Microsimulating Emissions and Population Exposure in Downtown Toronto

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Introduction

Air pollution is a major health issue for Ontarians, especially those living adjacent to congested freeways in the City of Toronto and the surrounding regions (Environics Research Group 2002). The purpose of this paper is to describe an air quality pollution modelling system developed for the Toronto Waterfront Area (Figure 1). Figure 2 shows the integrated modelling system that was developed which includes regional travel demand models for the Greater Toronto and Hamilton Area (GTHA), a microscopic traffic simulation model of the Toronto Waterfront Area, a model of vehicle emissions that is sensitive to vehicle driving cycles, a model of pollutant dispersion, and an assessment of population location by time of day for estimating personal exposure to vehicle generated emissions.

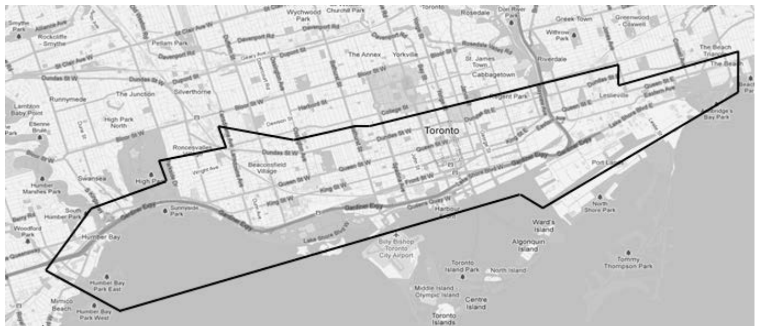

Figure 1-The Waterfront Toronto Area

In the first step, the origin-destination (OD) matrices required for the microsimulation model were produced using a regional travel demand model. These preliminary demand inputs were generated through a multiclass generalized cost static user equilibrium assignment for the Greater Toronto and Hamilton Area (GTHA) for light, medium and heavy trucks and passenger cars. More detail about the demand modeling approach is presented in Roorda et al. (2010). The second step is a microscopic traffic simulation model (in Paramics) that was extensively calibrated and is described in full detail in Amirjamshidi and Roorda (2011).

This paper focuses on the last three steps shown on Figure 2. The paper is organized as follows. Each modelling step is discussed in one section followed by the results of the model. The last section provides a summary of the conclusions for each model.

Vehicle Emission Modelling

Until recently most emissions studies have used the average speed models, such as Mobile6 (US Environment Protection Agency 2003), using 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 kilometers travelled (VKT). Examples of applications of such models in the GTHA can be found in Potoglou and Kanaroglou (2005) and Hatzopoulou (2011).

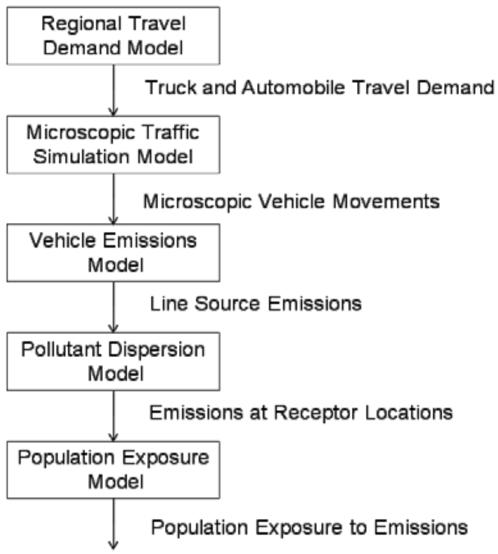

Figure 2-Integrated Modelling System for Estimating Human Exposure to Emissions

The problem with this method is that due to potential differences in speed and acceleration, average speed methods result in approximate emission estimates. However the accuracy of an emissions model highly depends on its ability to capture fluctuations in the speed. Recently, research in the field of emissions modelling has focused on developing better methodologies for emissions estimation incorporating fluctuations in speed. Models using this approach include Comprehensive Modal Emission Model (CMEM) (University of California 2009), and MOtor Vehicle Emission Simulator (MOVES) (United States Environmental Protection Agency 2009).

CMEM has been selected for this project. CMEM is microscopic in that it predicts second-by-second tailpipe emissions and fuel consumption based on different modal operations of the vehicles in the fleet. In CMEM, the fuel consumption and emissions process is broken down into components based on the physical phenomena associated with vehicle operation and emissions production. Each of these components is modelled separately with an analytical representation involving parameters that vary according to the vehicle type, engine, emission technology, and level of deterioration (University of California 2009). Applications of the Paramics/CMEM combination have been widely reported in the literature for estimating on-road vehicle emissions (Brownstone et al. 2008, Boriboonsomsin and Barth 2007, 2008, Noland and Quddus 2006).

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. Passenger vehicles are classified into different CMEM categories based on model year, odometer mileage, power-to-weight ratio, technology (e.g. carbureted engine, low emission vehicle), and presence of engine problems that result in high emission. Light duty trucks are distinguished based on model year, vehicle weight, power-to-weight ratio, and presence of engine problems that result in high emission. Medium duty trucks are distinguished according to the fuel used (gasoline versus diesel). Finally, heavy duty diesel trucks are distinguished according to vehicle age.

Distribution of model year was determined based on the vehicle age distribution obtained from the 2009 Canadian Vehicle Survey (Statistics Canada 2010). An average odometer mileage of 16,000 kilometers was also assumed based on data obtained from the 2009 Canadian Vehicle Survey. The distribution of vehicle power-to-weight ratio was determined based on the sales information of the most popular passenger cars sold in Canada for 2009, leading to an average distribution of 20% low and 80% high power to weight ratio. 0% carbureted engines and 0.29% ultra low emission vehicles were assumed based on information from internet sources and a consultant report (DesRosiers 2010). The proportion of vehicles with engine problems was based on CMEM default values, since no Canadaspecific information was found. Based on information available from the Canadian Vehicle Survey (Statistics Canada 2010), 13% of medium duty trucks were assigned to be gasoline powered and 87% to be diesel powered. Heavy duty trucks were divided into 3 CMEM vehicle categories based on the vehicle age distribution from the 2009 Canadian Vehicle Survey.

Emissions Results

The CMEM emissions model was used to calculate CO_2, CO, HC and NOx emissions, and fuel consumption for each roadway link. As an example, Figure 3 shows the total CO emissions (grams per kilometer) for the AM peak hour. The following observations can be made about this graph:

- 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 travelling inbound at that time of day.
- For all emission types, there are significant differences in emission factors throughout the network.

Dispersion Modelling

The fourth component of the integrated modelling suite assesses how vehicle emissions are dispersed in the air to result in human exposure to these emissions. 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).

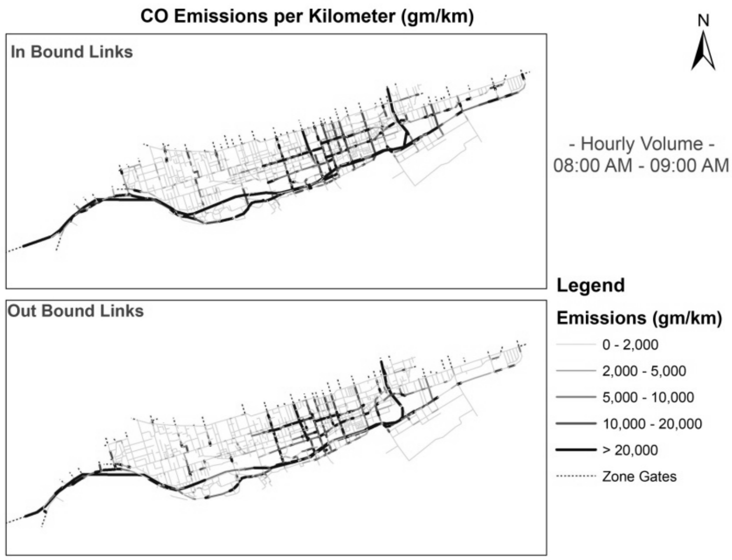

Figure 3- CO Emissions per Roadway Kilometer (gm/km)

Most air dispersion models used for regulatory purposes are based on the Gaussian model (Holmes, Morawska 2006), including the US Environmental Protection Agency preferred regulatory models for both near-field and long-range applications (US Environmental Protection Agency 2011). Based on the level of complexity and size of the study network, a Gaussian plume model was selected for this project because of its simplicity, reasonable data requirements and computational performance.

Pollutant concentrations are described using a Gaussian distribution curve in both the vertical and the cross-wind directions. Plume rise (the height of the plume above the point of emission) was assumed to be zero and the receptor height was fixed at the breathing height of an average individual (1.6m as used by Ishaque and Noland, 2008). The net pollutant concentration at any given receptor location due to a point source is a function of the downwind movement of the plume as well as the cross-wind and vertical plume distributions.

The AERMET meteorological model (Lakes Environmental 2011) was used to obtain wind rose patterns for a period from September 2009 to December 2009 for the AM peak period. The predominant wind direction was estimated to be from west to east with an average speed of 3.25 m/s.

The dispersion model described above was coded in a Geographic Information System (GIS) incorporating the pollution emission rates resulting from the CMEM model. The results of this model are AM Peak hour pollution concentrations (gm/m^3) for the Toronto Waterfront network calculated at zone centroids. Figure 4 shows the model results of CO pollution concentration, as an example. The following observations were made:

- In the AM peak hour, CO pollutant concentrations (from vehicle sources) at all zone centroids are far lower than the Environment Canada standard for CO pollution concentration of 35 mg/m^3.
- 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.
- Zones in residential areas tend to experience lower CO concentration, whereas zones in the central core of the city experience higher concentration.
- 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.

A caveat to this analysis is that pollutant concentration at zone centroids is generally lower than what would be expected at the roadside. Pollutant concentrations dilute rapidly at distances of 5 to 10 meters from the source. Thus, it is expected that people walking on sidewalks, waiting for a bus, cycling or using the street in other ways would experience higher levels of pollutant concentrations.

CO Concentrations (mg/m3) - 8:00 AM to 9:00 AM

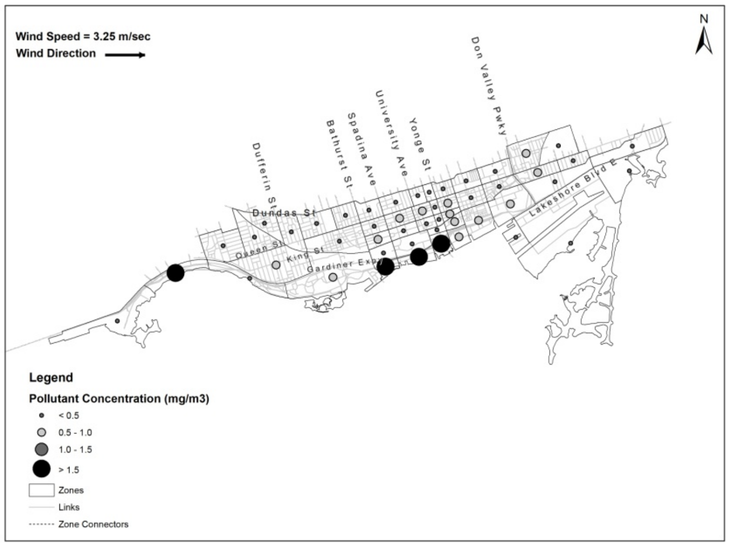

Figure 4- CO Pollution Concentration at Zone Centroids (mg/m^3)

Population Location and Exposure

The final component of the modelling system shown in Figure 2 estimates population location by time of day for assessing personal exposure to vehicle generated emissions. By comparing pollutant concentrations and population density in a zone, potential population exposure can be estimated simply by multiplying the population density and the pollutant concentration at each zone. A zone-based time-varying population density distribution is developed for this purpose.

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 5 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.

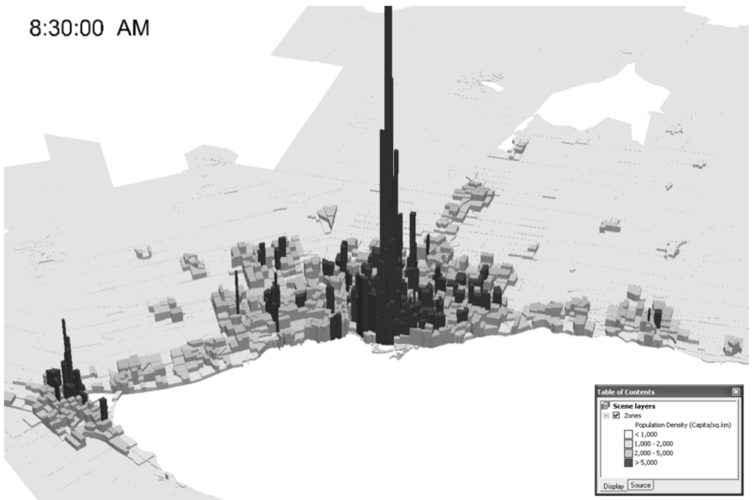

Figure 5- GTHA Zonal Population density Distribution- 8:30 AM

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 shows the outcome of this multiplication for the AM peak hour for CO emissions. The figure shows a rather different pattern from the distribution of pollutant concentrations shown in Figure 4. That is because the zones in the central business district, which have moderate/high relative CO pollutant concentrations, highlighted in Figure 5, have also very high population during the AM peak hour. Notable levels of exposure are also found in the Parkdale neighbourhood (located in the vicinity of the intersection of Dufferin and King Streets) and the Central Waterfront Area, as population density is relatively high and greater pollution concentrations are generated from the Gardiner Expressway / Lakeshore Blvd corridor. Other locations along the Gardiner Expressway / DVP do not result in the same high levels of population exposure to CO because of the lower adjacent population densities.

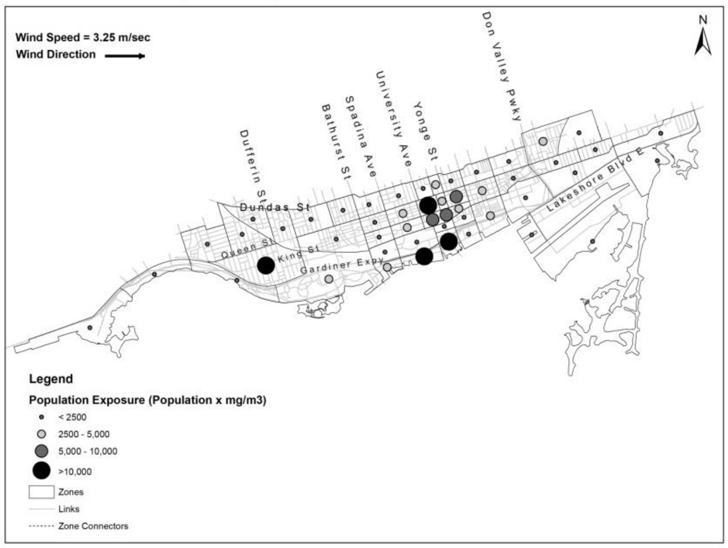

Figure 6- Population Exposure to CO Concentration

Conclusions

This paper has described the successful development and application of an integrated modelling system for the analysis of microscopic vehicle movements, emissions, emission dispersion, population location, and population exposure in the Toronto Waterfront Area. This modelling system represents the mobile sources of emissions in the Toronto Waterfront Area with a high level of detail and can be used as the "testbed" for analyzing various types of policy or technology implementations. Some of the main findings of the model 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;
- Under the assumption that people within a zone are potentially exposed to the pollution concentration measured at the zone centroids; the areas of greatest concern are the very densely populated zones in the CBD. In those zones we see high pollution concentration and population density during the peak hours of the day, which would result in higher potential exposure to vehicle emissions;

Several limitations of this study, however, are noteworthy and should be addressed in future research:

- The effect of roadway grade on emissions has been ignored in this research. For most of the Toronto Waterfront Area, grades are flat. However, some exceptions like ramps to the Gardiner Expressway may result in "hot-spots" of vehicle emissions. Data regarding roadway grades would be required to undertake this analysis.

- Emission of particulate matter could not be evaluated using the CMEM modelling software. Evaluating emission of particulate matter is complicated because the source of particulate matter includes other factors, as dust on the roadway, which is difficult to model accurately.

- The accuracy of vehicle emissions relies upon accurate acceleration and deceleration profiles within the microscopic traffic simulation model. Although some preliminary analysis has shown encouraging results, additional research is required to fully test the accuracy of acceleration and deceleration rates within the simulation model against real- world data. A significant sample of real world GPS data from probe vehicles is necessary for this purpose.

- The emissions model has not been adequately validated for Toronto using real-world emission sensors. A preliminary study conducted by Hoy et al. (2011) for the intersection of College Street and St. George Street in Toronto used the same suite of models described in this report. This study identified a linearly increasing trend synonymous to increasing traffic on the network and comparable to the observed concentration values for CO. However, ambient concentrations and emissions from vehicles outside of the study network appeared to be a significant contributing factor to the measured emissions. The sensitivity of atmospheric pollutants when using a dispersion model is also elucidated in the study. This continues to be a topic of sustained interest and further research.

- The Gaussian plume model adopted in this study is one of the simpler available dispersion modelling approaches. More detailed analysis, for example the identification of emissions “hot-spots” at the roadside, requires refinement of the dispersion model. Current research at the University of Toronto involves applying a refined Gaussian plume dispersion and a Lagrangian particle dispersion model both incorporating detailed atmospheric parameters to estimate pollutant concentrations and compare with measured values to validate the methodology used in this paper comprehensively. Such integration would help capture the sophistication of driving cycles represented in the traffic microsimulation model and lay the future for micro-simulated population exposure modeling for large traffic networks.

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