Calibration of a Micro-Simulation Model in a Large Urban Network

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Abstract:

This paper describes the calibration and validation of a micro-simulation model in the analysis of a large urban network. The Paramics micro-simulation model was applied to model traffic operations within the City of Niagara Falls, Ontario. The model is used to assess traffic operations and various traffic management initiatives including deployment of Intelligent Transportation Systems within the tourist area in the City. The analyzed network consists of freeways, arterial and collector roads with over 90 signalized intersections. The Paramics model incorporates a modeling procedure in which movements of vehicles through the network are governed by origin-destination matrices on the basis of various assignment techniques. Over 17 traffic zones were used to model points of traffic generation and destination including high traffic generators such as car parks in the tourist area. The calibration efforts focused on the PM peak hour and involved estimation of representative origin-destination matrices for the network, selection of appropriate assignment method and comparison of modeled and observed traffic volumes at the screen line, roadway segment and intersection levels using a modified Chi-Squared statistic test. The model validation was undertaken by comparison observed and modeled travel times and qualitative queue assessments along various routes in the network. The analysis shows that application a systematic approach that includes the above steps can result in a well calibrated and validated model that provides reliable results in practical applications. The paper also discusses the challenges and suitability using micro-simulation modeling in the analysis of large urban networks and notes that, focusing further calibration efforts on selected sub-areas and corridors would be more appropriate for such cases.

1. Introduction

This paper documents the calibration and validation of the City of Niagara Falls' Paramics Model that AECOM undertook in collaboration with the Delcan. The City developed a basic model of the entire road network within the City boundary including collector roads, Regional arterial roads and MTO highways using the Paramics micro-simulation model. A fully functional Paramics model was required to support transportation analysis in the Transportation Master Plan (TMP) Study. The completed model will be put to a variety of uses including assessment of traffic management initiatives, sub-area traffic operations, impacts of proposed developments, impacts of incidences on MTO highways and effectiveness of various Intelligent Transportation System (ITS) deployment.

The basic model was coded by City staff with further work involving coding of traffic signals and overall calibration with traffic volumes being undertaken by Delcan and AECOM.

1.1 Study Area

The Study Area included the entire network within the City of Niagara Falls, extending from Highway 405 to the north, Niagara Parkway to the east, the Sodom Road interchange on the Queen Elizabeth Way (QEW) to the south and Thorold Townline Road to the west. The network includes selected collector, the Region of Niagara arterial roads and freeways belonging to the Ontario Ministry of Transportation (MTO), including the QEW and Highway 405. The map in **Figure 1** shows the bulk of the Study Area but leaves out minor roadways south of Lyons Creek Road to the Sodom Road interchange on the QEW.

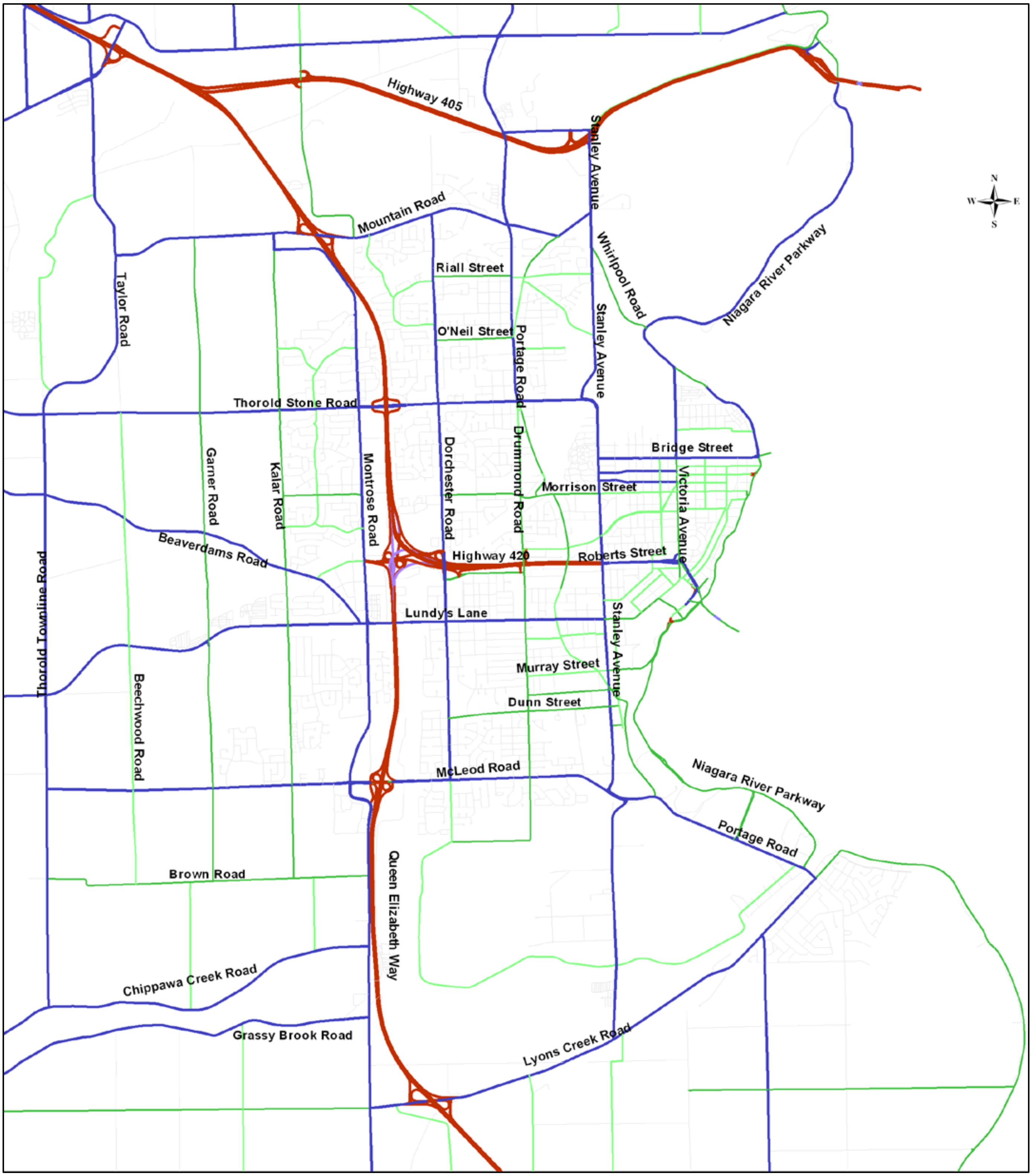
1.2 Study Objectives

The primary objective of this Study was to finalize coding and calibration of the model during the PM peak hour using the latest traffic data that was available. The Study process therefore involved the following steps:

- obtaining updated traffic volume data for the road network in the City;
- finalizing coding of the base model;
- calibration analysis that involved selecting suitable model parameters, undertaking simulation runs and comparing model results with the field data.

The calibration process was undertaken iteratively until the final model results matched observed field data to acceptable levels. These study steps are described in the sections that follow.

Figure 1: Study Area



2. Data Collection

A comprehensive traffic volumes count was undertaken to calibrate the model and update some traffic data that had been included in the basic model. The data included in the basic model was limited and relatively old and did not cover all the signalized intersection.

2.1 Traffic Volume Updates

Additional data collection was undertaken to provide an updated traffic volume data for use in the calibration process. The updated traffic volume data was obtained from the City and the Region of Niagara. Additional traffic volume data on the QEW, Hwy 405 and Hwy 420 were obtained from the Ontario Ministry of Transportation (MTO). The data was as follows:

- Intersection turning movement counts at over 50 signalized and some unsignalized intersections;
- ATR mid-link volume counts on various roads;
- Inventory counts on the QEW and Highway 405 mainline;
- Ramp volume counts; and
- Tuning movement counts at ramp terminal intersections.

The traffic volumes was mostly new, undertaken from 2007 to 2009, although a good number were fairly old with some as old as 2002. Although the data was generally comprehensive, a couple significant gaps and issues were noted as follows:

- MTO data did not include ramp volumes at the Mountain Road and Lyons Creek interchanges. In addition, a couple of ramp volumes were not available at the Hwy 420/QEW interchanges as well as at the other interchanges;
- Ramp data was not available at the two Highway 405 interchanges within the Study Area limits; and
- Travel speed data was not available for MTO highways.

Since the data was collected over a number of years, the base year for the analysis was set as 2009 and the older data projected to that year assuming an annual growth of 2% in traffic volumes. Where new data was not available, older data provided with the base model was used. That data represented operations in the year 2005 or earlier and was projected to the 2009 base year using the same growth assumptions. Volume balancing was not undertaken, although minor adjustments were carried out where data inconsistencies were evident. The resultant mainline volumes for the 2009 base year for MTO highways and regional arterial roads are presented in **Table 1**.

Table 1: Traffic Volume Data on MTO Highways

Highway	Highway Section	Northbound/ Eastbound - vph	Southbound / Westbound - vph	Comments
QEW	North of Hwy 405	3,054	2,965	
	Mountain Rd - Hwy 405	3,194	3,460	Volumes suspect
	Thorold Stone Rd. - Mountain Rd.	2,695	2,920	
	Hwy 420 - Thorold Stone Rd.	2,721	2,947	
	McLeod Rd. - Hwy 420	1,761	1,897	
	Lyons Creek Rd. - McLeod Rd.	1,601	1,653	
	Sodom Rd. - Lyons Creek Rd.	972	1,075	
Hwy 405	4.0 km West of Stanley Avenue	468	564	

Highway	Highway Section	Northbound/ Eastbound - vph	Southbound / Westbound - vph	Comments
	2.5 km West of Stanley Avenue	432	558	
	0.4 km West of Stanley Avenue	478	715	
Hwy 420	0.1 Km West of Dorchester Rd.	1,150	1,251	
	0.14 Km West of Drummond Rd.	1,859	2,059	

From **Table 1,** directional volumes on the QEW generally ranged from just less than 1,000 vehicles per hour (vph) on the southern section between Sodom Road and Lyons Creek Road to over 3,000 vph north of Mountain Road. Volumes on the section of the QEW between Mountain Road and Hwy 405 were suspiciously high and inconsistent with observed volumes north of Highway 405. Because of the split of the QEW and Hwy 405, volumes on that section cannot be higher than the volumes on the northern section before split since there is no travel from westbound Hwy 405 to southbound QEW. Traffic volumes on Hwy 420 and Hwy 405 are in the range of 1,150 to 2,060 vph and 400 to 700 vph respectively.

Typical base year traffic volumes on Regional arterial road ranged from 1,000 to 1,300 vph for the bussiest streets including Thorold Stone Road, Lundy's Lane, Marineland Parkway and McLeod Road . Apart from Beechwood Drive and Garner Drive that have directional traffic volumes of less than 100 vph, the majority the arterial roads have volumes in the range of 300 to 600 vph in each travel direction during the PM peak hour.

ATR speed data indicated operational speeds on collector roads generally in the range of 40 to 65 km/h which is in line with posted speeds along the various roadways.

Total intersection volumes were also reviewed. Of the 106 signalized intersections for which data was available, 29 had total volumes greater 2,000 vph. As expected, the busiest intersections included those on Stanley Avenue, Lundy's Lane, Thorold Stone Road and McLeod Road. The highest total intersection volume of 3,701 vph was observed at the Hwy 420/Stanley Avenue intersection.

2.2 Data Consistency and Quality

The data used was assumed to represent typical weekday PM peak hour operations in the summer months. The final data was derived for over 100 turning movement counts at signalized and unsignalized intersections and over 450 highway mainline and arterial mid link sections. Because of this extensive amount of data, a number of factors noted in the previous section impacted the overall quality and created uncertainties which in turn could have impacts on the overall calibrations results. These factors include:

- The data used in this Study was collected by the City, the Region and MTO over several years. Moreover, there was seasonal variation in the data as some was collected in the spring, summer and fall seasons. Final volumes on most roadway sections were derived by projecting older data on the basis of linear growth assumptions. These could introduce uncertainties on the accuracy of the base year volumes;
- Gaps in data available on certain key network element including freeway ramps and ramp terminal intersections; and
- Some data inconsistencies were identified on a section of the QEW where traffic volumes were found to be inconsistent with volumes on the upstream and downstream sections.

These inconsistencies and gaps create uncertainties which impacted the overall calibrations results.

3. Calibration Process

Calibration is necessary to ensure that the model is able to replicate actual traffic operations in the modelled network. It involves adjustment of model parameters iteratively until an acceptable match between the model results and the observed data is achieved. For this study, calibration was conducted by comparing modelled and observed link flows and turning movement volumes. For flow comparisons, the GEH statistic, which is a modified Chi-squared statistic that incorporates both relative and absolute differences, was used as the primary performance indicator. Percentage and absolute volume differences were also reviewed.

The main model parameters that were adjusted as part of that of calibration process included route control parameters target headways, drive reaction time and traffic assignment methods. Further efforts included adjustment were made for aggressiveness and awareness factors which affect the level to which modelled vehicles desire to achieve target speeds and headways. On-screen review of traffic animation was also undertaken to ensure correctness of model inputs and to visually confirm that the known problem areas were replicated accurately in the model.

3.1 Further Model Development

A review of the base model revealed a couple of areas that required modifications and update to ensure proper traffic behaviour. Since the model development was started using an earlier version of the Paramics model, it was necessary to upgrade certain elements including interchange ramps, to make them work in a proper manner. Update of network coding included the following:

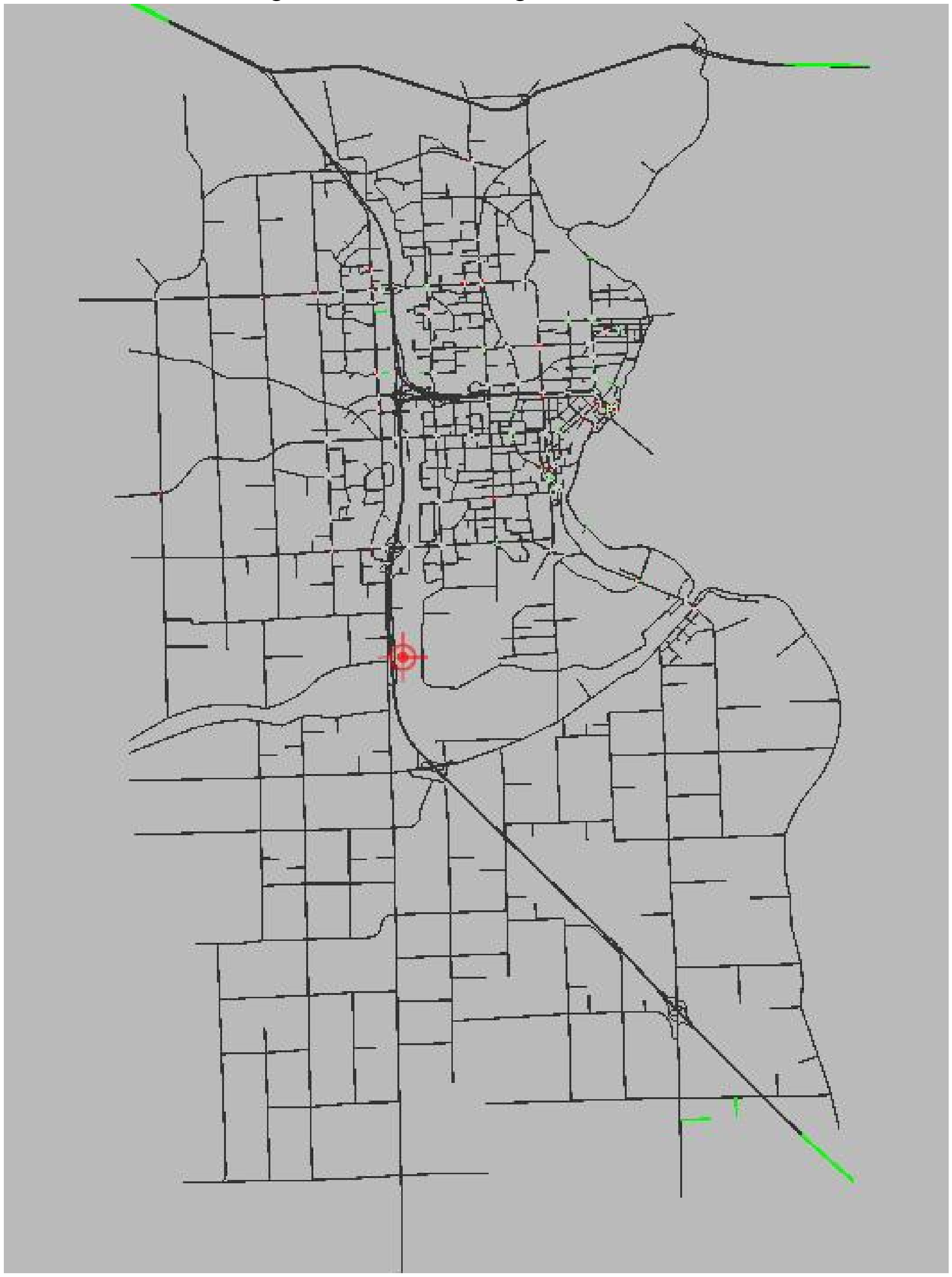
- General updates to traffic control elements including kerbs, stop lines and next lanes;
- Updating a number of intersections to show the correct number of lanes and lane configurations;
- Recoding of interchange ramps to eliminate erroneous representation of traffic movements on them;
- Updating of the zones including increasing the number from 168 in the base model to a total of 174 in the final model. Moreover, zone locations and connectors were assessed and modified at various locations to ensure proper traffic flow patterns and ease of calibration. Some zones were relocated and additional ones added to correspond more closely to points of traffic generation and departure from the network, including gateway locations on existing roadways. Zone connectors were also added and realigned as required to correspond more closely to the traffic loading and unloading patterns onto the surrounding collector and arterial roads;
- Additional traffic signals were implemented into the network including the new signals on Kalar Road between McLeod Road and Lundy's Lane. In all there were 106 signalized intersections that were coded in the model.

The final model of the Study area is shown in **Figure 2**. The network was coded with over 5,700 links which show individual roadway sections and transition points where roadway characteristics such as number of lane or start/end of curves change. In addition, over 2,500 nodes including 110 signalized intersections and 174 zones and gateways were modelled as shown in **Table 2**.

Table 2: Network Elements in Final Model

Network Element	Number
Roadway Links	5,720
Signalized Intersections	110
All nodes	2,500
Zones and Gateways	174

Figure 2: Model of Niagara Falls



3.2 Route Control and Matrix Estimation

Paramics uses a generalized costs function to calculate the least cost route between an origin and a destination zones. The generalized cost function is represented by the equation:

$$C = aT + bD + cP$$

Where:

C is generalized cost function;
T is time;

D is distance; and
P is toll costs
a, b,** and **c are coefficients for time, distance and toll costs respectively

Route control was achieved through a combination of factors, the primary one being the use of categories which define the speed and cost factor associated with each link. Traffic movement through the network is governed by the defined origin destination matrix.

The original matrix was developed using the Paramic's ESTIMATOR module that applies optimization approaches to obtain a suitable initial matrix. Subsequent updates considered the traversal matrices from the Regional Transcad demand forecasting model for City. The matrix was revised iteratively until the resultant modelled traffic volumes matched observed volumes to acceptable levels. The estimation took into consideration zone locations, the surrounding land use patterns, turning volume patterns at intersections and volumes on adjacent roadways. The estimation process was undertaken in tandem with the other model updates outlined in Section 3.1.

The final matrix applied in the model comprised close to 39,000 trips between various origin and destination zones as shown in **Table 3**. The zones included those that are internal to the City and Gateway zones representing cordon roadways leading into or outside the City periphery. The gateway zones included the QEW, Hwy 405, Peace Bridge, Thorold Stone Road, Beaverdams Road and Lundy's Lane. Most of the 2,637 trips originating from Gateways zones and exiting other Gateway zones were predominantly made on the QEW, Hwy 405 and the Peace Bridge. The number of trips with origin and destination as internal City zones was 25,073, which was generally comparable to the number of trips obtained from the Transcad demand forecasting model results.

Table 3: Trip Matrix Summary

From	To		
	Internal Zones	Gateway Zones	All Zones
Internal Zones	25,073	5,797	30,870
Gateway Zones	5,422	2,637	8,059
All Zones	30,495	8,434	38,929

3.3 Model Parameters

The simulation parameters used in the study are summarized in **Table 4**.

Table 4: Calibration Parameters Used

Parameter	Details
Assignment	Dynamic Feedback with Perturbation
Generalized Cost Coefficient	$C = aT + bD + cP$ (a=0.85, b=0.5, c=0.0)
Target Headway	0.65s
Driver Reaction Time	0.67s

The main elements were as follows:

- A two hour simulation period from 4:00 pm to 6:00pm was used in the Study. Results were gathered and summarized for the 5:00 pm to 6:00 pm period which was assumed to represent the PM peak hour. The previous period was essentially used as a prolonged warm up period but with reduced demands amounting to 75% of the PM peak hour demands;

- A dynamic feedback assignment method with perturbation was used in this Study. Under this assignment method, vehicles route tables were recalculated every six minutes. A 5% perturbation was used to introduce some randomness in the process whereby some vehicles would not necessarily follow the calculated shortest paths but would use alternative routes;

- The generalized cost function comprised 0.85 time coefficient and 0.50 distance coefficient. Because there were no tolls road modelled in the network, the coefficient for out of pocket cost was set to zero; and

- The target headway and driver reaction time was set at 0.65 and 0.67 seconds respectively. While the target headway is a model parameter that is used to control vehicle following, the reaction time is a representation of the average reaction time that drivers exhibit in real life. A value of 0.67s is therefore a realistic representation of general which has been observed to range from 0.6s to over 1.0s.

3.4 Analysis Approach

The actual analysis involved selecting suitable model parameters including adjustment of the demand matrix, undertaking simulation runs and comparing model results with the field data. Since micro-simulation is a stochastic process in which every computer run represents a single observation, a complete experiment consisted of six to eight computer runs and the results were averaged for each parameter. The mean values were then compared to the observed data.

The analysis was undertaken iteratively until the final model results matched observed field data to acceptable levels.

4. Volume Comparisons

Comparison of modelled and observed volumes was conducted at screen line locations, roadway sections and for turning movement volumes at intersections where data was available. The comparisons at the screen line and link levels considered travel in both directions of travel. The number of data sets compared at the various levels was 16 for screenline, 458 for link, 106 for total intersection volumes and 1020 for individual turning movement counts at intersections.

4.1 Screen Line Level

At the screen line level, modelled and observed traffic volumes were compared at 8 locations that included consideration of volumes in both travel directions. The screen line locations are illustrated in **Figure 3**.

Figure 3: Screen Line Locations

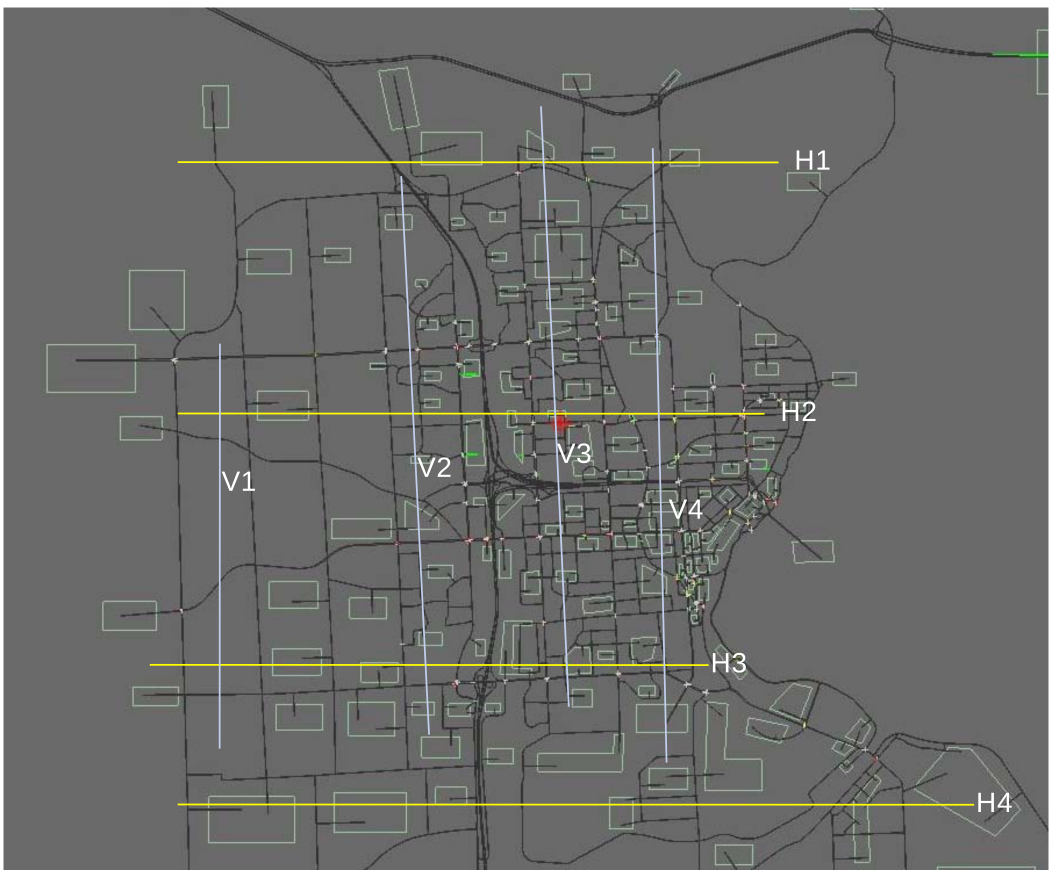
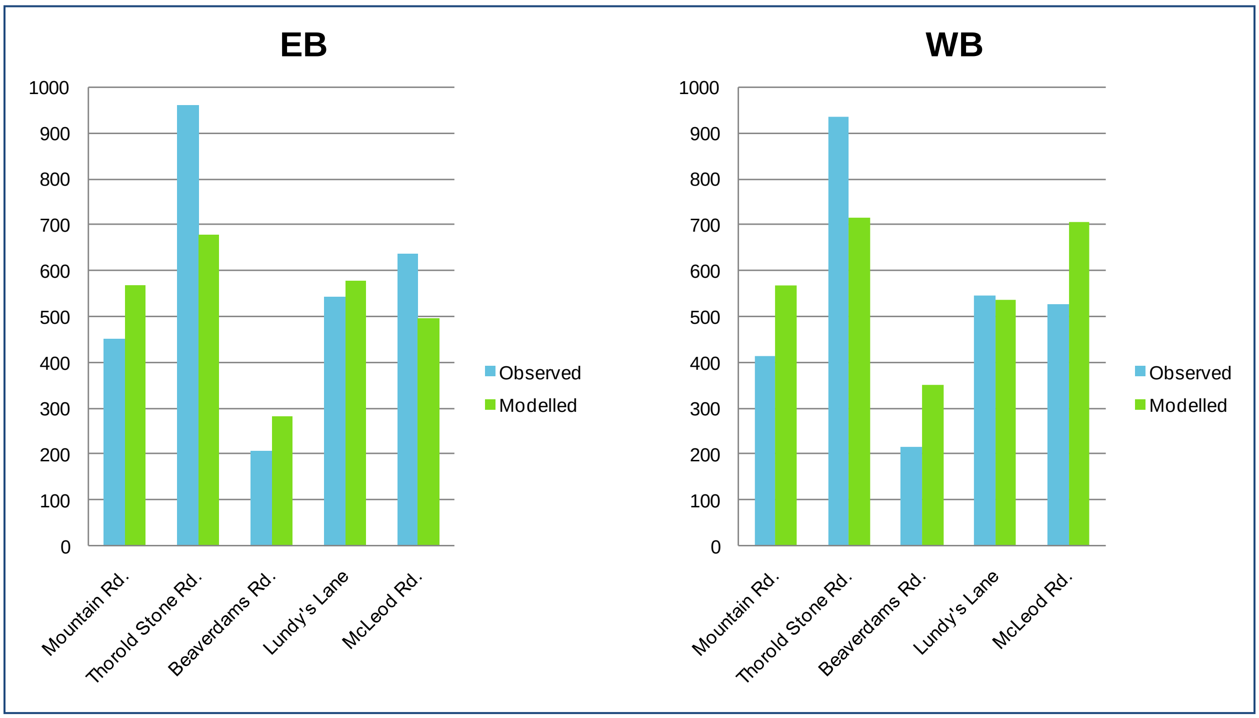


Table 5 provides results of the screen line volume comparisons. Modelled and observed volumes matched acceptably well at most screen lines with differences less that 15% at 75% of the locations. The greatest difference of 28% was recorded for the eastbound on the north-south screen line east of Dorchester Road. A review of the individual roadways crossing the screen line indicated that the difference could be attributed to over representation of traffic volume on Hwy 420. Further example of the variation of individual roadway volumes across Screenline V2 is provided in **Figure 4**.

Table 5: Volume Comparison at Screen Line Level

Screen Line	Eastbound / Northbound			Westbound / Southbound		
	Observed	Modelled	% Diff	Observed	Modelled	% Diff
V1 - East of Thorold Townline Rd.	1677	1817	8%	1490	1669	12%
V2 - East of Kalar Rd.	2797	2576	-8%	2632	2787	6%
V3 - East of Dorchester Rd.	5364	6868	28%	5846	6872	18%
V4 - East of Stanley	5309	4310	-19%	5544	5011	-10%
H1 - South of Hwy 405	4269	4166	-2%	3920	4146	6%
H2 - South of Morrison St.	6225	6827	10%	6822	5927	-13%
H3 - North of McLeod Rd.	4404	5129	16%	4565	4873	7%
H4 - North of Lyons Creek Rd.	2260	2595	15%	2291	2645	15%

Figure 4: Volumes at Individual Screen Line V2 Roadways



Overall, these results demonstrate that the modelled volumes matched observed volumes to acceptable levels at the screen lines.

4.2 Link and Intersection Level

Traffic volumes at the link and intersection levels were compared on the basis of the GEH statistic in addition to other criteria that have been applied elsewhere. The GEH statistic is represented by the equation below:

$$GEH = \sqrt{\frac{(M-O)^2}{0\cdot 5*(M+O)}}$$

Where

M: simulated flows

O: observed flows

Various GEH values give an indication of a goodness of fit as outlined below:

GEH < 5	Flows can be considered a good fit
5 < GEH < 10	Flows may require further investigation
GEH >10	Flows cannot be considered to be a good fit

The additional criteria involved dividing link volumes into various ranges and undertaking volume comparison for each range independently by both GEH statistic and absolute volume differences for roadway sections. The criteria and obtained results are shown in **Table 6.** The criteria were adapted from similar studies undertaken elsewhere.

Specific achievement targets were set to reflect the characteristics of this City's network. The targets were set based on considerations surrounding the data quality and the uncertainties arising from the network size and complexity. For smaller networks with few links and intersections, coordinated data collection efforts can be implemented to reduce the uncertainties and improve data quality. For this Study, the data collection was undertaken by three different jurisdictions over several years as noted in Section 2.2, and the base year volumes on most sections were derived by projection of older data on the basis linear growth assumptions. Moreover, data was not available for some key network element including interchange ramps and freeway mainline sections. Based on those considerations, achievement target of 75% was set for comparison of volumes on disaggregated link sections.

Table 6: Volume Comparison Details

Criteria	No of Links	Target	Results
Link flow with 700 < Flow < 2700 veh/h within 15%	122	75%	73%
Link Flow < 700 veh/h within 100vph	330	75%	79%
Link Flow > 2700 veh/h within 400 vph	7	75%	63%
Difference in sum of all link flows	-	< 5%	4.5%
GEH for all count locations < 5	458	75%	58%
Overall GEH for all links	458	<5	4.68

Criteria Adapted from: Traffic Analysis Toolbox Volume 111: Guidelines for Applying, Traffic Micro-simulation Modeling Software, USDOT & FHWA, June 2004.

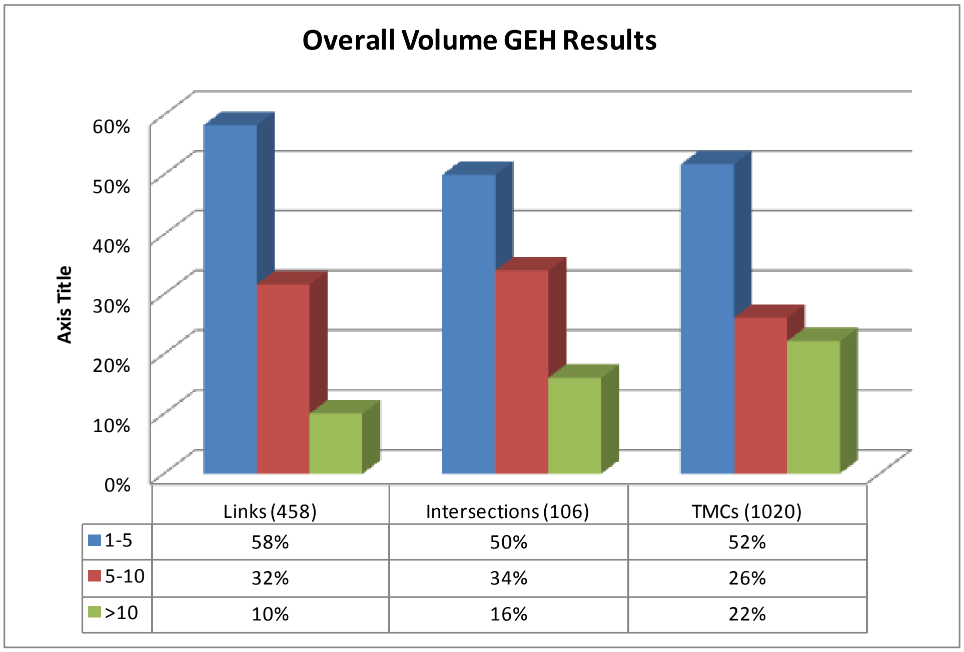
The results in **Table 6** show that significant calibration targets were achieved. Firstly, 79% of links with flows less than 700 vph had observed and modelled volumes within 100 vph of each other, thereby achieving the 75% target. Secondly, 73% of flows more than 700 vph but less than 2,700 vph had observed and modelled volumes within 15% of each other, thereby marginally falling short of the target. Noting that the two volume bands represent over 98% of the total data sets considered, the results show an acceptable match for those volumes ranges. Only 7 links had volumes greater than 2,700.

The overall results for all links were also acceptable. The difference is sum of all link flows was 4.5% and achieved the target of 5%. Moreover, the overall GEH value obtained by comparing link volumes in the entire network was 4.68 which is less than 5.0 and thereby fulfilled the targeted benchmark. The overall GEH results obtained for link volumes, total intersection volumes and individual turning movement volumes at intersections are illustrated in **Figure 5**.

At the other levels, GEH values less than 5 were obtained for 50% and 52% for the total intersection volumes and individual turning movement volumes at intersections respectively. These results suggest that over half the modelled flows would be considered a good match with the observed ones. It should be noted that because of high variability of turning volumes at intersections, it is more difficult to achieve the same calibration targets in these volumes as at the mid-link volumes. Since most of the volumes in this

Study represent data obtained over a single day over several years and various periods, the GEH results are not surprising.

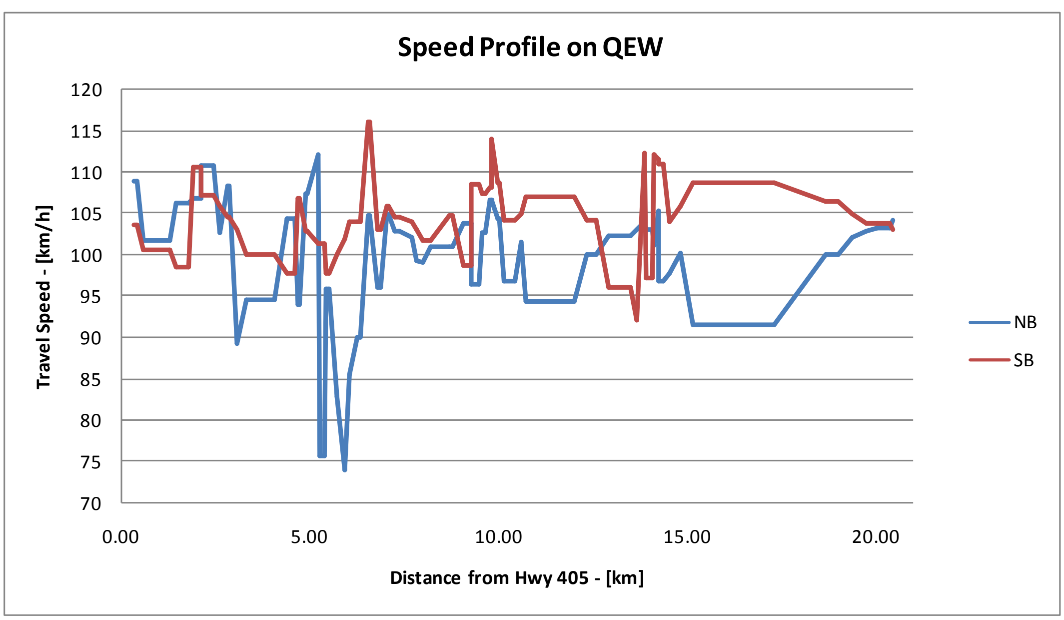
Figure 5: GEH Results for Various Elements



4.3 Selected Model Outputs

The calibrated model was used to examine traffic operations on a number of network elements within the City's network and the results were found to be consistent with observed operations in the City. Speed profiles along the QEW from Highway 405 to Sodom Road is presented in **Figure 6**.

Figure 6: Speed Profile on the QEW



The speeds were plotted for each component link over the 20 km section included in the Study Area. While the plot is consistent with the average section results discussed above, it also reveals the variation in average speeds which ranged from 75 km/h to 115 km/h. The lowest speeds were obtained in the NB direction within the Hwy 420 interchange area. This could be attributed to a high volume of traffic travelling NB on Hwy 420 and merging with the QEW NB traffic thereby resulting in higher density and lower speeds. In most cases, however, the speeds ranges from 90 to 110 km/h which appear to be consistent with expected operations on MTO 400 series freeways when volumes are high but do not exceed capacities. The obtained travel time for the 20 km section was approximately 10 minutes and 12 minutes in the SB and NB directions respectively.

Traffic operation and LOS on some high volume intersections are presented in **Table 7**. The table also provides the colour coded GEH statistic for the volumes to provide context for the obtained results. The intersections operated at LOS A to C with the highest delay of 29 seconds at Marineland Pkwy. & Stanley Ave. (West). Actual operations could be different at the intersections with high GEH indicating significant variations between modelled and observed volumes. For example operations at the Stanley Ave. Fallsview Blvd. & Ferry St. intersection is expected to be worse than the modelled result of LOS B, while that the Hwy 420 & Stanley Ave. intersection is expected to be better, since modelled volumes are significantly lower and higher at two intersections respectively.

Table 7: Traffic Operations on High Volume Intersections

Intersection	Total Volume -vph		GEH	Delay –[s]	LOS
	Existing	Modelled			
HWY 420 & Stanley Ave.	3,701	4,574	13.6	13.6	B
Thorold Stone Rd. & Dorchester Rd.	3,572	3,817	4.0	25.0	C
Thorold Stone Rd. & Montrose Rd.	3,440	3,165	4.8	15.5	B
Stanley Ave. & Ferry St.	3,274	2,799	8.6	14.1	B
Lundy's Ln. & Drummond Rd.	3,270	3,292	0.4	14.1	B
Lundy's Ln. & Dorchester Rd.	3,139	2,898	4.4	10.9	B
Dorchester Rd. & McLeod Rd.	3,092	2,902	3.5	9.8	A
QEW (WEST RAMPS) & McLeod Rd.	2,953	2,931	0.4	11.9	B
McLeod Rd. & Oakwood Dr.	2,831	3,361	9.5	7.6	A
McLeod Rd. & Niagara Square	2,824	2,794	0.6	12.1	B

4.4 Summary of Calibration Process

Given the considerations surrounding the data quality and the uncertainties arising from the network size and complexity, the obtained results show an acceptable match between observed and modelled volumes and demonstrate that the model was calibrated to acceptable levels.

Improved calibration can obtained with additional resources such as further parameter adjustments and additional simulation runs, improved data collection ensuring that the data is collected simultaneously over multiple day and filling in the data gaps identified previously. However, marginal improvements are expected to diminish at the network level as more efforts are expended. It may therefore be more prudent to focus further calibration efforts on sub-areas or corridors where specific issues such as network improvements or traffic management initiatives are to be investigated. Such focused calibration process should include model validation with observed operational data including travel times on arterial and freeway sections and typical queue reach information at selected intersections.

5. Conclusions and Recommendations

This paper documents the model update and calibration process for the City's Paramics model. As part of the update, additional data was obtained from the City and analyzed. Because of this extensive amount of data, a number of factors including gaps and age of the data factors impacted the overall quality and created uncertainties which in turn could have impacts on the overall calibrations results. The model coding was updated and a number of elements revised to provide improved traffic behaviour.

The calibration process involved adjusting model parameters, undertaking simulation runs with different random number seeds, summarizing the results and comparing them with observed field data. That process was undertaken iteratively until acceptable match between modelled and observed traffic volumes was achieved. Comparison of modelled and observed volumes was conducted at the screen line locations, roadway sections and turning movement levels using various sets of criteria.

Results of the volume comparisons showed that calibration targets were achieved for most of the criteria utilized. The obtained results showed an acceptable match between observed and modelled volumes. Although some targets were not achieved, it was concluded that the systematic approach employed in the process provided overall results that show that the model was calibrated to acceptable levels in view of the data quality concerns and the uncertainties arising from the network size and complexity.

Improved calibration results can be achieved with additional resources and updated data, but the marginal improvements at the network level are expected to diminish as more efforts are expended. It was therefore concluded that for simulations covering a large urban area like this, it would be prudent to focus further calibration efforts on selected sub-areas and corridors.

5.1 Recommendations

The following recommendations are made:

- Since further calibration efforts at the network level may achieve only marginal improvements, additional efforts should be focused on selected sub-areas and corridors where specific issues such as network improvements or traffic management initiatives are to be investigated. Such focused calibration process should include model validation with observed operational data including travel times on arterial and freeway sections, and typical queue reach information at selected intersections;

- The model functionality should be improved by modifying zone arrangements in sectors and increasing their number to correspond to the existing demand forecasting model. Furthermore, the renumbering of nodes should be implemented to make it easier to locate intersections; and

- A data map with the latest traffic data volume from the City, the Region and MTO should be maintained to assist in subsequent model updates.