Development of an Urban Transport Network and Emission Model for the Port City of Halifax, Canada

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ABSTRACT

This study develops a framework for regional transport network and emission modelling for the port city of Halifax, Canada. The proposed modelling framework generates, distributes and assigns commercial vehicles along with passenger car in the network, and estimates the resulting vehicular emissions. First, a four-stage travel demand forecasting model is developed for passenger car and long-haul truck movements in the network. The delivery truck tours are generated following a Monte-Carlo simulation technique and utilizing an Info Canada Business Establishment dataset that contains 12,877 firm records within the Halifax Regional Municipality. In the next step, a multiclass traffic assignment is performed to inform emission model that determines emission of major air pollutants from all vehicle classes. This study estimates the emission of GHG, CO, NOx, PM_{10}, $PM_{2.5}$, SO_2, THC and VOC from passenger car, long-haul truck, and delivery truck. The study examines the spatial and temporal variation of vehicular emission at Traffic Analysis Zone level. The results suggest that average emissions of GHG, CO, NOx, PM_{10}, $PM_{2.5}$, SO_2, THC and VOC in urban areas are 1562.26 gm/km^2, 94.71 gm/km^2, 6.8 gm/km^2, 0.309 gm/km^2, 0.274 gm/km^2, 0.029 gm/km^2, 16.14 gm/km^2, and 15.99 gm/km^2 respectively. The mode specific hourly profile for total emission of the pollutants is also examined in this study. The findings of this study will be beneficial for transportation, environmental and health professionals to develop strategies for traffic management and emission reduction.

1 INTRODUCTION

Commercial vehicles comprise a substantial portion of all traffic movements in the urban road network *(Hunt and Stefan, 2007)*. However, freight transportation has not received the same level of attention as passenger transport, despite its linkages to economic development and urban growth *(US Environmental Protection Agency, 2011; Grenzeback et al., 1989)*. At a local level, delivering goods adds additional substantial number of trucks to the existing large volume of commercial vehicles within the urban network. Results from a recent Calgary survey reveal that above 50% of urban commercial vehicle trips are made by light trucks *(Hunt and Stefan, 2007).* Such rise in the number of commercial vehicles will increasingly contribute to the traffic congestion and the environmental pollutions *(US Environmental Protection Agency, 2011).* This situation could further deteriorate as local delivery trucks add to the existing daily traffic, resulting in an increase in local congestion and vehicular emissions. Commercial vehicles are often larger than passenger cars, thus they can have greater impacts on road pavement wear, traffic congestion, traffic flows, Greenhouse Gas (GHG) emissions and other vehicular emissions depending on dimensions, weight and engine power *(Highway Capacity Manual, 2000; You, 2012).*

In recognition to the importance of passenger transport systems and the effects of commercial vehicle movement, it is important to model both systems simultaneously when developing a comprehensive multiclass transport network model for policy analysis and planning in urban areas *(Sharman, 2014).* This study intends to develop both the trip-based passenger car and tour-based commercial vehicle demand model to improve the estimation of the emission in the road network of Halifax Regional Municipality (HRM). The modeling of delivery truck tour movement along with passenger car component in Halifax is necessary, as the port, two container terminals and a large concentration of industries and service centers are located within the urban core of the city. Moreover, the city experiences a daily high truck traffic flow during the peak hours. The strategic location, efficiency, modern infrastructure, and world class security of the Halifax port has made it one of the most desirable ports in North America. Although rail carries a portion of freight in Halifax, trucks are still a predominant mode for commercial goods movement. According to a study *(US Environmental Protection Agency, 2009),* commercial vehicles contributes up to 38% of transportation's GHG emissions in USA. Therefore, traffic emission modeling considering emission generated from truck traffic and other modes is of paramount importance, especially for this region of Nova Scotia. To do so, a multiclass traffic network modelling is pre-requisite to assess emission from all types of vehicles.

Therefore, the objectives of this study are (i) to develop an enhanced regional multiclass transport network model that generates, distributes and assigns multiple modes simultaneously and (ii) to estimate the resulting emissions within an emission simulation platform for the year of 2016. The earlier trip-based Halifax travel demand forecasting model *(Bela and Habib, 2018)* is updated by utilizing 2016 Nova Scotia Travel Activity (NovaTRAC) Survey dataset. This study integrates a multiclass transport network model developed within the Equilibre Multimodal Multimodal Equilibrium (EMME) platform with an emission modelling framework based on Motor Vehicle Emission Simulator (MOVES), developed by the US Environmental Protection Agency (EPA). The first model provides the emission model with necessary inventories (i.e. VMT, speed distribution, vehicle type fraction) for estimating the emission of major pollutants in traffic analysis zone (TAZ) level for the Halifax Regional Municipality (HRM). Major pollutants include Greenhouse gas (GHG) as CO_2-equivalent, carbon monoxide (CO), nitrogen oxides (NOx), particulate matter ranging from 2.5 to 10 µm (PM_{10}), particulate matter smaller than 2.5 µm ($PM_{2.5}$), sulphur dioxide (SO_2), total hydrocarbons (THC), and volatile organic compound (VOC). The model results produce 24-hour link volume and emission generated by all modes within the Halifax Regional Municipality (HRM).

2 LITERATURE REVIEW

Air quality degradation is one of the most pressing environmental concerns worldwide, particularly in North American cities *(Abou-Senna and Radwan, 2014b).* Vehicular emissions contribute significantly in the deterioration of the climate that adversely affects social, economic, environmental and public health worldwide. Many studies assessed the emission rate of a specified area within a set of time period, to capture the temporal variation of a variety of pollutants *(Abou-Senna and Radwan, 2014a, Abou-Senna and Radwan, 2014b, Sider et al., 2013; Farzaneh and Zietsman, 2012; Choi and Frey, 2010; Frey et al., 2008; Hatzopoulou et al., 2008; Sivanandan et al., 2008).* According to several studies, the major air pollutants include CO2, CO, NOx, SO2, PM10, PM2.5, THC and VOC *(Abou-Senna and Radwan, 2014b, Sider et al., 2013; Farzaneh and Zietsman, 2012; Maoh and Tang, 2012; Environment Canada, 2014; Choi and Frey, 2010; Frey et al., 2008; Potoglou and Kanaroglou, 2008; Sivanandan et al., 2008; Behan et al., 2008; US Environmental Protection Agency, 2005; Gajendran and Clark, 2003).* Among these pollutants, EPA sets National Ambient Air Quality Standards (NAAQS) for CO, NOx, SO2, and PMs which are defined as Criteria Air Contaminant (CAC).

The transportation sector in Canada contributed to almost one quarter of the overall greenhouse gas emissions for the country in 2012, and over half of the CO_2 emissions is produced by fossil fuel powered vehicles *(Environment Canada, 2014; Behan et al., 2008).* Vehicle engines produce high amounts of air pollution due to incomplete combustion of the fuel gases which are released into the air through the exhaust fumes *(Behan et al., 2008).* Automobile exhaust fumes expend greenhouse gas emissions such as CO_2, CO, NOx, HC, and PM *(Potoglou and Kanaroglou, 2008).* Moreover, heavy duty diesel vehicles (HDDVs) contribute significantly to the emissions of NOx and PM *(Gajendran and Clark, 2003).* According to a study conducted by USEPA, heavy commercial vehicles are responsible for almost 46% and 54% of total NOx and PM emission respectively in United States *(US Environmental Protection Agency, 2005).* The amount of emissions from these vehicles is affected by type of fuel used, driving cycle, vehicle class and weight of corresponding vehicle *(Brodrick et al., 2004; Clark et al., 2002).* Research on commercial vehicle demand modeling has significantly increased in recent years with the increase in detrimental effects of commercial vehicles on congestion, environment and energy security *(Samimi et al., 2010; Bryan et al., 2008).* Pendyala et al. *(2000)* extensively reviewed the existing commercial vehicle travel demand models across North America. While there is a growing body of research on urban commercial vehicle movement, there is limited research that addresses delivery truck tour modeling issues *(Sharman, 2014; Bryan et al., 2008; Hunt and Stefan, 2007; Stefan et al., 2005; Ambrosini and Routhier, 2004; Grenzeback et al., 1989)*. The majority of the models take a trip-based approach to model urban truck movement, which cannot represent tour-based nature (i.e. intrazonal trips, trip-chaining behaviour) of urban commercial vehicle movement *(Tozzi et al., 2013; You and Ritchie, 2012; Comi et al., 2012; You, 2012; Samimi et al., 2010; Wang and Holguin-Veras, 2008; Donnelly et al., 2008; Hunt and Stefan, 2007; Hensher and Figliozzi, 2007; Hensher and Puckett, 2005; Boerkamps, et al., 2000)*. Studies found that, on average, approximately 4.9 – 12.2 trips are produced for each tour *(Greaves and Figliozzi, 2008; Hunt and Stefan, 2007; Figliozzi et al., 2007; Holguin-Veras and Patil, 2005; Vleugel and Janic, 2004)*. These one-to-many distributions of delivery trucks have an extensive impact on vehicle counts in urban areas *(You, 2012; Beagan et al., 2007; Outwater, 2005)*. A trip-based approach is not suitable to mimic such trip chaining behavior of commercial vehicles *(Tozzi, 2013; Comi et al., 2012; You and Ritchie, 2012; You, 2012)*. The emission modeling that accounts for delivery truck movement in combination with passenger car movement is limited in literature. There is also a clear gap in detailed calibration and validation of the regional urban transport network model. This study bridges the gap in literature by proposing a tour-based delivery truck movement network modeling framework in conjunction with passenger car movement model taking a traditional trip-based approach. Followed by this, the study develops an emission model for Halifax, which estimates the emission of major air pollutants generated from all available modes including trucks.

3 MODELLING APPROACH

This study integrates a multiclass transport network model and an emission model for Halifax, Canada. The transport network modeling framework includes three components (i) passenger car demand modeling, (ii) local delivery truck demand modeling, and (iii) long haul truck demand modeling component. The second model estimates emission of major air pollutants generated from these three modes. The detailed description of these two models is presented in the following sections.

3.1 Development of Regional Transport Network Model

Figure 1 shows all three components of the transport network model. Here, Passenger car and long haul truck take a four stage trip-based modelling approach while, local delivery trucks are modelled utilizing a tour based approach. This transport network model can be subdivided into two models: passenger car demand model and commercial vehicle demand model. These two models provide the necessary inputs to run a multiclass traffic assignment within the developed Halifax Regional Transport Network Model within an EMME platform.

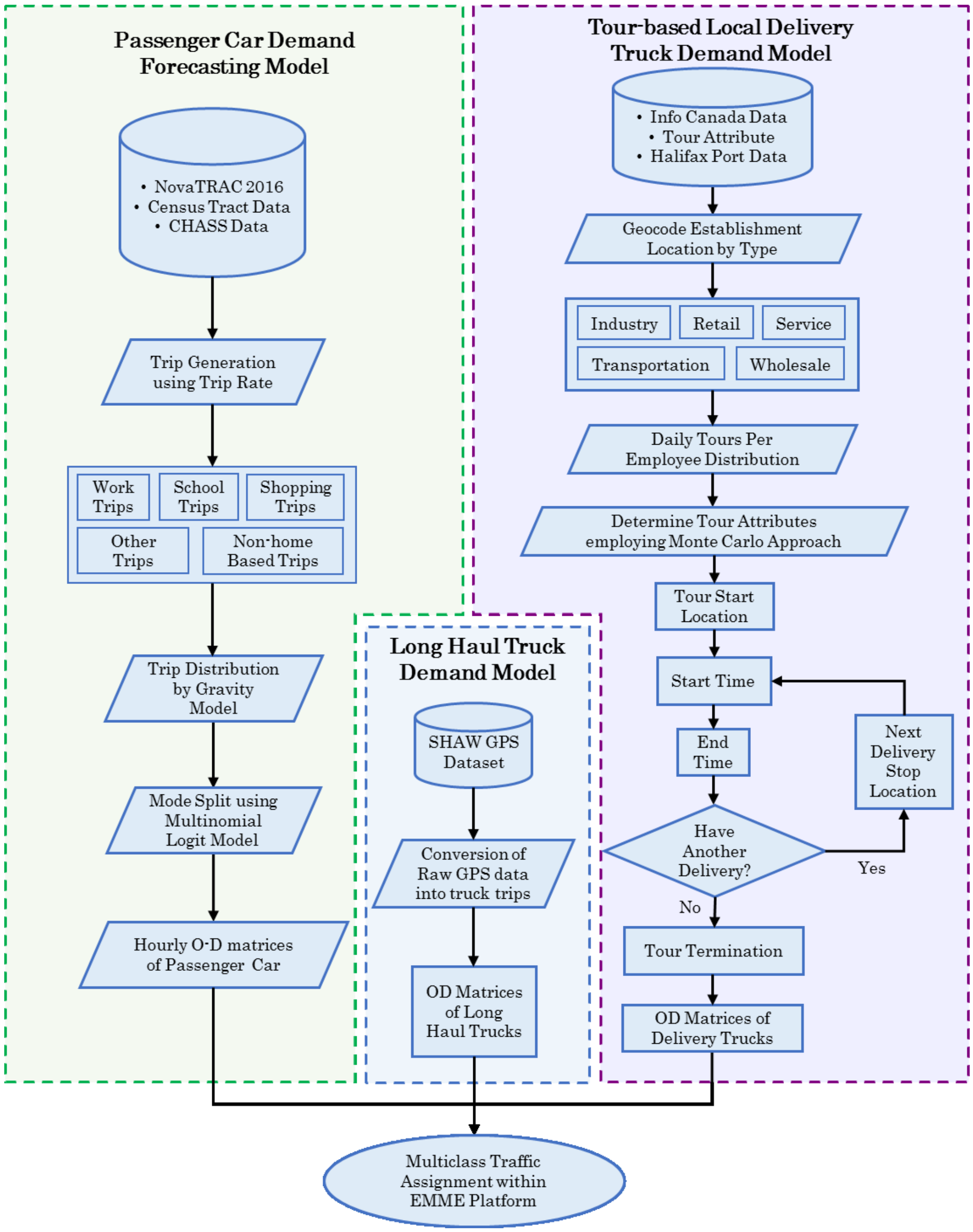

FIGURE 1 Framework of Halifax Regional Transport Network Model

3.1.1 Passenger Car Demand Forecasting Model

This study used multiple data sources to develop the 2016 travel demand forecasting model. NovaTRAC survey data is used to estimate the trip rate for each TAZ. This household travel activity survey was conducted by Dalhousie Transportation Collaboratory (DalTRAC) in partnership with the Province of Nova Scotia and Halifax Regional Municipality (HRM). The survey collected information regarding the household and its members, household vehicles, and a 24-hour travel activity log. The 24-hour travel activity log includes: household members' trip locations, arrival and departure time for each trip, accompanying person, mode used, and different purposes for trip making. The survey yielded in total 591 Household and

647 individual travel records. To acquire information regarding dwellings, socio-economic and demographic attributes, Census Tract (CT) data is utilized. Statistic Canada is used to obtain the census digital boundary in a shapefile format. Trip generation and trip distribution steps are conducted using trip rate analysis and gravity modeling approach respectively. Trip distribution stage outputs the hourly O-D matrices which contains total 24 trips tables. These hourly seed O-D matrices are modified through calibration and validation process in the traffic assignment stage of the transport network modelling. Detailed procedure used to develop the passenger car demand model can be found in Bela, 2018.

3.1.2 Commercial Vehicles Demand Forecasting Model

Unlike the passenger car demand model, this model takes a tour-based approach to capture delivery truck movements. For this study delivery truck yields both light and medium trucks. Movement of heavy trucks are modelled for long haul trips only. Therefore, this study considers two truck types: delivery truck, and long-haul truck. The study utilized a large Info Canada Business Establishment dataset and a Monte Carlo simulation technique to determine several tour attributes. Detailed procedure to develop the tour-based delivery truck movement model can be found in Bela and Habib, 2019. Long haul truck trips are modelled utilizing SHAW GPS tracking dataset *(Bela and Habib, 2019)*. This model outputs twenty eight O-D matrices, where fourteen matrices are produced for each type of trucks.

3.1.3 Multiclass Traffic Assignment

This study performs a standard multiclass traffic assignment within the Halifax Regional Transport Network Model. Although, this model considers passenger car movement for a twenty four hour of period, it considers truck mode for a fourteen hour of period starting from 7:00am to 9:00pm as major truck movement occurs between these hours. Number of vehicles present within the network and number of iterations required to complete each hour of assignment is listed in Table 1**Table** . It is evident that, link flow peaks during morning peak hour and evening peak hour; however, evening period is more critical. In evening peak time maximum number of vehicles is present in the network and it takes relatively more iteration to reach the equilibrium condition of the network.

Table 1 Number of Iterations Required and Number of Vehicle Present Within the Network during Each Hour of Multiclass Traffic Assignment

Time period	Iteration required	Total Link flows in the Network	Time period	Iteration required	Total link flows in the Network
12:00-12:59am	2	176,809	12:00-12:59pm	3	1,446,762
1:00-1:59am	2	49,183	1:00-1:59pm	2	1,104,616
2:00-2:59am	2	38,414	2:00-2:59pm	5	1,650,572
3:00-3:59am	2	153,019	3:00-3:59pm	7	2,127,650
4:00-4:59am	2	374,356	**4:00-4:59pm**	**16**	**2,833,918**
5:00-5:59am	2	595,560	5:00-5:59pm	8	2,253,406
6:00-6:59am	5	1,617,252	6:00-6:59pm	5	1,695,375
7:00-7:59am	9	2,202,894	7:00-7:59pm	4	1,514,299
8:00-8:59am	**13**	**2,696,709**	8:00-8:59pm	2	1,049,716
9:00-9:59am	7	2,024,684	9:00-9:59pm	2	802,202
10:00-10:59am	5	1,707,933	10:00-10:59pm	2	502,292
11:00-11:59am	3	1,391,646	11:00-11:59pm	2	295,901

3.1.4 Calibration and Validation of the Model

A traffic volume-based approach is used to calibrate and validate the developed urban transport network model. Observed traffic volume is obtained from video image processing-based and HRM traffic count data. The simulated and observed passenger car and truck counts are compared and the deviation is evaluated in terms of R^2, RMSE and GEH values. Certain links are imposed extra cost to discourage additional car and truck flows than expected across those links. R^2 values are obtained utilizing regression curve, and RMSE and GEH values are estimated using equations. In total nine locations (Figure 2) are validated with six hours (two hours of each morning, mid-day and evening peak period) of observed field traffic count data. For this model passenger car volume and truck volumes are validated separately. The validation results for both passenger car and truck movements are shown in Table 2.

FIGURE 2 Validation Location for the Study Area

Table 2 Validation Results of Enhanced Travel Demand Model

Criteria	Time		Goodness fit of the Model	
			Passenger Car Volume	Truck Volume
R^2	Morning Peak (7:00-8:59am)		0.94	0.84
	Mid-day Peak (11:00am-12:59pm)		0.84	0.89
	Evening Peak (4:00-5:59pm)		0.86	0.86
RMSE	Morning Peak (7:00-8:59am)		218.1	15.98
	Mid-day Peak (11:00am-12:59pm)		235.9	19.29
	Evening Peak (4:00-5:59pm)		323.2	20.98
GEH	Morning Peak (7:00-8:59am)	GEH < 1	44.59%	37.50%
		1 < GEH < 2	14.86%	16.67%
		2 < GEH < 5	17.57%	33.33%
		5 < GEH < 10	22.97%	12.50%
	Mid-day Peak (11:00am-12:59pm)	GEH < 1	39.19%	29.17%
		1 < GEH < 2	24.32%	29.17%
		2 < GEH < 5	18.92%	37.50%
		5 < GEH < 10	17.57%	4.17%
	Evening Peak (4:00-5:59pm)	GEH < 1	45.95%	33.33%
		1 < GEH < 2	18.92%	4.17%
		2 < GEH < 5	14.86%	50.00%
		5 < GEH < 10	20.27%	12.50%

The R^2 for three periods (morning, mid-day and evening peak period) are found as 40.94, 0.84 and 0.86 for passenger car and 0.84, 0.89, and 0.86 for truck movements respectively. RMSE estimates the absolute deviation of the simulated and observed traffic volume. The average RMSE values for three periods are found as 218.1, 235.9 and 323.2 for passenger cars and 15.98, 19.29, and 20.98 for truck movements respectively. GEH values are also evaluated for the flows of these modes. In the case of passenger car, GEH values of less than 1 has been found for 44.59%, 39.19%, and 45.95% of passenger car movement at three peak periods respectively and less than 5 for 77.03%, 82.43%, and 79.73% of total passenger car movement. On the other hand, for truck flows, GEH values of less than 1 has been found for 37.5%, 29.17%, and 33.33% of traffic movement at three peak periods respectively and less than 5 for 87.5%, 95.83%, and 87.5% of total traffic movement. No movement has a GEH value greater than 10.

3.2 Development of Emission model

The emission models for Halifax Regional Municipality (HRM) are developed within USEPA's Motor Vehicle Emission Simulator (MOVES) platform for the model year of 2016. This model includes three modes i.e., passenger car, delivery truck and long haul truck. The emission model is developed following three steps which include pre-processing, model execution and post-processing. Regional vehicular emission modelling requires a combination of data to reflect the local context, traffic characteristics, and traffic flow patterns of that area *(Koupal et al., 2002; US Environmental Protection Agency, 2015a)*. The pre-processing step includes the development of such inventories like: 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. The inventories developed at this phase are used for creating a RunSpec to estimate different emission rates in the phase of model execution. Multiple data sources and multiclass traffic assignment results are used to develop these inventories. Figure 3 shows the sequential steps of emission modeling within MOVES including the inputs, emission estimation and the outputs.

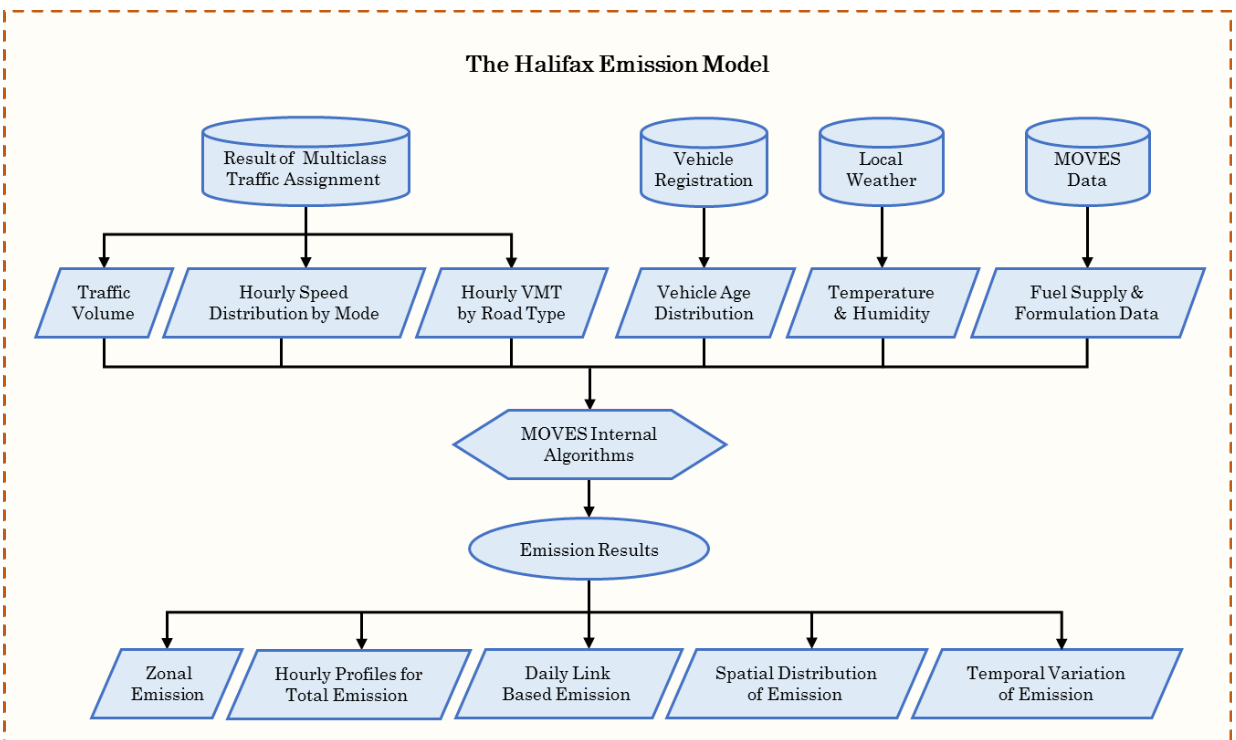

Figure 3 Framework for Emission Estimation from Multiclass Traffic Assignment

The vehicle age distribution fraction is estimated from the vehicle registry database of Canadian Vehicle Survey 2015. This data includes vehicle age fraction for the last 30 years. The data reveals that majority of the passenger cars running on the road are the age of 13 years or less. For example, 85% of the passenger cars are the age of 13 years or less. In the case of commercial vehicles, majorities are 15 years old or less and 81% of heavy trucks are 15 years old or less. The age of vehicle affects significantly to its emission as modern vehicles attempt to optimize combustion of fossil fuels *(Natural Resources Canada, 2018).*

Type of fuel used by each vehicle is determined from Nova Scotia Travel Activity (NovaTRAC) Survey 2016. Hourly meteorological data such as temperature and relative humidity are obtained from the Halifax Naval Dockyard weather station (located on the western side of Halifax harbor and elevation is +3.8m) by Environment Canada *(Environment Canada, 2016)*. Hourly meteorological data is obtained for April 2016. The traffic data used in this study is also collected at the same period.

Vehicle type VMT distribution, vehicle type distribution and average speed distribution for each road type are obtained from the simulation results of Halifax Regional Transport Network Model. Generally, MOVES deals with five types of roads. All roads of Halifax fall in the category of urban unrestricted, urban restricted and rural unrestricted access road type in MOVES. Although, some passenger cars use diesel fuel, for simplicity this study assumes that all passenger cars use gasoline fuel and all trucks use diesel fuel. MOVES considers multiple sources to estimate the emission of pollutants, for example, running exhaust, start exhaust, break wear, tire wear, evaporative fuel leaks, auxiliary power exhaust and others.

After the preprocessing phase, the next stage executes the emission model through multiple iterations within MOVES. Five emission rates are estimated in the execution phase such as 'Rateperdistance', 'Ratepervehicle', 'Rateperstart', 'Rateperhour', and 'Rateperprofile'. Total activity by fleets e.g., vehicle population, vehicle mile travelled (VMT), and others are estimated in the inventory mode. Then, in the last step i.e. post-processing generates output script that contains the disaggregated emission results for all pollutants. The post-processing of results involves multiplying the rate with appropriate activity to calculate emission resulting from different source types such as total running emission, total start emission, total hotelling emission, and total evaporative emission. The total emission is then referred to the aggregation of all types of emissions.

4 RESULTS AND DISCUSSIONS

4.1 Results from Regional Transport Network Model

Figure 4 presents daily trip (tour leg for delivery trucks) generation of different vehicles at TAZ level. The total trip generation comprises of 94.6% passenger car and 5.45% truck trips. Downtown Halifax and Dartmouth generate a significant number of trips. Generation of passenger car trips is higher in urban and sub urban areas. The results suggest that truck generation is concentrated in urban core, including port, airport, container terminals, intermodal terminal, and industrial areas located in Burnside and Bayers lake areas. In comparison to earlier trip-based model, this enhanced model estimates 3.3% and 12.1% higher passenger car and truck generation respectively.

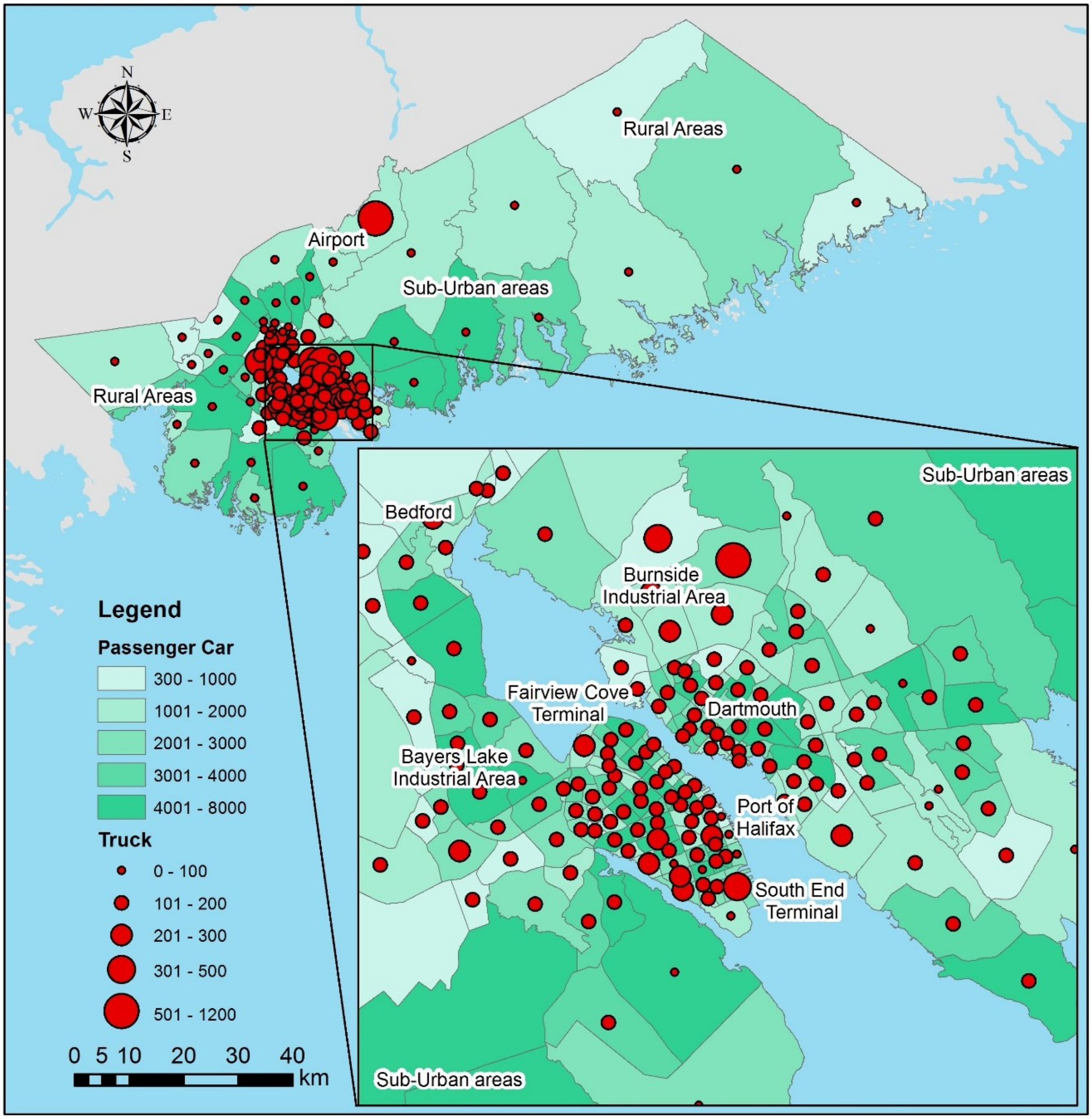

Figure 4 Daily Trip (or Tour Leg) Generation at Different TAZs

Halifax Regional Transport Network Model includes movement of passenger cars, local delivery trucks and long haul trucks. The result of multiclass traffic assignment provides hourly link-volume for all modes as shown in Figure 5. Figure shows the flows of three modes with three different colors where thicker to thin line represents low to high traffic volume respectively.

This result reveals that the two bridges anticipate the maximum flow in the network. Passenger car comprises the major portion the traffic flows in Halifax. In the case of truck flows, 52.29% of total delivery truck movement and 12.5% of total long haul truck movements occurs within the urban core. Results from the delivery truck tour model indicate that firms are likely to complete their deliveries in between morning and evening peak periods. 64.6% of long haul truck movement occurs through Truro (external TAZ). This external TAZ links Halifax with other parts of Canada.

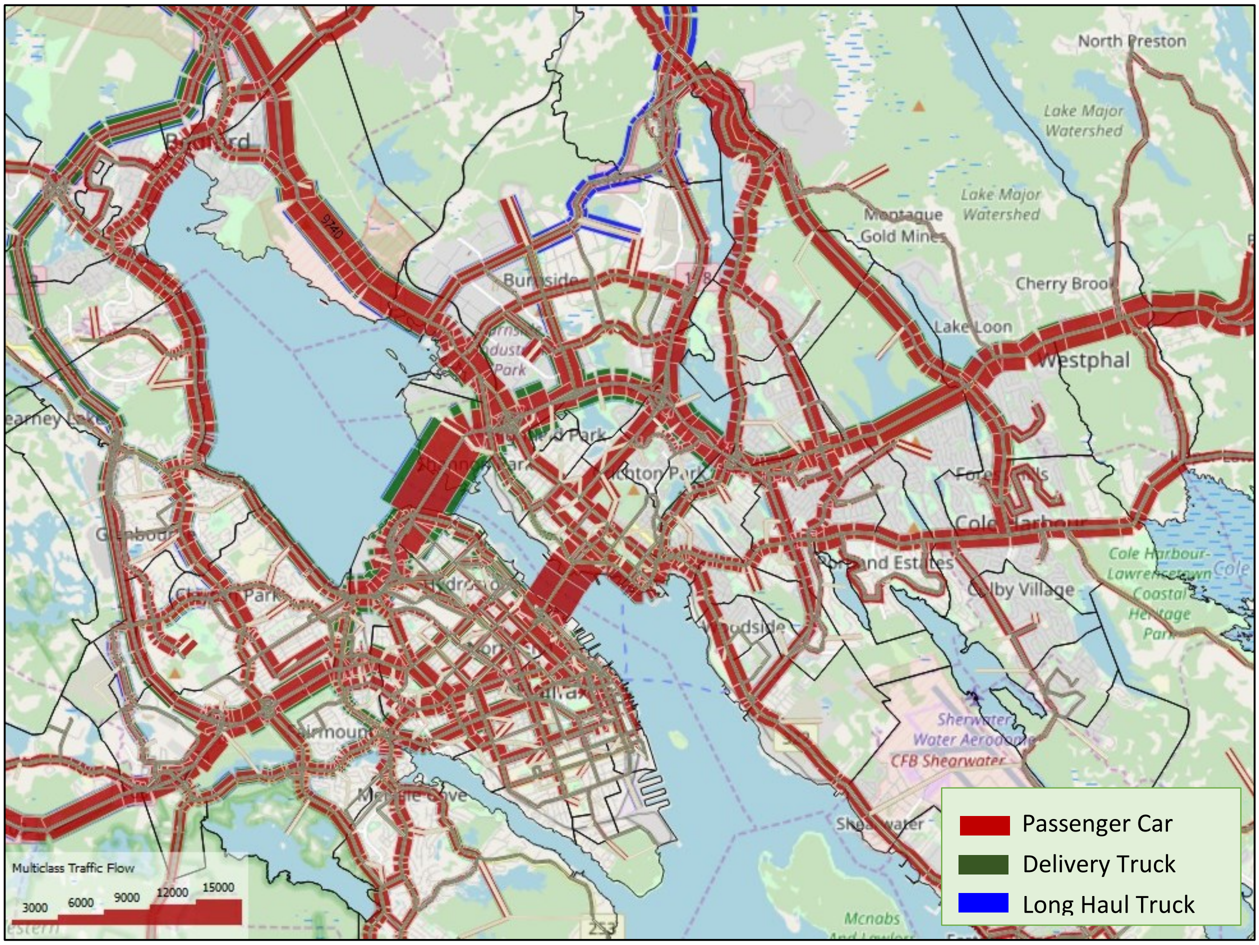

FIGURE 5 Result of multiclass traffic assignment

4.2 Results from emission model

4.2.1 Comparison of Zonal Emission

Table 3 presents a detailed statistics of emission at TAZ level resulted from all traffic operation in HRM. Emission is higher at urban zones compared to the emission at suburban zones.

Table 3 Emission Resulted at Different TAZs in the HRM

Pollutant	Area	Minimum (g/km^2)	25 Percentile (g/km^2)	Average (g/km^2)	Median (g/km^2)	75 Percentile (g/km^2)	Maximum (g/km^2)
GHG	Urban	36.08	543.03	1,562.26	1,210.69	2,473.87	5,106.73
	Suburban	36.42	192.63	383.10	342.55	476.28	1,121.93
	Rural	25.68	148.93	340.64	272.08	490.67	856.17
CO	Urban	2.19	32.92	94.71	73.40	149.97	309.59
	Suburban	2.21	11.68	23.22	20.77	28.87	68.01
	Rural	1.56	9.03	20.65	16.49	29.75	51.90
NOx	Urban	0.16	2.36	6.80	5.27	10.76	22.22
	Suburban	0.16	0.84	1.67	1.49	2.07	4.88
	Rural	0.11	0.65	1.48	1.18	2.14	3.73
PM10	Urban	0.007	0.108	0.309	0.240	0.490	1.011
	Suburban	0.007	0.038	0.076	0.068	0.094	0.222
	Rural	0.005	0.029	0.067	0.054	0.097	0.170
PM2.5	Urban	0.006	0.095	0.274	0.212	0.433	0.895
	Suburban	0.006	0.034	0.067	0.060	0.083	0.197
	Rural	0.004	0.026	0.060	0.048	0.086	0.150
SO2	Urban	0.001	0.010	0.029	0.022	0.045	0.094
	Suburban	0.001	0.004	0.007	0.006	0.009	0.021
	Rural	0.000	0.003	0.006	0.005	0.009	0.016
THC	Urban	0.37	5.61	16.14	12.51	25.56	52.76
	Suburban	0.38	1.99	3.96	3.54	4.92	11.59
	Rural	0.27	1.54	3.52	2.81	5.07	8.85
VOC	Urban	0.37	5.56	15.99	12.39	25.32	52.27
	Suburban	0.37	1.97	3.92	3.51	4.88	11.48
	Rural	0.26	1.52	3.49	2.79	5.02	8.76

Average emission of GHG, CO, NOx, PM_{10}, $PM_{2.5}$, SO_2, THC and VOC in urban areas are 1562.26 gm/km^2, 94.71 gm/km^2, 6.8 gm/km^2, 0.309 gm/km^2, 0.274 gm/km^2, 0.029 gm/km^2, 16.14 gm/km^2, and 15.99 gm/km^2. In case of suburban areas, these values are 383.1 gm/km^2, 23.22 gm/km^2, 1.67 gm/km^2, 0.076 gm/km^2, 0.067 gm/km^2, 0.007 gm/km^2, 3.96 gm/km^2, and 3.92 gm/km^2 respectively. Rural areas experience less emission compared to urban and suburban areas.

4.2.2 Hourly Profiles for Total Emission of Pollutants

Table 4 presents hourly profile of emission from passenger car for all pollutants. Here, wider bar represents larger values of emission.

Table 4 Hourly Profile for Total Emission from Passenger Car

Mode	Time	GHG (ton)	CO (ton)	NOx (ton)	PM_{10} (ton)	$PM_{2.5}$ (ton)	SO_2 (ton)	THC (ton)	VOC (ton)
Passenger Car	12:00-12:59am	9.05	0.28	0.02	0.00	0.00	0.00	0.05	0.06
	1:00-1:59am	12.54	0.38	0.02	0.00	0.00	0.00	0.07	0.09
	2:00-2:59am	1.90	0.06	0.00	0.00	0.00	0.00	0.01	0.01
	3:00-3:59am	6.26	0.19	0.01	0.00	0.00	0.00	0.04	0.04
	4:00-4:59am	12.35	0.38	0.02	0.00	0.00	0.00	0.07	0.09
	5:00-5:59am	37.20	1.14	0.07	0.00	0.00	0.00	0.21	0.26
	6:00-6:59am	84.28	2.57	0.16	0.01	0.01	0.00	0.48	0.59
	7:00-7:59am	206.76	6.31	0.38	0.03	0.02	0.00	1.19	1.45
	8:00-8:59am	183.63	5.61	0.34	0.02	0.02	0.00	1.05	1.29
	9:00-9:59am	93.58	2.86	0.17	0.01	0.01	0.00	0.54	0.66
	10:00-10:59am	93.20	2.85	0.17	0.01	0.01	0.00	0.53	0.66
	11:00-11:59am	104.54	3.19	0.19	0.01	0.01	0.00	0.60	0.74
	12:00-12:59pm	118.23	3.61	0.22	0.01	0.01	0.00	0.68	0.83
	1:00-1:59pm	80.91	2.47	0.15	0.01	0.01	0.00	0.46	0.57
	2:00-2:59pm	120.26	3.67	0.22	0.01	0.01	0.00	0.69	0.85
	3:00-3:59pm	111.94	3.42	0.21	0.01	0.01	0.00	0.64	0.79
	4:00-4:59pm	147.73	4.51	0.27	0.02	0.02	0.00	0.85	1.04
	5:00-5:59pm	151.05	4.61	0.28	0.02	0.02	0.00	0.87	1.06
	6:00-6:59pm	115.96	3.54	0.22	0.01	0.01	0.00	0.66	0.82
	7:00-7:59pm	88.43	2.70	0.16	0.01	0.01	0.00	0.51	0.62
	8:00-8:59pm	61.04	1.86	0.11	0.01	0.01	0.00	0.35	0.43
	9:00-9:59pm	50.18	1.53	0.09	0.01	0.01	0.00	0.29	0.35
	10:00-10:59pm	40.18	1.23	0.07	0.00	0.00	0.00	0.23	0.28
	11:00-11:59pm	35.58	1.09	0.07	0.00	0.00	0.00	0.20	0.25
Daily Total Emission from Passenger Car		**1966.76**	**60.06**	**3.65**	**0.242**	**0.214**	**0.026**	**11.28**	**13.84**

The colored bars show a similar pattern of volume in case of passenger car which generates highest emission during morning peak period. Total emission of GHG, CO, NOx, PM_{10}, $PM_{2.5}$, SO_2, THC, and VOC from passenger car during morning peak hour is 206.76 ton, 6.31 ton, 0.38 ton, 0.03 ton, 0.02 ton, 0.0 ton, 1.19 ton, and 1.45 ton respectively within the HRM. The lowest emission is found from 2:00am to 2:59am and the corresponding values are 1.9 ton, 0.06 ton, 0.0 ton, 0.0 ton, 0.0 ton, 0.0 ton, 0.01 ton, and 0.01 ton respectively. This table also offers daily total emission of these pollutants from passenger car and the values are 1966.76 ton, 60.06 ton, 3.65 ton, 0.0242 ton, 0.214 ton, 0.026 ton, 11.28 ton, and 13.84 ton respectively.

Table 5 Hourly Profile for Total Emission from Different Truck Types

Truck Types	Time	GHG (ton)	CO (ton)	NOx (ton)	PM_{10} (ton)	$PM_{2.5}$ (ton)	SO_2 (ton)	THC (ton)	VOC (ton)
Delivery Truck	7:00-7:59am	22.88	2.05	0.09	0.00	0.00	0.00	0.59	0.59
	8:00-8:59am	63.55	5.69	0.24	0.01	0.01	0.00	1.63	1.65
	9:00-9:59am	109.69	9.82	0.42	0.02	0.01	0.00	2.81	2.84
	10:00-10:59am	129.64	11.61	0.49	0.02	0.01	0.00	3.32	3.36
	11:00-11:59am	134.39	12.03	0.51	0.02	0.02	0.00	3.44	3.48
	12:00-12:59pm	122.52	10.97	0.46	0.02	0.01	0.00	3.14	3.17
	1:00-1:59pm	109.31	9.79	0.41	0.02	0.01	0.00	2.80	2.83
	2:00-2:59pm	95.03	8.51	0.36	0.01	0.01	0.00	2.43	2.46
	3:00-3:59pm	79.61	7.13	0.30	0.01	0.01	0.00	2.04	2.06
	4:00-4:59pm	66.69	5.97	0.25	0.01	0.01	0.00	1.71	1.73
	5:00-5:59pm	55.71	4.99	0.21	0.01	0.01	0.00	1.43	1.44
	6:00-6:59pm	44.23	3.96	0.17	0.01	0.00	0.00	1.13	1.15
	7:00-7:59pm	37.28	3.34	0.14	0.01	0.00	0.00	0.95	0.97
	8:00-8:59pm	30.08	2.69	0.11	0.00	0.00	0.00	0.77	0.78
Long Haul Truck	7:00-7:59am	53.14	3.79	0.35	0.01	0.01	0.00	0.39	0.32
	8:00-8:59am	148.36	10.57	0.96	0.04	0.04	0.00	1.08	0.89
	9:00-9:59am	254.21	18.12	1.65	0.07	0.06	0.01	1.86	1.52
	10:00-10:59am	303.10	21.60	1.97	0.08	0.08	0.01	2.22	1.81
	11:00-11:59am	313.30	22.33	2.04	0.09	0.08	0.01	2.29	1.87
	12:00-12:59pm	286.10	20.39	1.86	0.08	0.07	0.01	2.09	1.71
	1:00-1:59pm	258.89	18.45	1.68	0.07	0.07	0.01	1.89	1.55
	2:00-2:59pm	219.35	15.63	1.43	0.06	0.06	0.00	1.60	1.31
	3:00-3:59pm	185.35	13.21	1.21	0.05	0.05	0.00	1.36	1.11
	4:00-4:59pm	155.59	11.09	1.01	0.04	0.04	0.00	1.14	0.93
	5:00-5:59pm	129.23	9.21	0.84	0.04	0.03	0.00	0.94	0.77
	6:00-6:59pm	103.30	7.36	0.67	0.03	0.03	0.00	0.76	0.62
	7:00-7:59pm	87.15	6.21	0.57	0.02	0.02	0.00	0.64	0.52
	8:00-8:59pm	70.99	5.06	0.46	0.02	0.02	0.00	0.52	0.42
Daily Total Emission from Trucks		**3668.66**	**281.58**	**20.87**	**0.87**	**0.77**	**0.08**	**46.95**	**43.85**

Table 5 presents hourly profile of emission from delivery and long haul trucks. Emission generated from these trucks also poses similar pattern of their hourly volume profile. Maximum emission occurs during mid-day period starting from 11:00am to 12:59pm. Compared to delivery truck, long haul truck is the main contributor to the emission of GHG, CO, NOx, PM_{10}, $PM_{2.5}$, and SO_2. Delivery truck significantly contributes to the emission of THC, and VOC. Total daily emission of GHG, CO, NOx, PM_{10}, $PM_{2.5}$, SO_2, THC, and VOC generated from all trucks is 3668.66 ton, 281.58 ton, 20.87 ton, 0.87 ton, 0.77 ton, 0.08 ton, 46.95 ton, and 43.85 ton respectively.

5 CONCLUSION

This study developed an enhanced travel demand forecasting model that includes trip-based passenger car movement and tour-based delivery truck movement to perform a multiclass traffic assignment within the Halifax transport network. A NovaTRAC travel activity survey is used to inform passenger car demand modeling with 24-hour travel log information. A novel approach of Monte Carlo simulation technique is proposed to determine different tour attributes from a rich firm-level data source. The model was extensively calibrated and validated using video image processing-based traffic count data and HRM traffic count dataset. This study offers a better understanding of the spatial and temporal distribution of commercial vehicle movement in combination with passenger cars in Halifax.

The study found that passenger car flow is maximum during evening peak period. Solely downtown core experiences 45.53% of total daily car flows. Passenger car comprises the major portion the traffic flows in Halifax. In the case of truck flows, 52.29% of total delivery truck movement and 12.5% of total long haul truck movements occur within the urban core. 64.6% of long haul truck movement occurs through Truro. Results from the delivery truck tour model indicate that firms are likely to complete their deliveries in between morning and evening peak periods. The anticipated commercial vehicle flow results will be useful to determine the dimensions of the infrastructures on and around industrial sites that are being planned. This research will offer better integration of spatial and traffic planning by providing information about the effects of industrial activities on transport and traffic in early stages of the planning process of industrial areas.

The emission results found commercial vehicles as a significant contributor to the network emissions. In the morning, emissions are mainly associated with passenger cars; however, as the day passes, emissions increase with the number of trucks on the road. The maximum emission is estimated during evening peak period when the number of both passenger cars and trucks are maximum on the road network. The study results reveal that emission is higher at urban zones compared to the emission at suburban zones. Rural areas experience less emission compared to urban and suburban areas. This model captured the trip changing behavior of delivery truck which is reflected in higher emission within urban zones.

Nevertheless, the multiclass traffic network model developed in this study can be used by the policy makers to implement different regional-level transport policies for future emission reductions. The study provides a baseline emission utilizing the proposed comprehensive framework of multiclass transport network and emission modeling. These information will be useful for tracking progress to meet the target outlined in the sustainable transportation strategy 2013 adopted by Nova Scotia Department of Energy.

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