DEVELOPMENT OF A FREIGHT TRAFFIC MODEL FOR HALIFAX, CANADA

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1. Introduction

Greenhouse gases (GHG) and other vehicular emissions contributed by the transportation sector pose a growing challenge for Canadian cities (1). The transportation sector is responsible for almost one quarter (24% in 2012) of overall greenhouse gas emissions in the country (2, 3). It became the second largest contributor to GHG emissions in Canada due to the increase of emissions by 31% from 1990 to 2005 (2). These emissions can lead to lung cancer (4), developing asthma (5, 6) or other respiratory diseases (7), chronic obstructive pulmonary disease (8) and cardiovascular disease (9). Vehicle engines produce excessive air pollution due to incomplete combustion of the fuel gases which are released into the air through the exhaust fumes (3). From automobile exhaust fumes, greenhouse gases, i.e. carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HC) and particulate matter (PM) are released into the environment (10, 11). These emissions depend on the type of fuel used, driving cycle, vehicle class and weight of corresponding vehicle (12, 13). For example, according to a study conducted by USEPA, heavy-duty vehicles are responsible for almost 46% and 54% of total NOx and PM emission respectively in the United States (14).

Freight is a key component of a transport network, especially for urban movement. Although rail, ferry, air cargo and trucks all carry the freight, trucks provide the highest level of service in terms of reliability and minimal loss, damage and service cost. In case of a city like Halifax that has a port, two large container terminals (70 acres and 74.5 acres) and one intermodal terminal in its busiest and densely populated downtown core, commercial vehicle movement study becomes a primacy. Irin and Habib (11) estimated the emissions for only one Halifax truck route considering the truck mode alone. Although this link level study has been conducted for Halifax, a regional transport network and emission model has not fully been developed yet. The Southern California Association of Governments (SCAG) developed a methodology to determine the travel demand of heavy duty truck and associated emission for the SCAG Regional Model (15). In addition, Phoenix Metropolitan area also developed an urban truck travel model (16). However, these models lack the passenger car component within the modeling framework. Bela and Habib (17) developed a freight transport model by incorporating the passenger car component in to the Halifax Regional Transport Network model using a quick response method. This paper extends an extent of that model by utilizing multiple data sources. The uniqueness of this model is the disaggregation of emission from diesel and gasoline traffic. As well as results of this study can be used for future emission related health studies.

The objectives of this study are: (i) to amend the existing Halifax Regional Transport Network Model utilizing an improved dataset, (ii) to examine diesel and gasoline-fuelled traffic flow, and (iii) to estimate the disaggregated emission contributed by diesel and gasoline-fuelled traffic flow in different traffic analysis zones (TAZs) of Halifax Regional Municipality (HRM). This study updates the Halifax Regional Transport Network model by determining truck trips using employment location and employee size information obtained from the Info Canada Business Establishment dataset. Moreover, this study extends the capacity of the model to estimate diesel and gasoline-fuelled emissions separately. The updated model determines the link based auto and truck flow and estimates the emission of GHG as Carbon dioxide equivalent (CO_2-eq), carbon monoxide (CO), nitrogen oxides (NOx), particulate matters ($PM_{2.5}$ and PM_{10}), and total hydrocarbons (THC) at the traffic analysis zone (TAZ) level for HRM.

2. Methodology

This study develops a regional multiclass transport network model that generates, distributes and assigns trips of different modes (passenger cars and trucks) which informs emission modelling to estimate disaggregated emission. The following sections will elaborate the details of methodology.

2.1 Study Area

Halifax has a deepest, wide, ice-free harbor with minimal tides that made it one of Canada's top four container ports in terms of the volume of cargo handled (18). Ceres Cove terminal and South End terminal are two main container terminals owned by Halifax Port Authority which is located in the downtown of Halifax. The urban core of Halifax comprises downtown of Halifax and Dartmouth which are connected by two suspension bridges: the Angus L. Macdonald and the A. Murray Mackay Bridge. These two bridges regularly experience high traffic volume during the peak periods. Light vehicles are allowed to cross the Macdonald Bridge where as large commercial vehicles use the wider Mackay Bridge. The Mackay Bridge plays a significant role in truck movement as the main truck route of HRM is directly connected to the port of Halifax through this link. *Figure 1* shows the study area with the representation of its urban, suburban and rural areas.

2.2 Traffic Network Model

The Halifax Transport Network Model that incorporates both the passenger car and truck component (17) is developed within Equilibre Multimodal Multimodal Equilibrium (EMME/4) platform. The model uses a macro-simulation platform which mimic the actual traffic condition in the Halifax transport network. This model has in total 219 Traffic Analysis Zones (TAZs), 219 zonal centroids, 2249 link nodes, and 2985 truck permitted-links out of 5232 directional links. Among 219 TAZs 93 are urban, 93 are suburban and 33 are rural.

The three-stage freight modelling include trip generation, trip distribution, and traffic assignment. The modal split is eliminated as truck trips are estimated directly from different data sources assuming no other potential modes carry freight in the transport network. Details of this three-stage freight modelling is described in the following sections.

2.2.1 Trip Generation and Distribution

Necessary data for freight trip generation and freight movement is limited. For this study, Info Canada Business Establishment data set for the year of 2016 is used to determine the location of truck trip generation. This is a rich and reliable data set with 11,233 detailed firm records including 7-digit NAICS (North American Industry Classification System) code contained in HRM. The types of establishment considered in this study include agriculture, construction, manufacturing, mining, retail trade, wholesale trade, transportation, warehousing, utilities and services. Each establishment is geocoded using the latitude and longitude value. Additionally, this dataset provides total number of employee for each establishment. Using this employee size information, total number of employees per establishment type is estimated for each TAZ. A value for trip per employee is generated from a probability distribution used in study conducted by McMaster University (19). The employee size and the value are then used to estimate the total truck trips for each establishment type.

Long haul truck trips generated from or heading to HRM are extracted from SHAW GPS tracking data (20). This data contains truck trip records having either origin or destination outside of HRM for a month of 2016. The long-haul truck trips are added to the local truck trips estimated earlier.

Two container terminals and the Intermodal terminal act as special generators for commercial vehicle movements over Halifax. Using the Cargo Statistics of Halifax port authority, volume of cargo handled by port in the year of 2016 is calculated. Afterwards, the volume of cargo is converted into number of trucks using a quick response method (21) and combined with the local and long-haul truck trips. A gravity model is used to distribute the truck trips among the TAZs. Zonal distance is used as impedance of this gravity model. After multiple iterations, a balanced origin-destination (OD) truck flow matrix is obtained. Passenger car OD matrix remain same as of the previous model (17).

2.2.2 Multiclass Traffic Assignment

This study performs a multiclass traffic assignment within the developed transport network model. Dynamic-user equilibrium traffic assignments can incorporate the effect of congestion; therefore, it is the most popular process that is being used in urban traffic modelling (21). The model simulates passenger car and truck flows for the morning peak hour of 7:00am-8:00am and converges after 9 iterations. The model results generate different performance measures such as link-based classified traffic flow (passenger car and truck), travel time, and delays, vehicle kilometer travelled (VKT) etc. which inform the inventories building process for an emission modelling of HRM.

2.3 Emission Model

An emission model for HRM is developed within Motor Vehicle Emission Simulator (MOVES) platform. The emission modelling follows three steps which include pre-processing, action and post-processing. The pre-processing step includes the development of inventories such as vehicle age distribution, vehicle type VMT distribution, road type distribution, source type population, average speed distribution, fuel and meteorological information to replicate the local context of Halifax. Multiple data sources and multiclass traffic assignment results are used to develop these inventories. Vehicle age distribution and meteorological data are obtained from Canadian Vehicle Survey and Environment Canada respectively. Vehicle type VMT distribution, vehicle distribution, average speed distribution are obtained from Halifax Transport Network Model as mentioned earlier. Although, some passenger car use diesel fuel, for simplicity this study assumes that all passenger car uses gasoline fuel and all truck uses diesel fuel. After preprocessing, the action stage executes the emission model run. The last step i.e. post-processing generates output script that contains the disaggregated emission results for all the pollutants.

3. Results

The results of this study can be divided into three groups: trip generation and distribution, multiclass traffic assignment and emission results.

3.1 Results of Trip Generation and Distribution

The trip generation and distribution result reveals that the urban core of Halifax and Dartmouth shares 43.37% of total trips in HRM which is 47.02% for suburban area. Moreover, 53.27% of the total truck trips and 36.35% of total passenger car trips in HRM has the origin in the urban core. Additionally, the results suggest that truck trips and passenger car trips share 20.21% and 79.79% of the total urban core trips respectively. A high number of passenger car trips (48.51% of total passenger car trips in HRM) is found in suburban area which indicates the morning commuting traffic stream towards the downtown core. The peripheral rural zones are sparsely populated area which have some industries like agriculture, fishing, mining etc. In the case of rural zones, both the passenger car and truck trip generation are found significantly low (9.61% of total trips in HRM). *Figure 1* shows the location of truck trip generation within HRM.

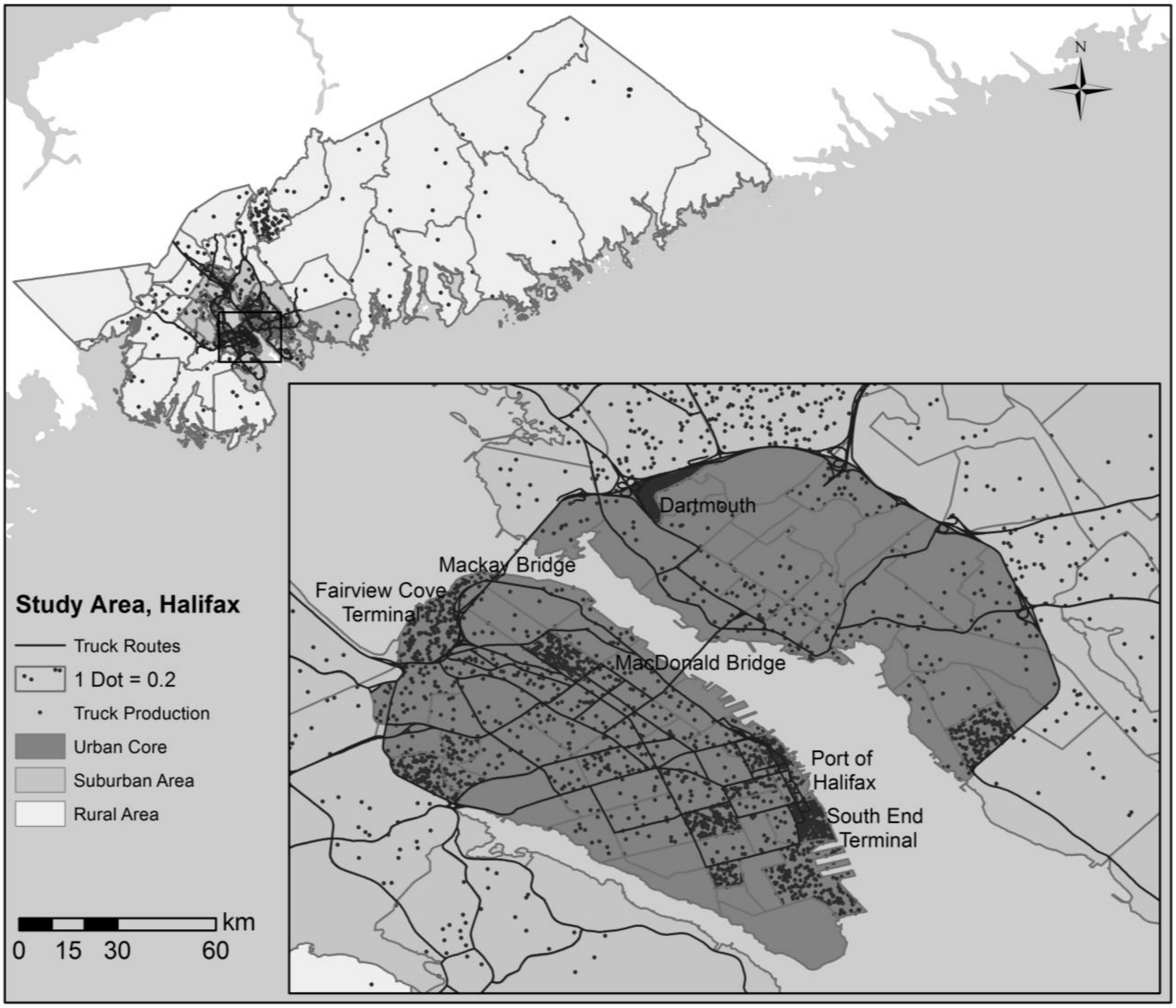

Figure 1: Truck Trip Production Location

3.2 Results of Multiclass Traffic Assignment

The assignment results in *Figure 2* shows that the vehicle flows are higher in urban core area, particularly across two bridges that connects twin cities, Halifax and Dartmouth. As truck is prohibited on the Macdonald Bridge, percentage of passenger car is maximum on this bridge. On the contrary, the Mackay Bridge has the highest volume of truck traffic that mostly generated from the port of Halifax. *Figure 2a* illustrates the results of multiclass traffic assignment. *Figure 2b* and *2c* shows the traffic flow over the connecting bridges and port.

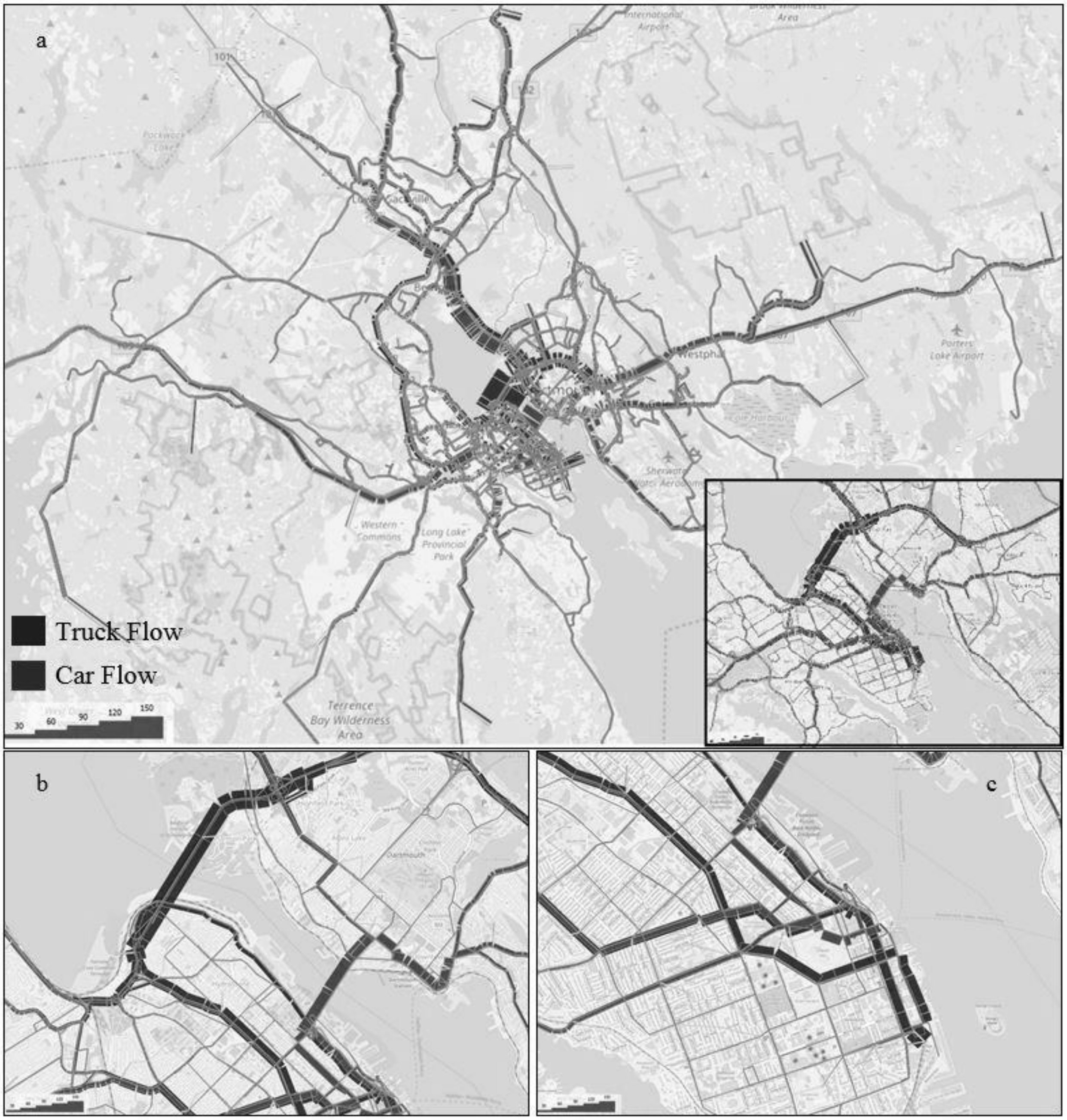

Figure 2: Results of Multiclass Traffic Assignment

3.3 Emission Results

Table 1 and *Table 2* present the disaggregated emission at TAZ level resulted from gasoline and diesel-fuelled traffic operation in HRM. In case of gasoline-fuelled vehicles (passenger cars), emission of CO_2, NOx, and THC is higher in urban zones where as emission of CO, PM_{10}, $PM_{2.5}$ is higher at suburban zones. Regarding diesel-fuelled vehicles i.e. trucks, emission is relatively higher at suburban zones. In summary, urban and suburban TAZs contribute to the emission of HRM significantly. Average emission of CO_2, CO, NOx, PM_{10}, $PM_{2.5}$ and THC released from passenger car are 2247.28, 15.23, 1.43, 0.038, 0.033, and 0.36 in gram per square kilometer and 8358.82, 6.57, 24.74, 1.15, 1.06 and 1.2 in gram per square kilometer for trucks respectively within HRM.

Table 1: Emission resulted from Gasoline fuelled vehicles at different TAZs in the HRM

Pollutant	Area	Minimum (g/km^2)	25 Percentile (g/km^2)	Median (g/km^2)	Average (g/km^2)	75 Percentile (g/km^2)	Maximum (g/km^2)	% change with respect to average
CO_2_Eq	Rural	109	461	783	984	1204	3793	-56.23
	Suburban	61	672	1813	2276	2806	16519	1.27
	Urban	21	311	1400	2597	3934	19820	**15.54**
CO	Rural	0.612	2.593	4.406	5.535	6.777	21.344	-63.66
	Suburban	0.504	5.542	14.950	18.768	23.138	136.223	**23.23**
	Urban	0.114	1.729	7.771	14.529	21.830	109.994	-4.60
NOx	Rural	0.070	0.298	0.507	0.636	0.779	2.454	-55.49
	Suburban	0.039	0.432	1.166	1.464	1.805	10.624	2.36
	Urban	0.013	0.195	0.876	1.638	2.461	12.398	**14.52**
PM_{10}	Rural	0.0015	0.0064	0.0108	0.0136	0.0166	0.0523	-64.30
	Suburban	0.0013	0.0140	0.0378	0.0475	0.0586	0.3448	**25.02**
	Urban	0.0003	0.0042	0.0189	0.0354	0.0532	0.2678	-6.91
$PM_{2.5}$	Rural	0.0013	0.0056	0.0096	0.0120	0.0147	0.0463	-63.63
	Suburban	0.0011	0.0124	0.0335	0.0420	0.0518	0.3050	**27.34**
	Urban	0.0002	0.0037	0.0167	0.0313	0.0470	0.2369	-5.17
THC	Rural	0.0157	0.0664	0.1129	0.1418	0.1736	0.5468	-60.61
	Suburban	0.0103	0.1128	0.3042	0.3819	0.4708	2.7719	6.08
	Urban	0.0032	0.0480	0.2157	0.4033	0.6060	3.0533	**12.03**

Table 2: Emission resulted from Diesel-fuelled vehicles at different TAZs in the HRM

Pollutant	Area	Minimum (g/km^2)	25 Percentile (g/km^2)	Median (g/km^2)	Average (g/km^2)	75 Percentile (g/km^2)	Maximum (g/km^2)	% change with respect to average
CO_2_Eq	Rural	427	3132	5150	5722	8487	14177	-31.55
	Suburban	101	1561	3842	8782	10604	75298	**5.06**
	Urban	48	874	3188	8440	9636	83234	0.97
CO	Rural	0.324	2.380	3.913	4.348	6.449	10.773	-33.82
	Suburban	0.078	1.210	2.977	6.804	8.216	58.338	**3.56**
	Urban	0.038	0.700	2.553	6.758	7.716	66.647	2.86
NOx	Rural	1.274	9.351	15.373	17.080	25.335	42.321	-30.96
	Suburban	0.296	4.558	11.215	25.636	30.956	219.815	**3.62**
	Urban	0.143	2.620	9.553	25.289	28.874	249.402	2.22
PM_{10}	Rural	0.0499	0.3661	0.6018	0.6687	0.9918	1.6568	-41.86
	Suburban	0.0152	0.2338	0.5754	1.3152	1.5880	11.2766	**14.36**
	Urban	0.0061	0.1119	0.4082	1.0807	1.2339	10.6578	-6.03
$PM_{2.5}$	Rural	0.0459	0.3368	0.5537	0.6152	0.9125	1.5243	-41.97
	Suburban	0.0140	0.2151	0.5293	1.2099	1.4610	10.3744	**14.15**
	Urban	0.0056	0.1030	0.3756	0.9942	1.1352	9.8051	-6.21
THC	Rural	0.0586	0.4297	0.7065	0.7849	1.1643	1.9449	-34.59
	Suburban	0.0143	0.2210	0.5438	1.2430	1.5009	10.6580	**3.58**
	Urban	0.0069	0.1270	0.4631	1.2259	1.3997	12.0899	2.16

Table 3 suggests that it is clear that, emission from diesel-fuelled vehicles are more extensive compared to the gasoline-fuelled vehicles for almost all pollutants. It has been found that emission of GHG, NOx, PM_{10}, $PM_{2.5}$, and THC is higher contributed by diesel-fuelled vehicle whereas CO is the only exception that emitted comparatively in low volume from diesel-fuelled truck. In case of rural area, truck is the main contributor to its total emission.

Table 3: Comparison of emission resulted from Gasoline and Diesel fuelled vehicles

Pollutant	Area	% change of emission with respect to passenger car	Pollutant	Area	% change of emission with respect to passenger car
CO_2_Eq	Rural	4.82	PM_{10}	Rural	48.29
	Suburban	2.86		Suburban	26.68
	Urban	2.25		Urban	29.55
CO	Rural	-0.21	$PM_{2.5}$	Rural	50.26
	Suburban	-0.64		Suburban	27.79
	Urban	-0.53		Urban	30.77
NOx	Rural	25.84	THC	Rural	4.54
	Suburban	16.51		Suburban	2.25
	Urban	14.44		Urban	2.04

4. Conclusions

This study contributes to the development of a freight transport module within the Halifax Regional Transport Network model. The uniqueness of this study is that it has developed an improved multiclass transport network model that can quantify traffic flows of different modes separately. The simulation results show that 53.27% of the total truck trips and 36.35% of total passenger car trips of HRM have the origin in the urban core area. Additionally, the results suggest that truck trips and passenger car trips share 20.21% and 79.79% of the total urban core trips respectively. This study also analyzed the disaggregated emission released from different modes at TAZ level. The emission studies inform that the urban-suburban TAZs experience the highest emission for all pollutants those are considered in this study. The average emission of CO_2, CO, NOx, PM_{10}, $PM_{2.5}$ and THC released from passenger cars are found as 2247.28, 15.23, 1.43, 0.038, 0.033, and 0.36 in gram per square kilometer respectively. Whereas, the average emission of those pollutants released from trucks are 8358.82, 6.57, 24.74, 1.15, 1.06 and 1.2 in gram per square kilometer respectively.

The model estimates emission based on individual trips in the morning peak hour for a typical day. The future research should focus on tour formation for each business establishment and estimation of hourly disaggregated emission. This study can positively influence urban planners in determining policy direction for future congestion reduction strategies. It is also expected that the results could be useful for further emission-related health studies.

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