0.00  0.00     0.00   0.00    0.00
  2343   315.00   256.00     0.00    59.00     0.00   922.83  3.60 271033.1063523.39    0.00
  2344     6.00     0.00     0.00     6.00     0.00     0.00  0.00     0.00   0.00    0.00
```

2345	345.00	0.00	0.00	345.00	0.00	0.00	0.00	0.00	0.00	0.00

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Fri Aug 12 03:22:30 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 /c 10am-2pm Tansit OD
----

destin zone	total demand	assigned demand	intrazonal demand	not ass. demand	aux.tr. only	total board.	lines /pass.	pass. hours	mean time	cpu time
2346	387.00	0.00	0.00	387.00	0.00	0.00	0.00	0.00	0.00	0.00
2347	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2348	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
2349	8.00	0.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00	0.00
2350	397.00	0.00	0.00	397.00	0.00	0.00	0.00	0.00	0.00	0.00
2351	149.00	0.00	0.00	149.00	0.00	0.00	0.00	0.00	0.00	0.00
2352	81.00	0.00	0.00	81.00	0.00	0.00	0.00	0.00	0.00	0.00
2353	16.00	0.00	0.00	16.00	0.00	0.00	0.00	0.00	0.00	0.00
2354	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2355	7.00	0.00	0.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00
2356	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2357	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2358	2.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
2359	14.00	0.00	0.00	14.00	0.00	0.00	0.00	0.00	0.00	0.00
2360	20.00	0.00	0.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00
2361	9.00	0.00	0.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00
2362	34.00	0.00	0.00	34.00	0.00	0.00	0.00	0.00	0.00	0.00
2367	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2368	5.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00
2369	19.00	0.00	0.00	19.00	0.00	0.00	0.00	0.00	0.00	0.00
2373	15.00	0.00	0.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00
2379	15.00	0.00	0.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00
2380	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2381	67.00	62.00	0.00	5.00	0.00	147.50	2.38	83890.3181184.17		0.00
2382	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2383	3.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00

-->

Fri Aug 12 03:22:31 2016Emme Module: 5.31 Date: 16-08-12 03:22 User: EF87/FAP-DU...none
Database Title: HRM
Scenario 1: Transit Run 10am-2pm
Matrix mf02 Tran2 /c 10am-2pm Tansit OD
----

destin zone	total demand	assigned demand	intrazonal demand	not ass. demand	aux.tr. only	total board.	lines /pass.	pass. hours	mean time	cpu time
2387	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2388	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2389	18.00	0.00	0.00	18.00	0.00	0.00	0.00	0.00	0.00	0.00
2390	4.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00
2391	10.00	0.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2392	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2393	7.00	0.00	0.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00
2394	3.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
2395	3.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
2396	2.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
2412	21.00	21.00	0.00	0.00	0.00	38.00	1.81	10516.5430047.25		0.00

TOTAL 30739.00 21850.00 0.00 8889.00 285.00 66117.99 3.039733056.9926726.93
6.25

Appendix B-3: Transit route in Halifax

		Headway (minute)			
#	Name	6am-10am	10am-2pm	2pm-6pm	6pm-12am
1	Spring Garden	10	10	10	15
2	Wedgewood	30	30	30	60
4	Rosedale	30	30	30	60
5	Chebucto	30		30	
6	Quinpool	30	60	60	60
7	Gottingen	15	15	15	20
9	Barrington	20	30	20	60
10	Dalhousie	15	30	30	30
11	Dockyard	30		30	
14	Leiblin	15	30	30	60
15	Purcells Cove	60	60	60	
16	Parkland	30	30	30	60
17	Saint Mary's	30	30	30	
18	Universities	30	30	30	30
19	Greystone	20	30	30	30
20	Herring Cove	20	30	30	30
21	Timberlea	30	30	30	60
22	Armdale	30	30	30	30
23	Timberlea/ Mumford	30		30	
31	Main	20		20	
32	Cowie Hill	20		15	
33	Tantallon	60		60	
34	Glenbourne	20		20	
35	Parkland	45		45	
41	Dartmouth	20	20	20	
42	Lacewood	20	20	20	
51	Shannon	30	30	30	60
52	Ilsley	20	30	20	30
53	Notting Park	20	30	20	30
54	Montebello	30	60	30	60

55	Port Wallce	30	60	30	60
56	Dartmouth Crossing	30	30	30	30
57	Russel Lake	30	30	30	30
58	Woodlawn	30	60	30	60
59	Colby	20	30	20	30
60	Eastern Passage	15	30	15	30
61	Forest Hills	20	30	20	60
62	Cherrybrook	30	60	30	60
63	Woodside	30	30	30	
64	Akerley	30		30	
65	Astral	30	30	30	30
66	Gaston	30	30	30	60
68	Cherrybrook	30	30	30	60
72	Portland Hills	30	30	30	60
78	Mount edward	30		30	
79	Cole harbour	30		30	
80	Sackville	15	30	30	30
81	Hemlock Ravine	30	30	30	
82	Millwood	30	30	30	
83	Springfield	40	60	60	
84	Glendale	15		15	
85	Downsview	60		60	
86	Basinview	60		60	
87	Dartmouth	30	30	30	60
88	Dumacus	30	60	60	
89	Bedford	30	60	60	
90	Larry Uteck	30	30	30	60
159	Portland Hills	10	60	30	
185	Sackville	10	60	60	60
320	Airport	30	30	30	60
330	tantallon	20		20	
370	Porters lake	30		30	
400	Beaver bank	60		60	
401	Preston	90		90	
402	Sambro	60		60	
	Ferry - Dartmouth	15	30	15	30
	Ferry Woodside	15	30	15	30

Appendix B-4 NSTIR traffic volume survey sample data

NOVA SCOTIA

Transportation and Infrastructure Renewal

*** Hourly Volume Summary for : Mon, August 15 2011 to Mon, August 22 2011 ***

Name: 0102-030-01-1 Start Date: 15 Aug,2011 End Date: 22 Aug,2011 Counter: 143 Lane: combined

County: HAL Location: 1 KM NORTH OF KEARNEY LK RD INTR/C (NORTHBOUND) (LOOP)

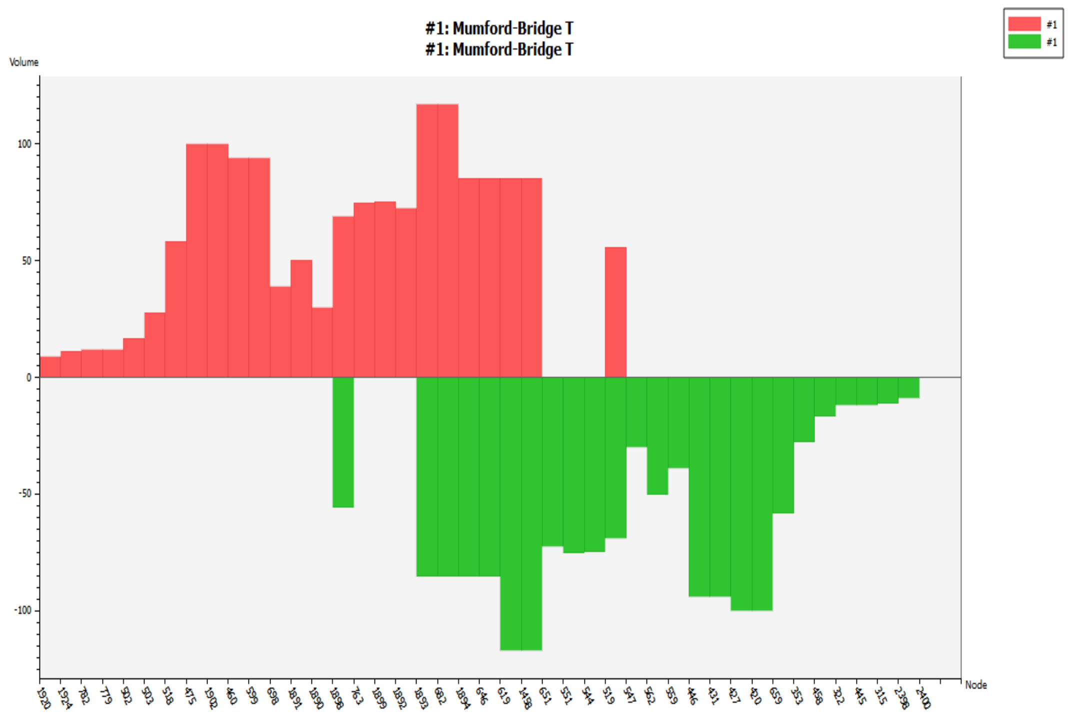
Hour Periods for 24 Hour Clock

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
M15	0	0	0	0	0	0	0	0	0	0	0	0	1430	1463	1684	2204	2774	2594	1534	1136	1009	748	367	206	17149
T16	151	65	39	64	103	227	617	1151	1344	1218	1180	1427	1501	1579	1748	2311	2901	2697	1654	1387	1213	967	464	312	26320
W17	199	78	37	56	95	246	690	1320	1478	1334	1305	1442	1541	1572	1671	2313	2916	2648	1503	1391	1208	988	520	296	26847
T18	148	57	49	65	114	242	653	1385	1439	1273	1416	1456	1588	1609	1696	2246	2899	2876	1798	1392	1219	924	486	299	27329
F19	185	80	63	49	126	233	664	1184	1363	1407	1444	1603	1798	1848	2091	2471	2947	2604	1658	1249	1122	888	495	337	27909
S20	198	130	88	73	110	175	325	550	768	1087	1409	1651	1607	1735	1655	1620	1507	1506	1260	947	780	642	445	320	20588
S21	221	122	87	73	78	113	225	376	471	764	1062	1303	1436	1544	1453	1425	1446	1329	991	924	715	519	355	204	17236
M22	133	66	42	53	114	244	662	1285	1309	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3908

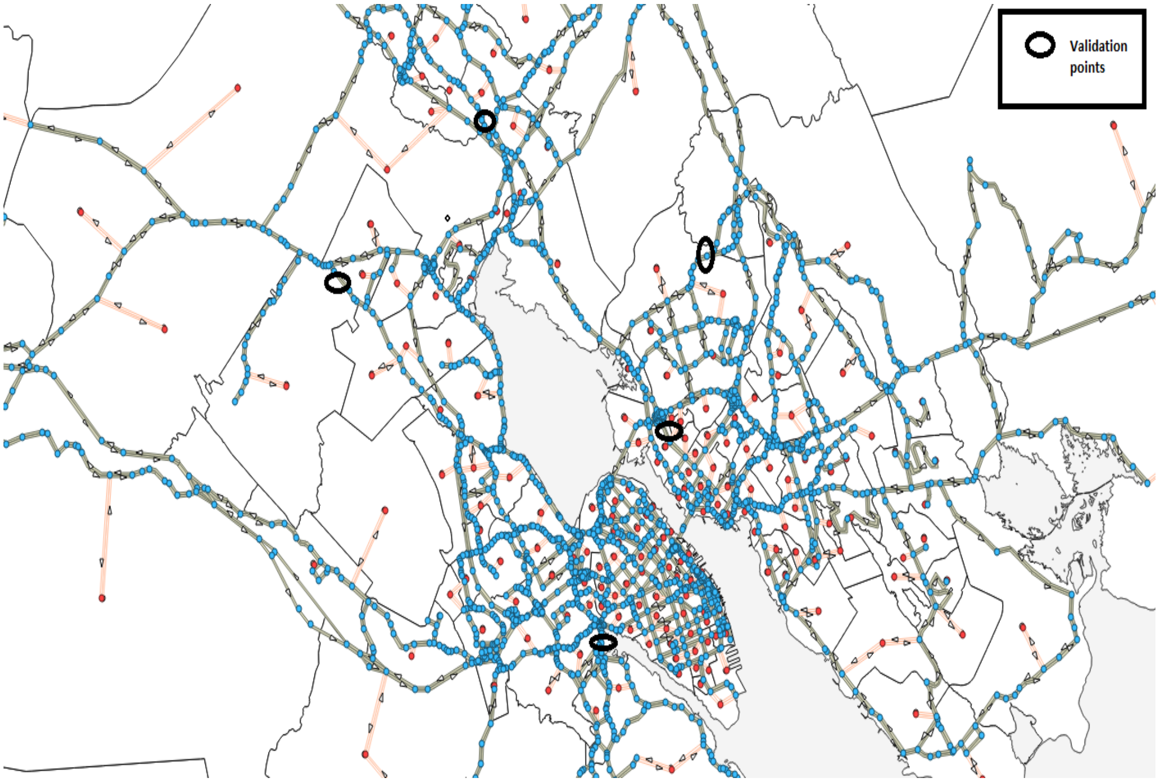
Group: A Week Total: 171111/7 = ADT 24444.43 x Factor 0.82975 = AADT 20300* Total for Count: 167286

Appendix B-5: Transit route map in Halifax

Appendix B-6: Transit route profile map (route #1)in Halifax



Appendix B-7: Model validation points



APPENDIX C

Appendix C-1 Emission factor (*Megenbir and Habib*)

Table 1: Passenger Kilometre Fuel Consumption and Vehicle Emission Factors

	CO (g/km)	THC (g/km)	VOC (g/km)	NOx (g/km)	PM10 (g/km)	PM2.5 (g/km)	GHG (g/km)	Fuel (L/km)
Passenger Vehicle Drive Alone	6.266	0.716	0.676	0.475	0.00282	0.00262	242.942	0.098
Passenger Vehicle Carpool	2.3126	0.261	0.249	0.176	0.00104	0.000966	89.663	0.0362
Diesel Bus	0.131	0.0137	0.0136	0.574	0.00106	0.0115	93.049	0.0338

APPENDIX D

Appendix D-1 TAZ considered in alternative transit evaluation

	Zone Number	Location	Area (km2)	Population (2011)	Employment (2011)
Halifax Downtown (Urban)	11	Downtown-Pier 21	0.29	2063	1138
	12	Downtown-Lower Water Street	0.18	987	3466
	25	Downtown-Citadel	0.54	787	1606
	26	Downtown Core	0.17	541	13180
	27	Downtown-Upper Water street	0.18	578	14094
	28	Downtown-Casino NS	0.11	338	8252
	29	Downtown-Cogswell	0.17	527	12842
	30	Downtown- North St	0.26	1582	791
Bedford (Suburban)	121	Larry Uteck	2.54	4652	1629
	122	Kearney lake Rd	1.53	149	54
	123	Kearney lake	4.82	469	169
	125	Hammonds Plains Rd	1.40	136	49
	127	Bedford West	1.95	189	68
	128	Bedford South	1.72	2881	530
	129	Mill Cove	1.36	2478	867
	130	Bedford core	1.05	1959	1553

Appendix D-2 Change of AM and PM peak GHG emissions pollution Experienced