CALIBRATION OF THE TORONTO WATERFRONT MICROSIMULATION NETWORK WITH OD UPDATING

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Abstract

The calibration of a large scale microscopic traffic simulation for the downtown Toronto Waterfront Area for 2009 conditions in the AM peak is discussed. This calibration is part of a larger project to simulate driving cycles and to estimate emissions using microscopic emission models. Microscopic traffic simulation is essential for representing the speed-acceleration profiles in enough detail to predict emissions.

For calibration, the Mean Square Error (MSE) was used as the goodness-of-fit measure, while satisfying the GEH criterion. The parameters selected for optimization were headway, reaction time, timesteps per sec, feedback interval, driver familiarity, perturbation, and the distance coefficient factor. Average speed obtained from GPS speed data for trucks and loop detector data for all vehicles on the Gardiner expressway was used to validate the simulation.

Introduction

This paper is part of a project to analyze commercial vehicle emissions in the Toronto Waterfront Area (Figure 1). The integrated modelling system (Figure 2) for the project starts with a regional travel demand model producing the preliminary OD matrix required for the microsimulation 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. The second stage focuses on calibrating a microscopic traffic simulation model (in Paramics) and is the focus of this paper.

Figure 1-The Waterfront Toronto Area

Microscopic traffic simulation is widely used in research for policy analysis and network performance evaluation. There are several micro-simulation packages available including PARAMICS, VISSIM, and CORSIM. Microscopic traffic simulation is essential for representing the speed-acceleration profiles in enough detail to predict emissions in the third step using a microscopic emission model (CMEM) which will produce emissions on a link-by-link bases. These emissions will then be dispersed using the CAL3QHC dispersion model, which can account for queuing and idling. The final stage of the project focuses on estimating population exposure to these emissions.

This paper focuses on the calibration methodology and results. Development of a quality microscopic traffic simulation model requires substantial data acquisition, coding and calibration effort, even for a relatively small study area. Thus, one of the reasons for selecting the Toronto Waterfront network was that an existing calibrated network was available from previous work conducted for the Toronto Waterfront Revitalization Corporation (Abdulhai et al., 2002). Within this project, tremendous effort was invested into building the correct geometry, defining the roadway attributes (speeds, and land configurations) and coding signal timing. For signalized intersections, actuation algorithms were developed to best represent the SCOOT traffic signal control system in the Waterfront area. Detailed information about the steps taken is available in Abdulhai et al. (2002). This model was calibrated for 2001 traffic conditions and vehicle demand; therefore, significant additional calibration was required in this project to update the model for 2009 traffic conditions.

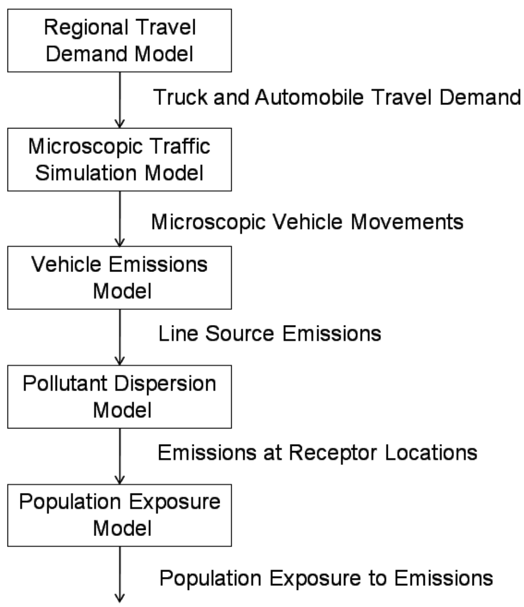

Figure 2-Integrated Modelling System for Estimating Human Exposure to Emissions

Calibration is the process of adjusting the model parameters used in the various mathematical relationships within the model to reflect reality. In other words it is the iterative process by which various parameters of the microscopic traffic simulation model are optimized to achieve the best possible representation of traffic conditions on the real network. To assess the quality of the representation, measures of effectiveness are selected to assess goodness of fit.

Each microscopic traffic simulation package has a set of parameters that affect the results of the simulation. Inappropriate choice of model parameters that describe driving behaviour, traffic system operations and traffic flow characteristics will lead to erroneous model results. Therefore collecting sufficient data is essential to calibrate and validate the network. For this two data sets are needed: one to calibrate the model (i.e. to select the parameters that result in the closest goodness of fit to the observed data) and one to validate (i.e. external data not used in selection of parameters, used to test the model's ability to forecast key system characteristics). GPS data are proposed to be used in this study for model validation, as suggested by Goulias and Janelle (2006).

GPS data has been used in several other studies also. Yu et al. (2006) calibrated a network in VISSIM using GPS and traffic data for evaluation of the Beijing BRT system before the 2008 Olympics. Using the GPS data, they calculated speed at selected cross sections spaced at 20-meter intervals. They used the sum of square errors between the observed and estimated speed at these point as the measure of effectiveness and used a genetic algorithm for model calibration. Wong and Nikolic (2007) simulated HOV lanes for Hwy 404 between Hwy 401 and Hwy 7 using VISSIM. They used both travel time and speed data collected by iTREC along with traffic counts to calibrate and validate the network (Wong & Nikolic, 2007). iTREC is a GPS/GIS based traffic counting software developed by iTRANS.

For this project the goal is to replicate several observed characteristics of traffic on the road network, including observed road counts, speed information from loop-detectors along Gardiner Expressway, and speed data from GPS units installed on a small sample of trucks. Given the difficulty in optimizing the network model to reflect all of these observed traffic characteristics, a two step procedure was employed. First, adjustments were made to the demand matrices and the road network to reflect available road counts. Second, speed information from loop detectors and GPS probe vehicles were used to validate the calibrated network.

To calibrate the microsimulation, a set of parameters are adjusted to optimize a goodness-of-fit measure. The set of parameters and the measure of effectiveness used in this project are discussed below.

Identification of Calibration Parameters in PARAMICS

In Paramics, there are two sets of parameters: parameters that the analyst is certain about and does not wish to adjust (e.g. the size of the vehicles) and the parameters that the analyst is less certain about and willing to adjust. The set of adjustable parameters is then further subdivided into those that impact capacity (i.e. mean headway) and those that directly impact route choices made by drivers (i.e. driver familiarity with the network) (Quadstone Ltd, 2008).

The adjustable parameters used for network calibration are: headway (sec), reaction time (sec), timestep, feedback interval (min), familiarity (%), perturbation (%), and the distance cost coefficient (min/km). These parameters were selected based on a series of sensitivity, and are adjusted to optimize the goodness-of-fit measure discussed below.

Calibration Measures of Effectiveness (MOE)

To assess overall goodness of fit between modeled traffic volumes and road counts, an objective function is defined. The objective function that was used for this research was the Mean Square of Errors (MSE) which is calculated as follows

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Sim_i - Obs_i)^2 \qquad \text{Equation 1}$$

Where:

Sim_i is the simulated traffic volume at location i;
Obs_i is the observed road counts at location i;

In addition to the overall goodness of fit statistic, we wish to also ensure that the maximum number of individual road segments are performing close to observed conditions. The GEH is a measure of individual road segment performance that is recommended by the Wisconsin Department of Transportation for freeway model calibration (Dowling et al, 2004; Balakrishna et al, 2007). The GEH measures the percent error with respect to the mean value of the observed and simulated counts, The GEH statistic is calculated as follows:

$$GEH = \sqrt{\frac{(Obs - Sim)^2}{(Obs + Sim)/2}} \qquad \text{Equation 2}$$

Where:

Obs is the observed road count at a specific location,
Sim is the simulated traffic volume at a specific location

In this research, model parameters were selected to minimize the MSE while keeping the GEH within an acceptable range for the maximum number of road segments. According to the literature, GEH values below 5 are considered to be a good match between model volumes and observed counts. If the GEH is greater than 10, there is a probability of error or errors with either the travel demand model or the network coding. According to FHWA guidelines for highways, at least 85% of the observed links in a traffic model should have a GEH less than 5.

While FHWA criteria provide a useful benchmark for freeway microsimulation models, we found that it was not possible to achieve this level of fit for the Toronto Waterfront study area as a whole, since the network consists of a complicated system of freeways, arterials, collectors and some local road segments. Furthermore, the road counts available for network calibration are largely obtained from single day counts that exhibit significant day to day variability. Thus the target GEH criterion was modified for this project, such that an acceptable level of calibration was considered to be achieved if 85% of all GEHs were below 10.

Calibration Process

As mentioned in the introduction section, the preliminary OD matrices were obtained from a regional travel demand model for the GTHA. However due to the limitations of the macro model in predicting trip patterns accurately in the network, and accounting for geometry design, signals and queuing; an OD matrix updating procedure is applied based on simulation results. This OD updating procedure is used to refine the Microsimulation performance after the optimization of global parameters in the microsimulation.

An iterative process of parameter adjustment, reasonable adjustments to the demand matrices, and minor network modifications were employed to arrive at an acceptable calibration. The most significant demand matrix and network adjustments included:

- O-D matrix updates were made to all four demand matrices (automobile, light truck, medium truck, heavy truck) to address some systematic underestimates of traffic volumes for the screenlines. The Waterfront Area was divided into four areas (the West, Centre, North and East sections) using Bathurst Street, Richmond Street and the Don Valley Parkway as boundaries between the areas. Demand matrix factors were applied to all origin-destination pairs between these areas based the simulation results. This result was part of the iterative process, and multiplying all the seven factors used in this step, approximate factors to increase all demands by were:
    - West to Centre: +66.3%
    - Centre to West: +177.9%
    - East to Centre: +35.9%
    - Centre to East: +9.1%
    - North to Centre: +87.3%
    - Centre to North + 55.2%

  These factors were applied at each step in order to:

    - Reflect real-time traffic behaviour observed on the roads since the original demand did not produce the congestion seen in reality;
    - Match road counts to a degree acceptable by the GEH criteria.

- Manual demand matrix adjustments at network gateways in the vicinity of High Park, due to unrealistic traffic volumes entering the network using High Park as a through route (traffic counts were not available at this location, but our local knowledge of the system helped us to identify problematic demand at this location arising from the use of the simplified EMME demand modelling approach).

- Network adjustments to reflect the closing of the Jameson on-ramp to the Gardiner expressway during the AM Peak hour.

Model Calibration and Results

A mixture of freeway ramps, road counts and highway counts –at 67 locations in total- were used in the calibration process. The calibrated parameters that optimized the MSE while achieving the GEH goodness of fit criterion are as follows:

Mean Headway= 1.8 sec
Mean Reaction Time= 0.65 sec;
Timesteps=2;
Feedback interval= 2 min;
Familiarity= 90%;
Perturbation= 5%;
Distance Cost Coefficient= 0

Table 1 summarizes the traffic volume comparisons (observed traffic counts versus Paramics model volumes) aggregated to the screenline level after all calibration adjustments were made. Figure 3 also shows the simulated counts graphed against the observed road counts.

Table 1- Comparison of Simulated Volumes vs. Road Counts

	count	Paramics count	par/count
EB onramps	2479	2021	-18.5%
EB off ramps	6770	6354	-6.1%
WB on ramps	7379	8077	9.5%
WB off ramps	1929	3227	67.3%
Total ramps	**18557**	**19679**	**6.0%**
Bath IB	3153	3005	-4.7%
Bath OB	2056	1958	-4.8%
Don IB	3466	3572	3.1%
Don OB	2461	2368	-3.8%
Total: E/W screen Lines	**11136**	**10903**	**-2.1%**
Richmond-IB (N)	6761	5703	-15.6%
Richmond-OB (N)	8347	8095	-3.0%
Total: North screen Line	**15108**	**13798**	**-8.7%**
Gard+Lake, (IB)-W end	7589.78	6076	-19.9%
Gard+Lake, (OB)-W end	5800.472	6255	7.8%
Gard+Lake, (IB)-E end	4789.616	4154	-13.3%
Gard+Lake, (OB)-E end	2974.735	2928	-1.6%
	21154.6	**19413**	**-8.2%**
Grand Total	**65955.6**	**63793**	**-3.3%**

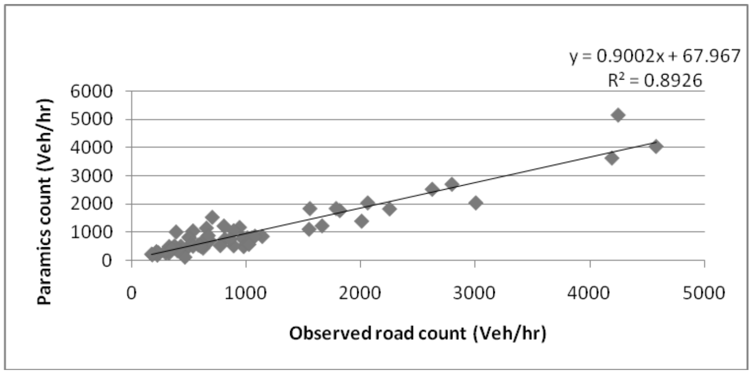

Figure 3-Simulated Vs observed counts

Model Validation Using GPS Speed Data

GPS data were made available for this project by Turnpike Global Technologies (TGT) for a three month period in 2009. The dataset provides location and speed information for TGT's GPS outfitted trucks travelling in the Toronto Waterfront Area. Data points are collected by TGT's system approximately every 500 meters, therefore many observations are required to provide a suitable dataset for model calibration. The numbers of points within the Toronto Waterfront Area is 22,552. Extraction of the points that represented only the AM peak period resulted in 1329 points (Figure 4).

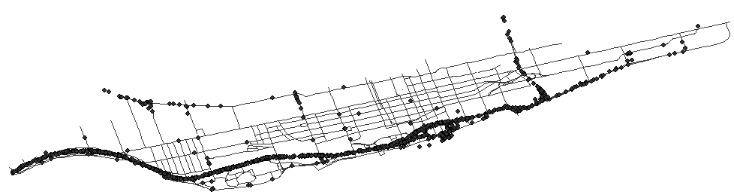

Figure 4-TGT GPS Points for AM peak period

As shown in Figure 4-8, very few GPS data points are available for calibration of the network outside of the Gardiner / Lakeshore corridor. Furthermore, many sections of the Gardiner Expressway and Lakeshore Boulevard are very close to one another, such that GPS points cannot easily be assigned to one of the two facilities. Therefore, the only sections that were used for GPS model validation were those segments of the Gardiner Expressway and Lakeshore Boulevard that are situated far enough apart that the GPS points belonging to Lakeshore and the Gardiner could be distinguished. These segments are identified in Figure 5.

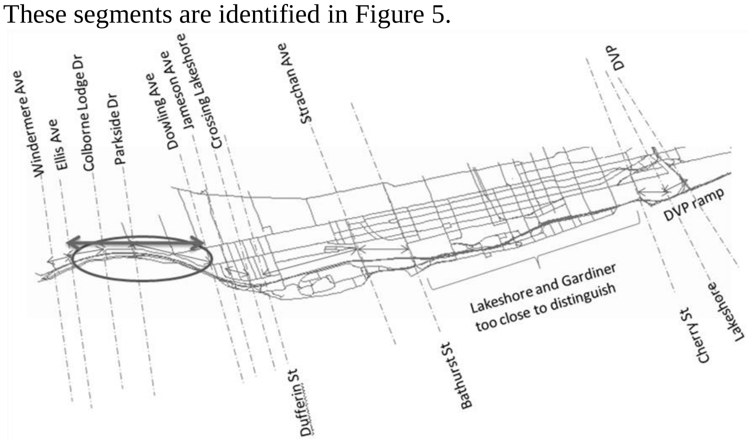

Figure 5-Chosen Sections of the Gardiner Expressway

GPS points were assigned to roadway segments using a buffering procedure in a Geographic Information System. This procedure assigns each GPS point to the nearest roadway segment if the point is within a 40 meter buffer of the road. Average GPS speeds were then compared to the average speeds resulting from the microsimulation. Average speeds by direction on the Gardiner Expressway are shown in Table 2.

To assess average speeds for individual roadway segments, the GPS data were augmented with loop detector data. Loop-detector data availability was also limited, for example for the westbound direction on the Gardiner Expressway west of Dowling Avenue, data for only one loop detector was available. Therefore, both the loop-detector and the GPS data were used in the comparison (i.e. the simulation speeds were compared with GPS data if a large enough sample is available and with the loop detector data otherwise).

Table 2-Comparison of GPS and Microsimulation Speeds by Direction

Westbound Direction			**Eastbound Direction**		
GPS	Simulation	%Diff	GPS	Simulation	%Diff
N=177	N=146,053		N=253	N=58,733	
Avg=52.3 km/hr	Avg=46.3 km/hr	-11.5%	Avg=58.4 km/hr	Avg=67.66 km/hr	15.92%
std=11.42	Std=25.56		Std=7.2	Std=26.17	

The results of this comparison are shown in Figure 6. As can be seen from the figure, average loop detector speeds were only used for Gardiner Expressway segments east of the Central Business District and the GPS average speeds were used for roadway segments to the west of the CBD. It should also be noted that when comparing simulated speed against GPS speed, only heavy duty vehicle speeds are computed, but in the case of comparing against loop detector speed, all vehicles in the simulation are considered. The comparison shows that the simulation appears to be underestimating speeds in the westbound direction and overestimating speeds in the eastbound direction to some degree. Given the shortcomings of the observed data, and the lack of any obvious method to remedy this problem in the simulation, no adjustments to the model have been made as a result of this comparison.

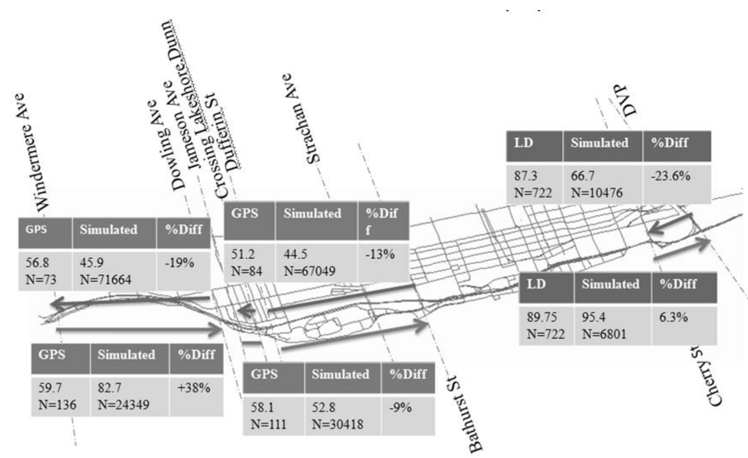

Figure 6- Simulated vs. GPS/Loop Detector (LD) Speeds on the Gardiner Expressway

Recommendations and Future Steps

This paper discussed the calibration and validation steps necessary to obtain the best microsimulation model that will be used as the base case for all the next steps of the project including scenario analysis. As mentioned in the validation section, data availability was limited to suggest any need for readjusting parts of the calibration. If more data becomes available, the model can be validated against more data and for other sections of the network to provide better feedback.

The next steps that are currently being undertaken are integrating the CMEM emission model into this simulation, and integrating the results with the CAL3QHC dispersion model.

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