MICROSIMULATING EMISSIONS AND POPULATION EXPOSURE IN DOWNTOWN TORONTO

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ABSTRACT

Air pollution from vehicles is a major health issue, and is most problematic for people located adjacent to heavily traveled and congested roadways. The purpose of this paper is to describe an air quality pollution modelling system developed for the Toronto Waterfront Area and to describe the application of the system to a set of scenarios related to the conversion of medium duty trucks to low emission vehicles. This research analyses the impact of converting medium duty trucks (MDT) to ultra-low emission vehicles (ULEV) in the downtown Toronto. The integrated tool used in this study models traffic at the individual vehicle level, estimates individual link emissions, estimates how emissions are dispersed through the atmosphere to neighbouring communities under given weather conditions; and finally estimates the exposed population at times of peak emissions.

Keywords: Microsimulation, Vehicle emission, Dispersion modelling, Population exposure

INTRODUCTION

Poor air quality is a significant health threat in large cities in developed and developing countries. According to the World Health Organization, air pollution leads to over two million premature deaths each year (WHO, 2006). People living in the City of Toronto and its surrounding regions, especially those living adjacent to congested freeways, are experiencing air quality impacts (Environics Research Group, 2002). In the Toronto Area, the transportation sector is a major emitter of air pollutants, producing almost three quarters of carbon monoxide (CO) emissions, over half of nitrogen oxide (NOx) emissions, and over one-quarter of hydrocarbons (HC) affecting air quality (Statistics Canada, 2006). As a result, governments have introduced policies to improve the air quality. These policies include, for example, tightening vehicle emission standards, subsidy programs for the purchase of low-emission vehicles, and tax changes (Demerse and Bramley, 2008). In order to deliver more effective policies, governments need to be able to model the impact of the transportation system on the air quality and be able to compare the effect of different policies.

Over the last decade, research activity focused on modelling of on-road vehicle emissions has increased substantially. Until recently, most emissions studies have used a three step approach: 1) calculate the average speed on each link (roadway segment), 2) estimate the emission rate for each link for each vehicle type and model year, and 3) calculate the total emissions for each time interval and pollutant by multiplying the emission rate by the vehicle kilometres travelled (VKT). Models following this approach include Mobile6 (US Environmental Protection Agency, 2003), COPERT-4 (European Environment Agency, 2011), and EMFAC (California Environment Protection Agency, 2009). Examples of applications of such models can be found in Gokhale (2012), Hatzopoulou (2011), and Potoglou and Kanaroglou (2005).

Lv and Zhang (2012) and Xie et al. (2012) used microscopic traffic simulation models (Paramics or Vissim) to more accurately estimate the traffic parameters used in estimating the emission factors. However, a wide variety of drive cycles can result in the same average speed. The accuracy of emissions models that rely on average speed is limited because the accuracy of an emissions model highly depends on its ability to capture fluctuations in the speed (Ahn and Rakha, 2008). Recently, methodologies for emissions estimation incorporating fluctuations in speed have been developed. Models using this approach include Comprehensive Modal Emission Model (CMEM) (Barth et al., 2000), and MOtor Vehicle Emission Simulator (MOVES) (United States Environmental Protection Agency, 2009). Examples of applications of such models can be found in Brownstone et al. (2008), Noland and Quddus (2006), and Boriboonsomsin and Barth (2007; 2008).

Dispersion models are required to estimate the dispersion of on road emissions and the pollution concentration at different points in space. Dispersion modelling is the application of mathematical formulations that assess atmospheric conditions (e.g., atmospheric stability) and describe processes that explain plume movement to estimate pollutant concentrations at receptor locations. Dispersion models have been generally classified into Box models, Gaussian models, Lagrangian models, Computational Fluid Dynamics (CFD) models and models that include aerosol dynamics (Holmes and Morawska, 2006).

Population exposure models are required to estimate the final impact of the pollutants on people's health. There are a few studies that use hybrid traffic-emission- dispersion models to estimate population exposure (Beckx et al., 2009; Hatzopoulou et al., 2011; Lim et al., 2005). To the best of our knowledge, however, no study has integrated a microscopic traffic simulation, an emissions model, and dispersion models to estimate population exposure to emission. This paper estimates NOx, CO, and HC concentrations for the Toronto Waterfront Area (Figure 1), using an integrated modelling system for the analysis of microscopic vehicle movements, emissions, emission dispersion, population location, and population exposure.

The paper further estimated emission reduction for scenarios where gasoline and diesel MDTS are converted to ULEVs.

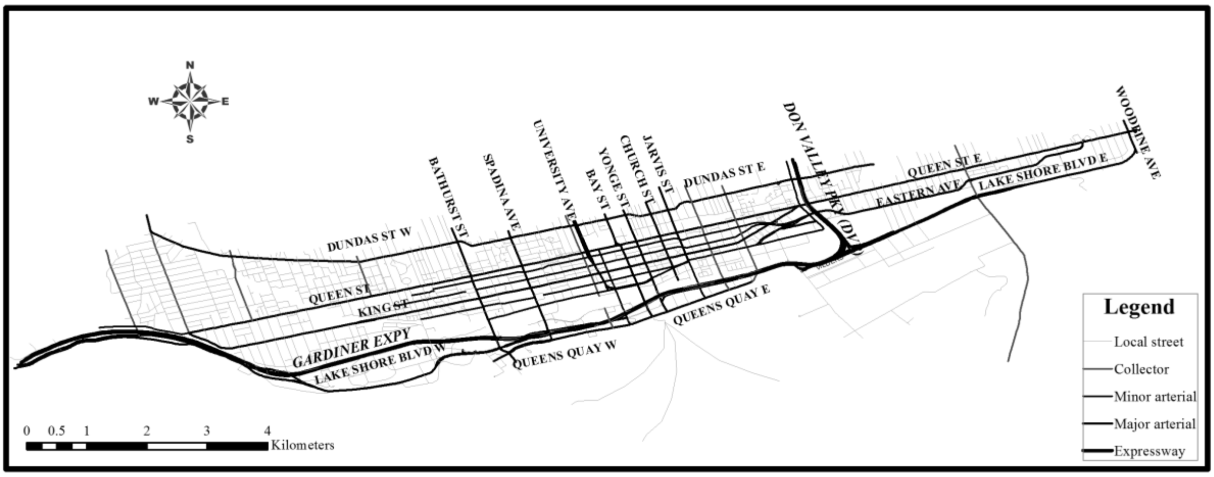

Figure 1- The Toronto Waterfront Area

INTEGRATED MODELLING SYSTEM

Detailed explanation about the modelling system can be found in Amirjamshidi et al (2013).This section provides a summary of each step to provide the necessary background for the reader before focusing on the results. The integrated modelling system (Figure 2) starts with the regional demand model that was generated using a multiclass generalized cost static user equilibrium assignment (in the EMME modelling software) for the Greater Toronto and Hamilton Area (GTHA) for light, medium and heavy trucks and passenger cars. The steps for this stage and the data sources used to develop the model are described in detail in Roorda et al. (2010).

The second model component is a microscopic traffic simulation model that explicitly represents the acceleration and deceleration patterns of vehicles in congestion, which are essential for the estimation of vehicle emissions. The software selected for this modelling step is Paramics (Quadstone Paramics Ltd.). The model was calibrated and validated to represent 2009 traffic conditions using a two-step calibration / validation for the AM peak hour (8-9 am.). The calibrated parameters were: headway of 1.85 seconds, reaction time of 0.65 seconds, 2 time-steps per second, a feedback period of 2 minutes, 90% familiarity in the drivers in the network, 5% perturbation and a distance cost coefficient of zero.

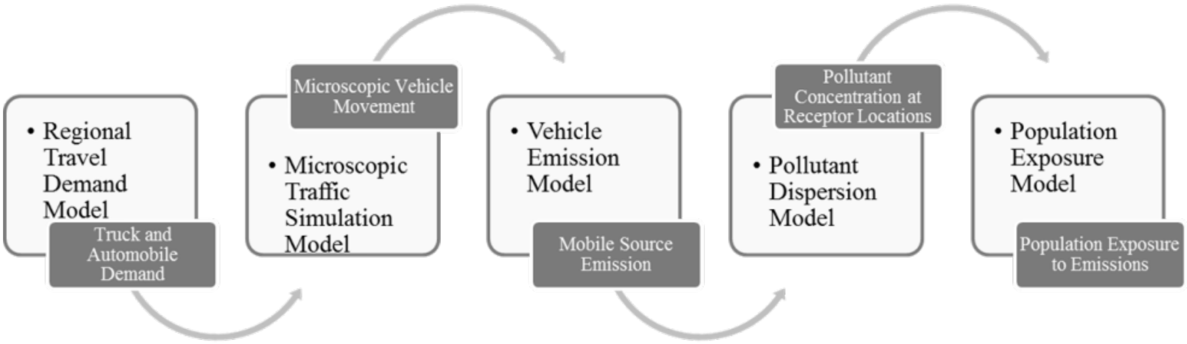

Figure 2- Integrated modelling system for estimating population exposure to emissions

The model was validated using GPS data for medium and heavy duty trucks made available by Turnpike Global Technologies (TGT) for a three month period in 2009. The Ontario's Ministry of Transportation (MTO) provided probe vehicle speed data from their travel time survey which were used as an additional source of data for model validation (MTO, 2009). Details of this calibration can be found in Amirjamshidi and Roorda (2011).

CMEM was selected as the microscopic emissions simulation model for this project; and predicts second-by-second tailpipe emissions of CO_2, CO, HC and NO_x emissions and fuel consumption based on different modal operations of the vehicles in the fleet. The required inputs for CMEM include vehicle activity (second-by-second speed profile) and fleet composition of traffic. The most recent version of CMEM, used in this project, has 28 light duty vehicle/technology categories and 3 heavy duty vehicle/technology categories. These vehicle classifications are more detailed than the four vehicle classifications that are the outcome of the travel demand models (passenger cars, light duty trucks, medium duty truck and heavy duty trucks). Multiple data sources such as the 2009 Canadian Vehicle Survey (Statistics Canada, 2010), sales information of the most popular passenger cars sold in Canada for 2009, personal communication with experts from the DesRosiers Automotive Consultants Inc., and CMEM default values were used to estimate the fleet composition for the study area. A Monte Carlo simulation was used to assign a vehicle type to individual vehicles in the network. More detail about this step can be found in Amirjamshidi et al (2013) .

The fourth component of the modelling suite uses a Gaussian distribution curve in both the vertical and the cross-wind directions, assuming a plume rise of zero (the height of the plume above the point of emission), the receptor height of 1.6 m (which is the average breathing height of an average individual (Ishaque and Noland, 2008)), and the predominant wind direction being from west to east with an average speed of 3.25 m/s. The dispersion model was coded in a Geographic Information System (GIS) incorporating the pollution emissions resulting from the CMEM model. The result of this section is pollution concentration at each receptor location (assumed to be the zone centroids in the network) during the modelling period.

The last component of the modelling system estimates population exposure to emissions as a multiplication of the pollutant concentration and the population density at each zone centroid. Data from the 2006 Transportation Tomorrow Survey (TTS) (DMG, 2008) and EMME3 modelled travel times were used for the analysis. Population distribution by time of day was then determined. Figure 3 shows the population density distribution for the 8:30 AM analysis period. At this time, many people are either en route to or have arrived at their workplace. As expected, this results in a high population density in the Central Business Districts of Toronto, Mississauga, Hamilton, and the downtown Whitby-Oshawa area. More detail on this step can be found in Amirjamshidi et al (2013).

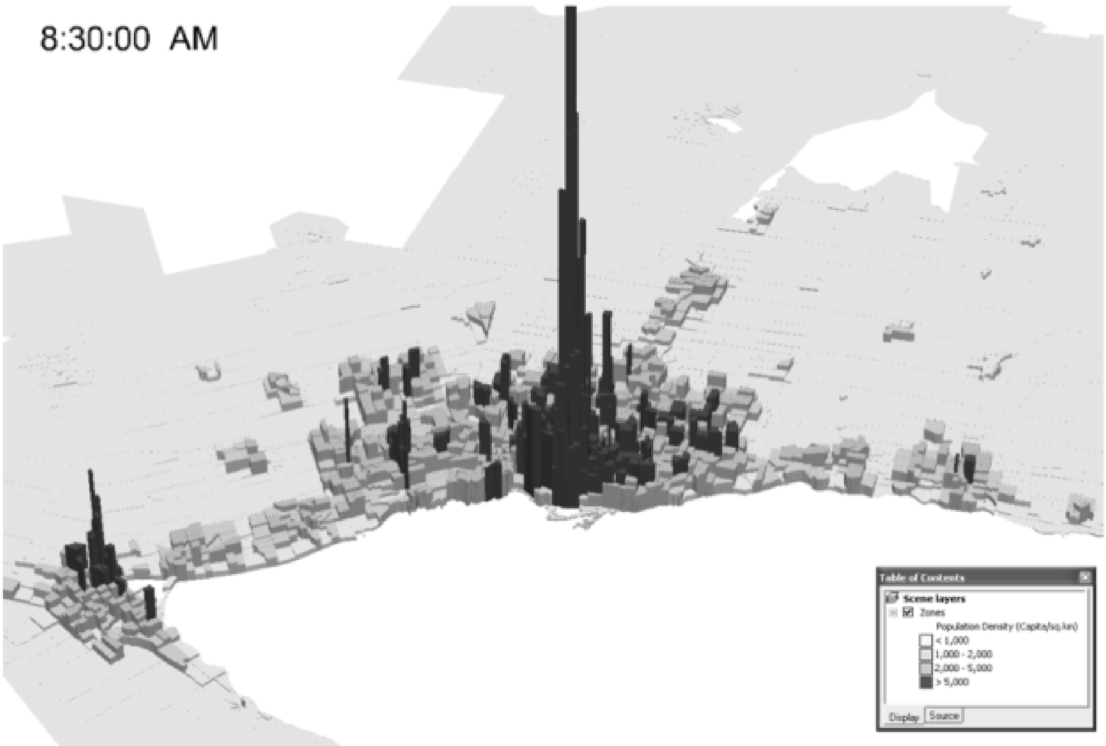

Figure 3- GTHA zonal population density distribution- 8:30 AM

BASE CASE RESULTS

Emission results

The results of the CMEM emission model are CO_2, CO, HC and NO_x emissions for each roadway link (Figure 4). The following observations can be made.

- Emissions are highest on the high capacity roadways, including the Gardiner Expressway, Don Valley Parkway, Lakeshore Blvd, and University Avenue.
- Vehicle emissions tend to be higher in the inbound direction in the am peak hour. This is because there are a greater number of vehicles traveling inbound at that time of day.
- NOx emission factors are higher in the Portlands Area, an industrial district on the waterfront to the east of Downtown, where truck traffic is a greater proportion of traffic flow. Since diesel fuelled vehicles contribute a disproportionate share of NOx emissions, this result is intuitive.

- For emission factors, fuel rate is most highly correlated with CO2 and HC emission factors. This makes sense because CO2 is a normal by-product of fuel consumption, and HC is simply unburned fuel.
- CO emission factors follow a somewhat different pattern than other pollutants and tend to be higher on a smaller number of heavily travelled routes.

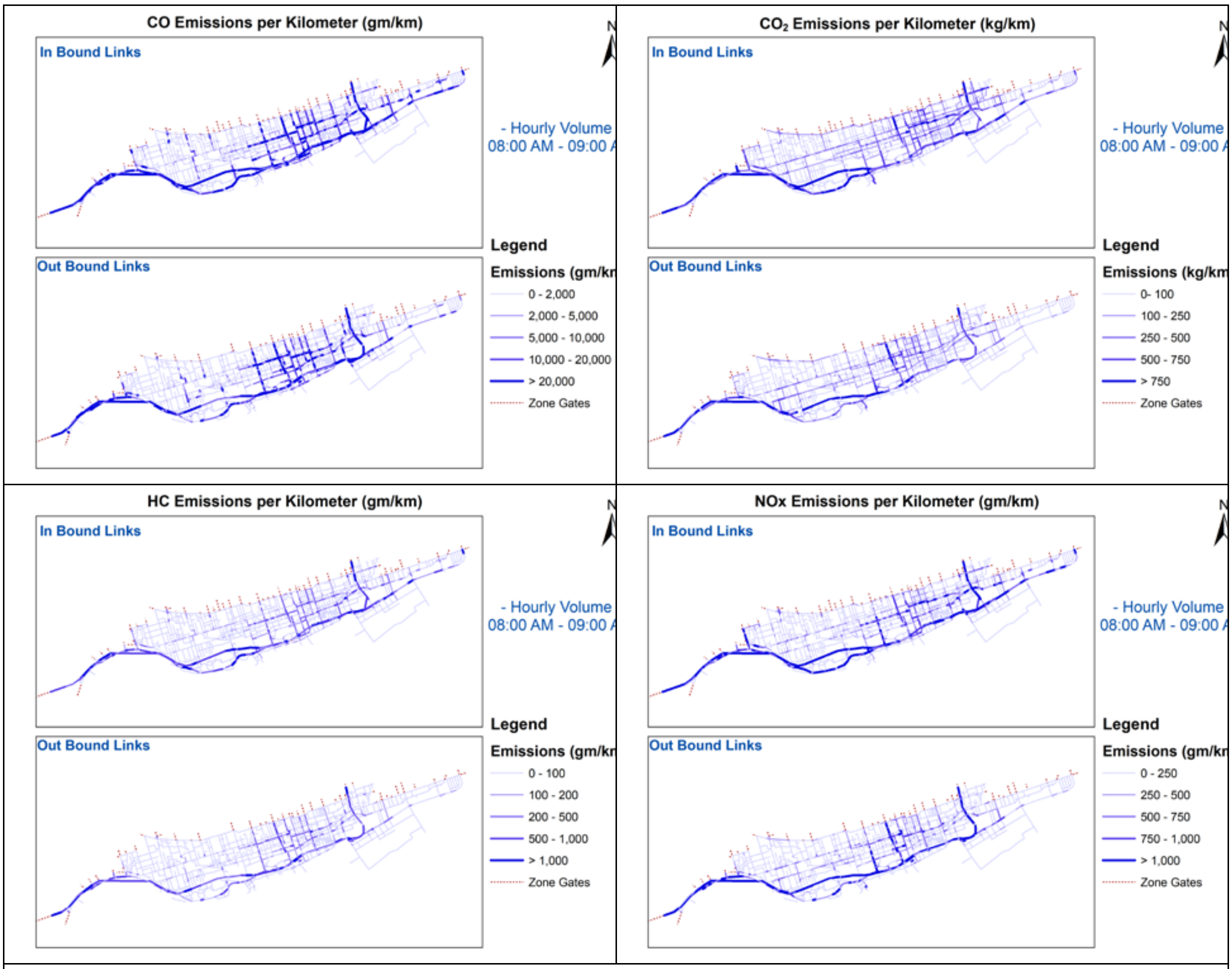

Figure 4- Emissions per roadway kilometre (gm/km) between 8 and 9 AM for CO, Co2, HC and NOx

Dispersion results

The results of this model are am peak hour CO, NOx, and HC pollution concentrations (gm/m3) for the waterfront area calculated at zone centroids (Figure 5). CO2 concentrations are neglected in the analysis because CO2 is not considered a criteria pollutant, even though the emitted CO2 is obviously important because of its role as a greenhouse gas. The following observations can be made.

- In the am peak hour, pollutant concentrations (from vehicle sources) at all zone centroids are less than standards mandated by Environment Canada.
- Zones along the Gardiner Expressway/Lakeshore Blvd/Don Valley Parkway corridor are experiencing relatively high pollution concentrations, mainly because these roadways are the largest sources of vehicle emissions.
- The wind direction is west to east, which leads NOx emissions generated in downtown Toronto and on the Don Valley Parkway/Gardiner Expressway to disperse in an eastward

direction. In addition, the high pollutant concentration just east of the downtown core confirms this dispersion pattern.
- Boundary zones exhibit low pollutant concentration, but it is important to view boundary zone concentrations with caution, since pollutants from roads outside the study area are not included in these estimates.

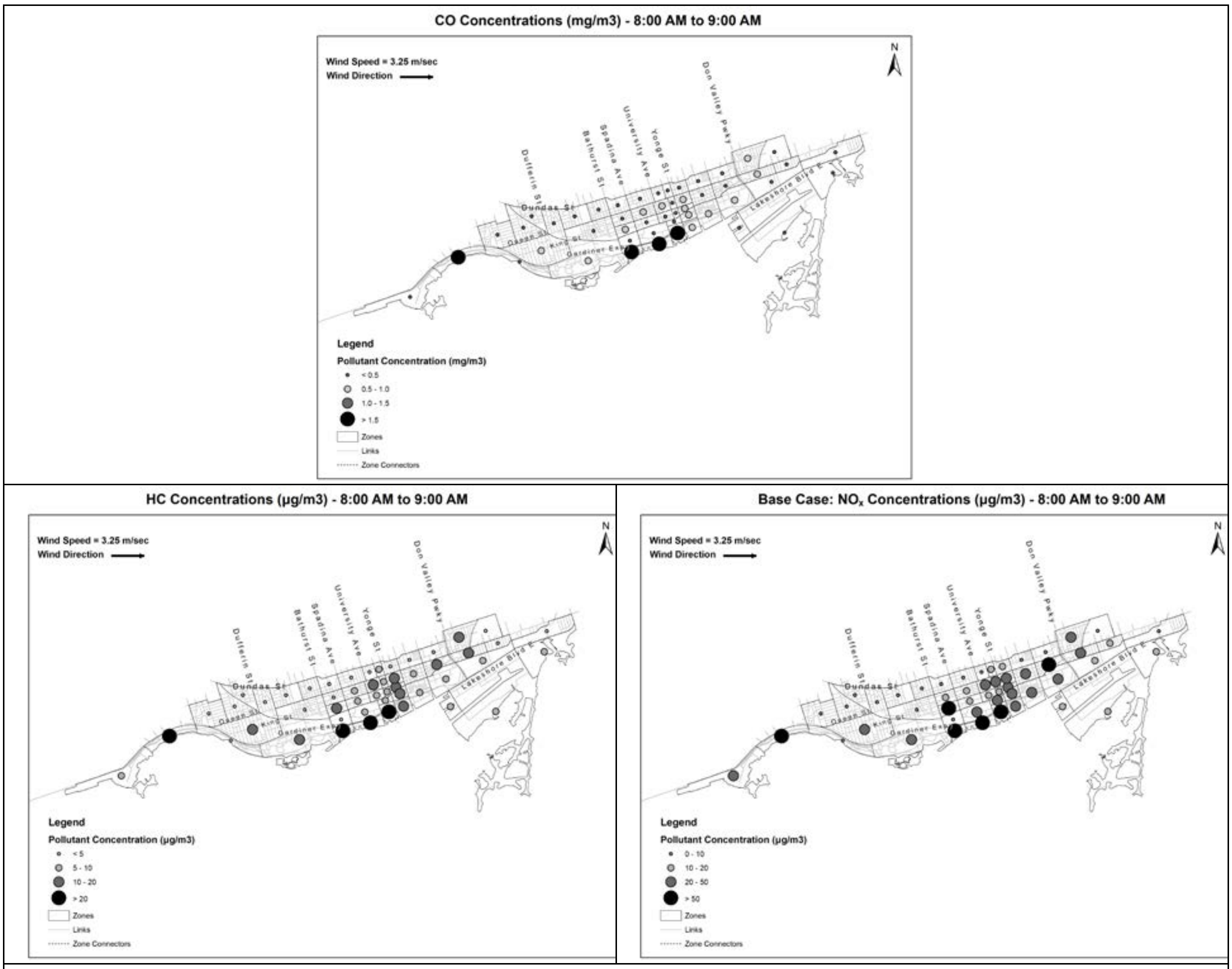

Figure 5- Pollution concentration (gr/m3) for CO, HC and NOx between 8 and 9 AM

Population exposure

Population exposure to emissions was estimated simply as a multiplication of the population located in each zone and the pollutant concentration at the zone centroid (Figure 6). Figure 6 shows a different pattern from the distribution of pollutant concentrations shown in Figure 5, because the zones in the central business district, which have moderate/high relative pollutant concentrations (as shown in Figure 5), have also very high population during the AM peak hour (shown in Figure 6).

Figure 6- Population exposure for CO, HC and NOx between 8 and 9 AM

SCENARIO ANALYSIS

The integrated modelling system was used to evaluate scenarios that reflect investment toward the conversion of medium duty trucks (MDT) to ultra-low emission vehicles (ULEV). The following three scenarios were tested:

Scenario A: Convert 100% of gasoline medium duty trucks to ultra-low emission vehicles

Scenario B: Convert 100% of diesel medium duty trucks to ultra-low emission vehicles

Scenario C: Convert 100% of gasoline and diesel medium duty trucks to ultra-low emission vehicles.

This set of scenarios reflects the maximum achievable reduction given readily available engine technologies, and assuming full participation of all companies whose medium duty trucks access the Toronto Waterfront Area. In the AM peak hour, medium duty trucks comprise approximately 2.5% of all vehicles travelling in the Toronto Waterfront Area. As mentioned in Section 5, 87% of these medium duty trucks are diesel fuelled, and 13% are gasoline powered (Statistics Canada, 2009).

The network emission and pollution concentration reduction at zone centroids that result from these vehicle technology conversions were calculated (Figure 7). It was seen that:

- NOx emissions are reduced by 12% and almost all of this reduction is due to the conversion of diesel powered trucks. This major reduction is expected because NOx is a by-product of diesel fuel combustion.
- HC emissions are reduced by over 4%, and all of this reduction is a result of the conversion of diesel powered trucks. Notably, HC emissions are over-represented in diesel powered vehicles.
- A slight increase in CO emissions is observed for Scenarios B and C. This occurs because gasoline powered vehicles emit the majority of CO. Thus, the conversion of diesel powered medium duty trucks to ultra-low emission vehicles, which are gasoline powered, results in a slight increase in CO.
- Pollution concentration reductions are small for NOx and HC over all zones for Scenario A, and larger for scenarios B and C.

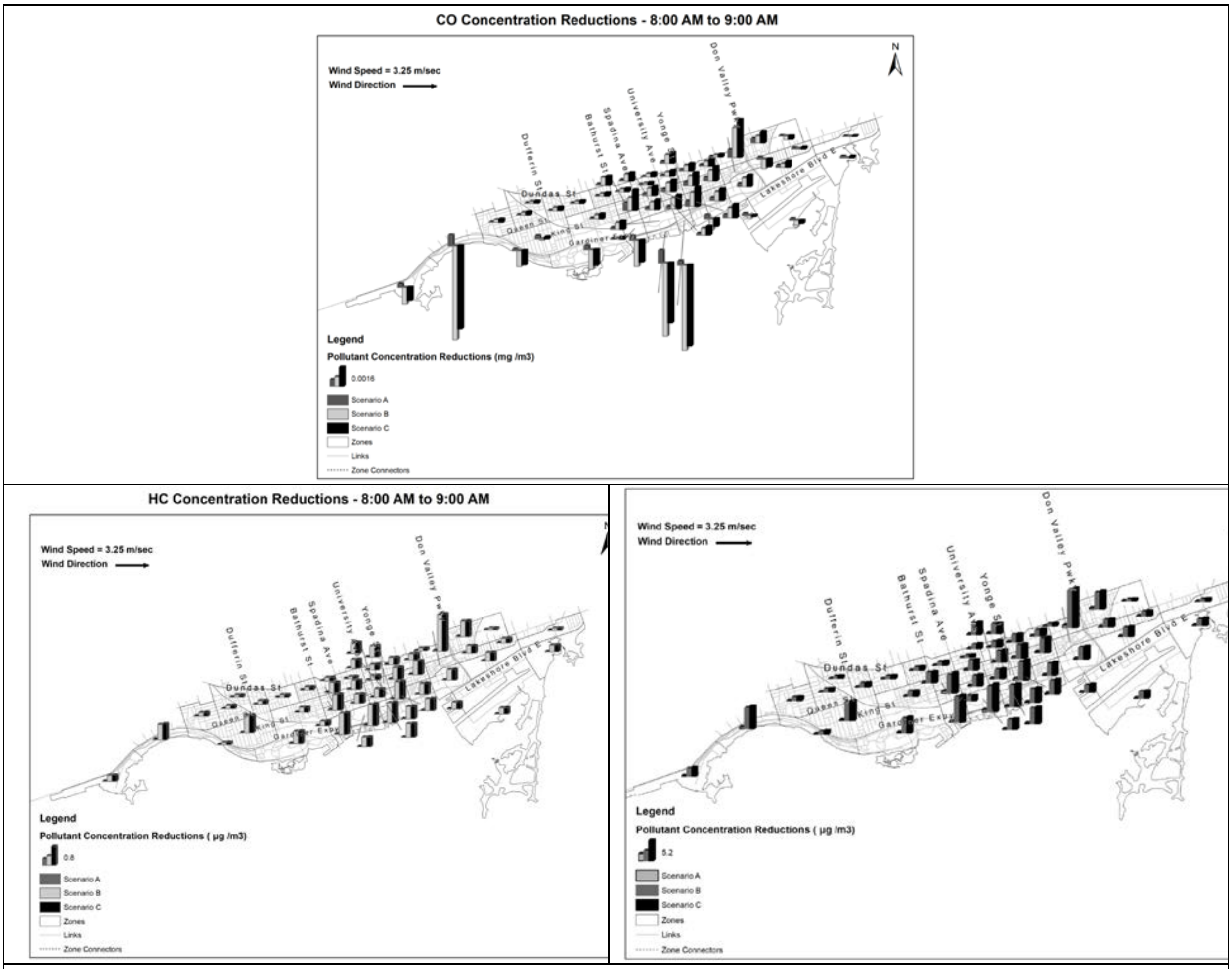

Figure 7- Pollution concentration reduction (gr/m3) for CO, HC and NOx between 8 and 9 AM for scenarios A, B, and C

CONCLUSIONS

This paper estimated NOx, CO, and HC concentrations for the Toronto Waterfront Area, using an integrated modelling system for the analysis of microscopic vehicle movements, emissions, emission dispersion, population location, and population exposure. The paper further estimated emission reduction for scenarios where gasoline and diesel MDTS are converted to ULEVs. The main findings of the model application are as follows:

- Within the Toronto Waterfront Area, emissions of HC, CO, CO2 and NOx are highest on the high capacity roadways, including the Gardiner Expressway, Lakeshore Blvd, and University Avenue, and are higher in the peak directions;
- Emission factors (emissions/vehicle kilometer travelled) vary over each roadway segment in the network because of the unique speed acceleration profile and traffic composition on each roadway. This justifies the use of a microscopic simulation of emissions rather than an emission factor model, if localized air pollution is of interest;
- CO, NOx and HC vehicle emissions lead to pollutant concentrations at zone centroids that are within recommended levels (Environment Canada, 2011) on a day with typical wind direction and average wind speed;
- Zones along the Gardiner Expressway, Lakeshore Blvd, and the Don Valley Parkway experience higher pollutant concentrations than other zones, because these roadways are the largest sources of vehicle emissions;
- The greatest daytime populations in the GTHA are within the central core of Toronto. It is assumed that people within a zone are potentially experiencing pollution that is measured at zone centroids. Under this assumption, the areas of greatest concern are those very densely populated zones in the Central Business District of Toronto and the Central Waterfront, and densely populated areas near the major highways (such as the Parkdale neighbourhood). In these zones, both emissions and population are high during peak hours of travel, resulting in higher potential exposure to vehicle emissions;
- NOx and HC emissions are reduced significantly when diesel powered medium duty trucks are converted to ultra-low emission vehicles. In the AM peak hour, for example, a 100% conversion of diesel powered medium duty trucks (which represents 2.2% of total vehicles in the AM peak hour) is estimated to reduce total HC and NOx emissions by 4% and almost 12%, respectively.

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