# Calibration and Validation of a Micro-Simulation Model in Network Analysis

By:

**Timothy Oketch, Ph.D, P. Eng.**, Project Manager, TSH Associates, 300 Water Street, Whitby, Ontario, Canada L1N 9J2. Tel 905-668-6393 Fax: 905-668-0221 Email: toketch@tsh.ca

**Marzenna Carrick, CET.,** Manager of Traffic Operations, Community Services Department, Corporation of the City of Niagara Falls, P.O. Box 1023, 4310 Queen Street, Niagara Falls, ON., L2E 6X5. Tel 905-356-7521 Fax: 905-353-0651 Email: mcarrick@city.niagarafalls.on.ca

**Word Count :**

| | |
|---|---|
| Words | 5722 |
| Tables & Figures: 7 x 250 = | 1750 |
| **Total:** | **7472** |

**Paper # 05-1938: Presentation at the TRB Annual Meeting, January 2005 Washington DC and included in the Compendium of Papers CD- ROM**

# Calibration and Validation of a Micro-Simulation Model in Network Analysis

By:
**Timothy Oketch, Ph.D, P. Eng.**, Project Manager, TSH Associates, 300 Water Street, Whitby, Ontario, Canada L1N 9J2. Tel 905-668-6393 Fax: 905-668-0221 Email: toketch@tsh.ca

**Marzenna Carrick, CET.,** Manager, Traffic and Parking Services, Community Services Department, Corporation of the City of Niagara Falls, P.O. Box 1023, 4310 Queen Street, Niagara Falls, ON., L2E 6X5. Tel 905-356-7521 Fax: 905-353-0651 Email: mcarrick@city.niagarafalls.on.ca

**Abstract:**

This paper documents the calibration and validation efforts carried out as part of network analysis of a sub-area in the City of Niagara Falls using the *Paramics* micro-simulation model. The calibration effort involved comparing the model results to the field data that included not only link traffic volumes and turning movement counts at intersections but also measures of effectiveness such as average travel times and approach queues. *Paramics* uses a dynamic assignment procedure in which movements of vehicles through the network are governed by origin-destination matrices on the basis of various assignment techniques. For that reason the modeling exercise involved estimation of suitable origin-destination matrices which could replicate the observed traffic volumes and turning movement counts at selected intersections to acceptable levels. Target benchmarks were chosen and used as the basis of comparison between modeled and observed volumes using a modified Chi-Squared statistic test. Further model validation was conducted by comparing modeled and observed measures of effectiveness. It was found that target benchmarks that demonstrated an acceptable match between modeled and observed results were achieved with moderate calibration efforts. However, greater efforts are required to achieve marginal improvements in the accuracy of the model outputs and the ability of the model to predict the measures of effectiveness largely depended on the closeness of the match between observed and modeled traffic volumes. The study demonstrates that micro-simulation can be applied successfully to network analysis but notes that detailed data is required to conduct the calibration and validation of the model successfully.

## INTRODUCTION

Micro-simulation has been applied predominantly in research to model complex transportation systems and to test various traffic control algorithms. It is however finding greater application in network analysis where they are bridging the gap between planning models on the one hand and operational ones on the other. Planning or demand forecasting models are used in predicting future traffic volumes based on land use patterns and socio-economic factors such as income levels, vehicle ownership and other household information. They are suited for large networks and are unable to provide operational information that is often required at the arterial, link or intersections level. The operational models on the other hand are more concerned with arterial analysis and capacity analysis at intersections and are usually deficient in capturing area wide effects of a localized improvement, restriction or incident because their focus excludes route choice decisions.

Microscopic modeling allows for tracing of individual vehicles right from entry into the network until departure and for assigning to each vehicle type specific performance capabilities such as maximum speeds and acceleration and deceleration rates. In addition, individual vehicle movements can be described by use of appropriate models that can be drawn for both lateral and longitudinal movements. Microscopic modeling relies on the use of car following and lane changing rules to depict longitudinal and lateral movements of individual vehicles respectively.

The advantage of micro-simulation models lies their ability to model relatively large networks to sufficient details to enable operational outputs at the link or intersection level while correctly accounting for area wide impacts of localized activities. The majority come with dynamic assignment tools that facilitate realistic modeling of route choice decisions and hence better network performance. More so, their powerful animation and graphical user inter-phase endear them to users and especially where the results of the analysis is to be communicated to non-technical persons.

However, because the human behaviour in real traffic that these models try to depict is hard to observe and measure, the models are more difficult to validate. Moreover, the model parameters may also be sensitive and there is a higher danger of obtaining misleading results especially if the model is used inappropriately. For these reasons, proper calibration and validation is required when using micro-simulation models particularly in network analysis.

The process of model calibration and validation forms an integral part of the overall development and application of any model. It is through it that credibility and reliability of the model results can be demonstrated. As outlined in (***1***), verification process should be conducted at the onset of the modeling task to to ensure that the model logic is correctly represented by the computer codes and that the whole system functions as intended. Validation is considered to be the process of determining the extent to which the model fundamental rules and relationships are able to portray actual traffic behaviour as specified by the underlying theories and field data. Finally, the calibration process involves assigning appropriate values to default input parameters so as to reflect the local traffic conditions being modeled.

The process elements are interrelated and there is no clear demarcation of what activities, or parts thereof, constitute each of them. As pointed out by Hellinga (***2***), there appears to be little uniformity and conduct of these elements in current traffic engineering practice. Benekohal (***3***) provided a first step in creating a framework for the process procedure and suggested that it should consist of conceptual verification, computerized and operational validation and the use of adequate and correct data in the calibration stage. Other researchers also distinguish between the calibration at the conceptual and operational levels (***4,*** **5**) and note that calibration at the conceptual level is often achieved by the model developer through extensive testing of the inherent algorithms to ensure that they adequately perform the functions for which they are intended. At the operational level, the process is dependant on the context (or scenario being modeled) and data is required to adjust the model parameters to achieve acceptable match between model results and field data.

However, the implementation of these processes are subjective and left to the discretion of the modeler especially in networks analysis. A common practice that is often implemented in such circumstances (for example in (***6, 7***) is to conduct only visual verification and comparison of observed and modeled link volumes in calibrating and validating micro-simulation models. In advanced modeling like in real time applications, calibration is often achieved through schemes aimed at computing and minimizing aggregated error between field and observed data over a range of variables and locations. Such schemes have been implemented in real time modeling application such as DYNASMART (***4, 5***). Although calibration on the basis of volumes alone is generally sufficient for planning models, using micro-simulation may necessitate a closer look at the intersections where implementation of controls and vehicle characteristics could have significant impacts on discharge rates. As such, for micro-simulation modeling, it advisable to implement other calibration parameters such as intersection measures of effectiveness (MOEs), or link travel times in addition to the volume comparisons.

The aim of this paper is to document the steps applied in the calibration and validation of a sub-area network analysis using the *Paramics* micro-simulation model. The study was conducted as a pilot project in a sub-area of the City of Niagara Falls to establish calibration parameters and network benchmarks for use in a wider modeling task covering the entire city. The paper is organized into five sections the first being the introduction. In the second section, a review of the *Paramics* model is provided and the network is described in the third section. Section four reviews the calibration and validation process and its findings followed by discussion in the fifth section. Lastly, conclusions are provided in section six.

## OVERVIEW OF THE PARAMICS MODEL

*Paramics* is one of the micro-simulation models available for commercial usage. Other well known examples include VISSIM, INTEGRATION, AISUM, and TSIS (formerly CORSIM/FRESIM). Micro-simulation modelling is recognized as the only available method that allows examination of complex traffic problems including intelligent transportation systems, complex junctions, effects of incidents, and congested networks. Whereas most common operational models follow macroscopic approaches in which stream characteristics are determined on the basis of aggregate relationships of traffic variables of speeds, volumes and flows, micro-simulation models depict movement of individual vehicles and follows them from the time of generation to the time they exit the network. Stream characteristics are derived from the behaviour of individual vehicles which are controlled through various models, and the overall traffic performance is dependant upon driver and vehicle capabilities. Movements of individual vehicles are usually controlled by car-following models, lane change models and gap acceptance rules. These rules range from simple deterministic relationships and numerical approaches to more complex functions involving advanced methods like fuzzy logic and neural networks. *Paramics* has been used in a number of studies in North America including study of HOV lane implementations, complex freeway analysis (***6, 7***) and for evaluation of intelligent transportation initiatives as outlined in (***6***).

### Model Structure

PARAMICS in an acronym for PARAllel MICroscopic Simulation and was developed as part of large research and development projects under the European Community project. The complete model range is composed of six modules, although the program is available in suites which may include some or all of the model modules. The six components are:

- ***Modeller:*** The core simulation and animation tool;
- ***Processor:*** The batch analysis tool for multiple scenario
- ***Analyser:*** The post simulation data analysis tool
- ***Programmer:*** The applications programming interface
- ***Monitor:*** The pollution modeling interface; and
- ***Estimator:*** The OD estimation tool

The Modeller and Analyser are the basic components required to run simulations and analyze the output. Network build-up, simulation control and demand information is carried out using the Modeller which also facilitates 3D traffic animation. Simulation output from the Modeller is then loaded into the Analyser for detailed analysis and graphical output of results. The Processor is a batch assignment tool and is useful for running the simulation in a batch model. This allows running of predefined scenarios which may included simulation runs with different random numbers and other control parameters, varying flow levels and analysis for various time periods. The *Paramics* Programmer is an Application Programming Interface (API) which provides the Modeller with an opportunity to simulate additional features and user defined algorithms and functionality such lane change models and car following rules. In addition, it allows for development of plug-ins to interface *Paramics* with third party software or real word systems such as network control systems. The Monitor is an emissions calculating tool that allows inputting of emissions data based on speed and acceleration of different engine categories. It is primarily based on emissions inventories of the United Kingdom. The Estimator is an origin-destination matrix estimation package that operates at the microscopic level and integrates seamlessly with the Modeller.

*Paramics* is available for a variety of platforms including Windows and other operating systems, although it was developed to run on a Unix environment. For that reason, operating the program on a Windows environment requires a connecting interface which is provided by a third party vendor software known as the Hummingbird Program. In this study the Modeller, Processor, Analyser and Estimator modules of version 4.2.1 of the model were used.

### The Simulation Algorithm

Vehicular movements in *Paramics* is achieved through car following and lane change models that are based on a driver-vehicle-unit's desire to achieve target headway and speeds. Driver-vehicle-units (DVU) terminology is used to reflect the fact that movements are affected by both vehicular and driver characteristics. From a stopped position, a DVU will accelerate to desired speeds and headways in free flow conditions or to those it can safely maintain in constrained flow conditions. A DVU will attempt to change lanes if sufficient gaps are available to enable it complete the manoeuvre safely and if doing so would enhance its target movement parameters (***8***).

### Assignment Methods

The model uses a dynamic assignment approach in which vehicles travel from origin to destination zones using the least cost routes. The assignment techniques is achieved by associating each link with a generalized cost function that takes into consideration the time taken to complete the journey including walking to and from the car park, the distance between the origin and destination and any tolls that may be encountered enroute. The costs are specified for each link and take the form:

$$Cost = a * T + b * D + c * P$$

where

| | |
|---|---|
| a | time coefficient in minutes |
| b | distance coefficient in minutes per km |
| c | toll coefficient in minutes per monetary cost |

### Calibration and Validation Requirements

Calibration and validation form a crucial element of the simulation task through which confidence in the model results can be ascertained. Because of the stochastic nature of traffic, variations between the model and observed data is always expected and the onus is upon the model user to establish the desired reliability level and the validation effort required to achieve it (***8, 9***). The calibration process for *Paramics* follows similar procedures to conventional traffic models with the implementation of a two phase process covering a thorough check of the input data and comparing modeled results with observed data. Comparison of modeled and observed data is possible for operational analysis where an existing system is being studied. *Paramics* applies the GEH statistic, a modified chi-squared statistic that incorporates both relative and absolute differences, in comparison of modeled and observed volumes. Generally the GEH static should be used in comparing hourly traffic volumes only. It is represented by the equation as 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 |
| **10< GEH** | Flows cannot be considered to be a good fit |

Once the model has been calibrated for the existing situation it can then be used to model future scenarios.

## STUDY LOCATION

### Network Description

The network under review was a sub-area within the south western area of the City of Niagara Falls, Ontario, Canada. The City plans to model its entire network using the *Paramics* model and decided to proceed with a pilot network to establish the necessary model parameters and calibration benchmarks to be used in the larger modeling task. The area was chosen because of the rapid development taking place there. It consists of several road hierarchies including local and collector roads, arterial systems and a section of the QEW freeway. Through traffic on the freeway was not included in the analysis but the traffic exiting it to or accessing it from the study area was taken into account.

**Figure 1** shows the study location. It roughly extended four kilometers in width and about two and half kilometers in breadth. The study area was modeled with over 100 links to properly account for approach widening to accommodate turning movements and also change in road alignments. In addition, there were 16 major intersections in the study area four of which are signalized (marked 1 to 4 in **Figure 2**). Other intersections were either all-way stop controlled or two was stop sign controlled intersections. Detailed analysis was conducted on six of the intersections.

## Data Collection

The traffic data consisted of 24 hour Automatic Traffic Recorders (ATR) counts on link sections in the study area as well as manual turning movement counts (TMC) at the major intersections. Most of the link volume data was collected in the early months of 2004 although not all locations were covered and older inventory data had to be used. Qualitative data for measures of effectiveness like intersection delays and queues were collected at the same time. Travel time measurements along the various link sections were carried out in May 2004.

## CALIBRATION AND VALIDATION

As noted previously, there are no universally accepted procedures for conducting a calibration and validation for a network like this one. The responsibility lies with the modeler to implement a suitable procedure which provides an acceptable level of confidence in the model results. In this study, the first step in the calibration and validation process involved choosing of suitable model parameters like vehicle characteristics, aggressiveness, awareness, target headways and reaction times that provided realistic results. The range of suitable values for these parameters have been established through calibration of the *Paramics* model in other sites as reported in model documentation (***6,7***). Most of these were chosen based on previous experience in using the model in similar urban conditions. This was followed by estimation of representative matrices for both morning (AM) and afternoon (PM) peak periods using the Estimator module of the software. Much emphasis was laid on comparison modeled and observed flows as well as measures of effectiveness as described in the following sections. Because of the specific future analysis scenario, more effort was put on calibrating PM peak period volumes. This provided a basis of evaluating the value of trying to achieve a better match between observed and modeled link volumes and turning movements.

### Matrix Estimation

*Paramics* model relies on an origin destination (OD) matrix to define the vehicle paths through the study area. Since this information was not readily available to level detail necessary to conduct a sub-area analysis like this one, it was generated from the observed traffic volumes and turning movements using the matrix estimation module (Estimator) of the software. The procedure involved estimation of the OD trips on the basis of observed link volumes and turning movement counts at the intersections. For that reason, it was necessary to balance the observed data ensuring that sums of all incoming (destination) and outgoing (origins) were the same. Independent link volumes data and approach volumes obtained from turning movement counts at intersections were also balanced to ensure consistency.

The program utilizes the GEH statistic, as described previously to compare observed and modeled flows. Starting from an initial pattern matrix, an initial matrix defined by the user or generated by the program, flows are recalculated iteratively until a specified GEH value was achieved. In the study, the process was considered successfully completed when the whole network, and at least 80% of the link and turning volumes, achieved GEH values of 5 or less. A GEH values of 5 or less can be considered as a good match; values between 5 and 10 may require further investigation and those more than 10 may not be considered as a good match. The process was conducted with different assignment methods to identify the one that provided the best results. It was found that a stochastic process in which link costs and travel times were perturbed to a 15% level provided the best overall results. These assignment settings were maintained in the actual modeling process.

### Flow Comparison

Flow comparison was conducted at 55 link locations and in addition to turning movement comparisons at intersections and at screen line locations. There were six screen line locations as shown in **Figure 2**. Figure 2 is a modified screen shot from the simulation model. Since micro-simulation is a stochastic process in which every computer run represents a single observation, a complete experiment consisted of five computer runs and the results were averaged for each parameter. As a general rule the following benchmarks were targeted as part of the calibration effort:

- Target 1: Achieve GEH value of 5.0 or less in the overall network
- Target 2: Achieve GEH value of 5.0 or less for at least 80 percent of all link locations, approach and turning movement flows considered.

- Target 3: Verify that no significant link, intersection approach or turning movement flows had a GEH value of greater 10.0

These targets were set taking into consideration the general recommendations that GEH values of 5 or less can be considered as a good match; values between 5 and 10 may require further investigation and those more than 10 may not be considered as a good match. The benchmarks were set to guide the process, and results not fully meeting the requirements were still accepted where it was felt that sufficient efforts had been expended without significant improvements.

Overall the GEH values obtained for link flows in the entire network were 5.0 and 2.52 for the AM and PM peak periods respectively, thereby fulfilling the first targeted benchmark in both cases. Distributions of the GEH values for all the 55 link locations considered are plotted in **Figure 3**. The figure shows that for PM peak period, over 35% of the locations had GEH of 1.0 or less indicating a close match between the modeled and observed flows. Less than 15% had GEH values of more than 5 thereby meeting the second target during the PM peak period. But that was not achieved for the AM peak period where 25% of the locations had a value of 5 or more. For that period the target of 80 % values being less than 5 was also not achieved.

Comparison of flows at screen line locations and at approaches of selected intersections is summarized in **Table 1** and **Table 2.** At the screen line locations, the GEH values were all around 5.0 or less except in three cases during the morning period when values as high as 11.7 were obtained particularly for the screen line SL-4 where the total volumes were low. The differences between the observed and modeled could be attributed to sensitivities in modeling low volumes. Similar trends were obtained for the intersection approach volumes as shown in Table 2. Out of a total of 23 approaches at the six intersections considered, GEH values more than 5 were obtained in five and six locations during the AM and PM peak periods respectively and in only one case was the value greater than 10.

### Queue Comparison

As part of the model validation, queue data was collected at several intersections in the study and compared with the model results. The results were found to match closely within acceptable tolerances. A comparison of modeled and observed queues at Lundy's Lane / Kalar Road Intersection during PM Peak is provided in **Table 3**. The intersection is signalized and the table shows volumes on all approaches. The average queues on all approaches ranged from 1.8 to 2.9 and 2.6 to 3.4 vehicles per cycle for observed and modeled datasets respectively. The respective maximum queue were 8 to 11 and 7 to 15 vehicles per cycle. Although the parameter values were relatively low, the results indicate that the observed and matched acceptably well although the modeled generally tended to be higher than the observed. Further evaluation of the differences was not possible because of the limited amount of data that was available.

### Travel Time Comparisons

The calibrated model was used to estimate the travel times along various links in the network and the results are summarized in **Table 4**. Travel time observations were made by means of floating car measurements within the traffic in both directions of travel. For each link, only a number of observations were made, and detailed statistical analysis of the data was therefore not possible. In addition, additional link volume and turning movement counts were not conducted with these travel time measurements on the assumption that the calibrated model represented typical conditions. Because of that, the observed data was presented in ranges but the modeled ones shown as mean values.

In most cases the modeled travel times fell within the observed range except on Montrose Road where the modelled travel times were significantly higher than the observed values. For example during the AM peak period, the observed travel time range from 2 minutes 37 seconds to 3 minutes and 4 seconds in both directions of travel. The modeled average travel time was however 6 minutes and 39 seconds. The differences can be attributed to the fact the model flows were significantly higher (310 vs. 233 vehicles per hour) than the observed flows and resulted in over-saturation at southbound approach at the McLeod Road/Montrose Road intersection. The differences could also have arisen normal fluctuation in traffic volumes.

## DISCUSSIONS

The calibration and validation process undertaken in this study was detailed and incorporated all the elements including verification, comparison of flows at selected links, screen lines and intersections as well as comparison of measures of effectiveness at selected intersections. In most cases, the targeted benchmarks were achieved with moderate modeling efforts. Comparisons of volumes at both mid-block area and turning movements at intersection yielded GEH values which were less than 5 in most cases, indicating close agreement. However, the match was better for the PM period than for the AM period indicating that the former was better calibrated. Validation with various measures of effectiveness such as approach queues at intersections as well as travel times also show that the model yields results that are comparable to field observations. However, not all parameters met the targeted calibration benchmarks. Those results were nevertheless accepted since they were not considered critical to the overall study objectives.

Comparison of the results for AM and PM peak periods indicated that the extra efforts expended for the PM resulted in a better match for the link flows and turning movement counts at intersections. In addition, the overall network GEH value was better. However, the improvement was only marginal for the link volume comparisons where the proportion of links with GEH values greater than 5 reduced from about 25% to 15%. In addition, the screenline flows and the approach volumes were not significantly different. The extra efforts expended in the PM included use of additional data, minor network adjustments and a more rigorous matrix estimation process.

The success of the process largely depends on the effort expended and the targeted benchmarks to be achieved and it is therefore a trade off between the level of accuracy desired and the amount of effort that the modeler is willing to expend. Obviously, the level of detail in this study was possible because of the relatively small size of the network used in the pilot study; however, where large networks are to be modeled, the same level of detail may not be feasible and coarser calibration methods such as comparison traffic volumes at only few selected links may be applied. But as demonstrated in this study, achievement of the overall benchmarks may not always ensure that critical movements within the network are calibrated properly.

The analysis also highlights the data requirements to conduct detailed calibration and validation for a network like this. For example differences in travel time along the links could be attributed to a number of factors including differences between modeled and observed volumes, differences in operational speeds, and normal variations in traffic volumes. In order to minimize errors arising from these factors, extensive data would be required and more rigorous control of the calibration process is necessary. That could lead one to question whether the value obtained from conducting a detailed calibration and validation to achieve a particular level of accuracy and confidence in the results warrants corresponding effort and resources expended required to achieve it.

## CONCLUSIONS

The study detailed the calibration and validation efforts for a sub-area network analysis using the *Paramics* micro-simulation model. The efforts included comparison of flows at selected links, screen lines and intersections as well as comparison of measures of effectiveness at selected intersections as well as travel times along major streets in the study area. Specific benchmarks were set to guide the calibration effort in order to achieve results that corresponded with the observed data to acceptable level of confidence. It was found that in most cases, the targeted benchmarks were achieved with moderate modeling efforts. Comparisons of volumes at both mid-block locations and turning movements at intersection yielded GEH values which were less than 5 in most cases, indicating close agreement between modeled and observed data. However, the match was better for the AM period than for the AM period indicating that the former was better calibrated. Validation with various measures of performance such approach queues at intersection as well as travel times also show that the model yields results that are comparable to field observations although, not all parameters met the targeted calibration benchmarks.

The results demonstrate that such a network analysis can be conducted successfully using micro-simulation approaches with moderate calibration and validation efforts. However, the efforts required to achieve higher levels of accuracy may not always match the marginal improvements obtained. Consequently, the type of calibration and validation process chosen is a trade off between the level of accuracy desired and the effort that the modeler is willing to expend.

## ACKNOWLEDGEMENTS

The authors wish to thank the traffic support technicians the City of Niagara Falls who were responsible for most of the data collection during this study.

## REFERENCES

1. Oketch Timothy (2001): A Model for Heterogenous Traffic Flows Including Non-Motorized Vehicles, Ph.D. Dissertation, Institute of Traffic Studies, University of Karlsruhe, Germany

2. Rakha H., B. Hellinga,, and M. van Aerde (1996): Systematic Verification, Validation and Calibration of Traffic Simulation Models. Presented at the 1996 *Transportation Research Board Annual Meeting*, Washington DC

3. Benekohal Rahim (1991): Procedure for Validation of Microscopic Traffic Flow Simulation Models, *Transportation Research Record* 1320, pages 190-202

4. Jun Seok O., C.E. Cortes, R. Jayakrishnan, and D. Lee (1999): Microscopic Simulation with Large-Network Path Dynamics for Advanced Traffic Management and Information Systems, Report UCI-ITS-WP-99-16, Institute of Transportation Studies, University of California, Irvine

5. Jayakrishnan R., O. Jun Seok, and A. Sahraoui (2000): Calibration and Path Dynamics Issues in Microscopic Simulation for Advanced Traffic Management and Information Systems, Report UCI-ITS-WP-00-22, Institute of Transportation Studies, University of California, Irvine

6. Basak S., and B. Abdullahi (2004): Microscopic Operational Analysis of SOV to HOV lane conversion optoions for Three Major Expressways in Toronto. Paper # 04-2743, TRB Annual Conference 2004, TRB preprint CD.

7. Shaw W. John and Do Nam (2002): Micro-simulation, Freeway System Assessment, and Project Selection in Southeastern Wisconsin: Expanding the Vision, submitted for presentation at TRB Annual Meeting, 2002.

8. Quadstone (2003): Quadstone PARAMICS Version 4.1, User Guides, Edinburgh, Scotland, 2003

9. Quadstone (2003): Quadstone PARAMICS Version 4, Technical Notes, Edinburgh, Scotland, 2003

## LIST OF TABLES

**Table 1: Comparison of Modelled and Observed Volumes at Screen Lines**
**Table 2: Comparison of Approach Volumes at Selected Intersection**
**Table 3: Queue Reach at Lundy's Lane/Kalar Road Intersection during PM Peak**
**Table 4: Comparison of Modelled and Observed Travel Times**

## LIST OF FIGURES

**Figure 1: Map of Study Area in the City of Niagara Falls**
**Figure 2: Screenshot of the Study Area showing screen lines and analyzed intersections**
**Figure 3: Distribution of GEH values for selected links**

**Table 1: Comparison of Modelled and Observed Volumes at Screen Lines**

| Screen Line Location | Direction | AM | | | PM | | |
|---|---|---|---|---|---|---|---|
| | | Observed Flow | Modelled Flow | GEH | Observed Flow | Modelled Flow | GEH |
| SL-1:West of Beechwood | EB | 416 | 416 | 0.0 | 536 | 515 | 0.9 |
| | WB | 294 | 318 | 1.4 | 559 | 521 | 1.6 |
| SL-2: East of Montrose | EB | 1551 | 1410 | 3.7 | 1902 | 1771 | 3.1 |
| | WB | 1043 | 1214 | 5.1 | 1345 | 1310 | 0.9 |
| SL-3: North of Lundy's Lane | NB | 876 | 1036 | 5.2 | 1140 | 1057 | 2.5 |
| | SB | 922 | 960 | 1.3 | 1026 | 1011 | 0.5 |
| SL-4: South of McLeod | NB | 183 | 306 | 7.9 | 608 | 608 | 0.0 |
| | SB | 274 | 505 | 11.7 | 301 | 290 | 0.6 |
| SL-5: Between Kalar and Garner | EB | 532 | 501 | 1.4 | 601 | 604 | 0.1 |
| | WB | 491 | 450 | 1.9 | 637 | 647 | 0.4 |
| SL-6: Between McLeod and Lundy's Lane | NB | 596 | 814 | 8.2 | 707 | 790 | 3.0 |
| | SB | 493 | 531 | 1.7 | 711 | 757 | 1.7 |

**Table 2: Comparison of Approach Volumes at Selected Intersection**

| Intersection | Approach | AM | | | PM | | |
|---|---|---|---|---|---|---|---|
| | | Observed | Modelled | GEH | Observed | Modelled | GEH |
| 1. McLeod Road/ QEW off Ramp | SB | 375 | 448 | 3.62 | 503 | 570 | 2.88 |
| | WB | 433 | 515 | 3.75 | 569 | 440 | 5.75 |
| | EB | 387 | 377 | 0.52 | 576 | 552 | 1.01 |
| 2. McLeod Road/ Montrose Road | EB | 437 | 369 | 3.39 | 521 | 596 | 3.17 |
| | NB | 129 | 124 | 0.48 | 205 | 190 | 1.07 |
| | SB | 233 | 310 | 4.67 | 282 | 472 | 9.78 |
| | WB | 516 | 631 | 4.82 | 584 | 427 | 6.98 |
| 3. Lundy's Lane/ Montrose Road | WB | 610 | 692 | 3.21 | 905 | 972 | 2.19 |
| | NB | 605 | 613 | 0.34 | 387 | 395 | 0.42 |
| | SB | 614 | 594 | 0.81 | 729 | 655 | 2.83 |
| | EB | 902 | 508 | 14.82 | 702 | 711 | 0.34 |
| 4. Lundy's Lane/ Kalar Road | SB | 183 | 227 | 3.06 | 334 | 337 | 0.15 |
| | NB | 260 | 151 | 7.59 | 290 | 327 | 2.09 |
| | WB | 514 | 496 | 0.80 | 509 | 644 | 5.62 |
| | EB | 561 | 392 | 7.72 | 421 | 499 | 3.61 |
| 5. McLeod Road/ Kalar Road | NB | 28 | 39 | 1.90 | 31 | 77 | 6.28 |
| | SB | 220 | 325 | 6.38 | 210 | 205 | 0.36 |
| | EB | 100 | 206 | 8.60 | 171 | 159 | 0.96 |
| | WB | 311 | 379 | 3.67 | 331 | 453 | 6.14 |
| 6. Lundy's Lane /Garner Road | SB | 56 | 80 | 2.93 | 90 | 108 | 1.84 |
| | NB | 47 | 55 | 1.17 | 54 | 68 | 1.75 |
| | EB | 389 | 329 | 3.14 | 453 | 420 | 1.60 |
| | WB | 394 | 360 | 1.77 | 534 | 543 | 0.37 |

**Table 3: Queue Reach at Lundy's Lane/Kalar Road Intersection during PM Peak**

| **Approach** | **Flows [veh/h]** | | **Average Queues [veh]** | | **Maximum Queues [veh]** | |
|---|---|---|---|---|---|---|
| | **Observed** | **Modelled** | **Observed** | **Modelled** | **Observed** | **Modelled** |
| Southbound | 334 | 337 | 2.2 | 3.4 | 9 | 12 |
| Northbound | 290 | 327 | 1.8 | 2.6 | 11 | 15 |
| Westbound | 509 | 644 | 2.9 | 3.4 | 11 | 13 |
| Eastbound | 421 | 499 | 2.2 | 2.7 | 8 | 7 |

**Table 4: Comparison of Modelled and Observed Travel Times**

| Street | Direction | AM Travel Time [mm:ss] | | PM Travel Time [mm:ss] | |
|---|---|---|---|---|---|
| | | Observed | Modelled | Observed | Modelled |
| Lundy's Lane | EB | 4:11-5:00 | 4:15 | 4:32-4:36 | 4:29 |
| | WB | 4:35-6:16 | 4:19 | 4:18-5:49 | 4:38 |
| McLeod Road | EB | 4:48-5:14 | 4:24 | 4:30-5:26 | 4:50 |
| | WB | 4:36-5:38 | 4:28 | 4:23-4:27 | 4:39 |
| Montrose Road | NB | 2:37-2:49 | 4:30 | 2:32-2:34 | 4:29 |
| | SB | 2:49-3:04 | 6:39 | 2:17-2:22 | 4:49 |
| Kalar Road | NB | 2:57-3:17 | 3:20 | 2:47-3:37 | 3:31 |
| | SB | 2:36-2:36 | 2:47 | 2:39-3:23 | 3:37 |
| Garner Road | NB | 2:12-2:35 | 2:34 | 2:32-2:38 | 2:52 |
| | SB | 2:20-2:23 | 2:17 | 2:12-2:24 | 2:49 |
| Beechwood Road | NB | 2:04-2:14 | 2:13 | 2:13-2:43 | 2:39 |
| | SB | 2:18-2:22 | 2:30 | 2:20-2:35 | 2:37 |

**Figure 1: Map of Study Area in the City of Niagara Falls**

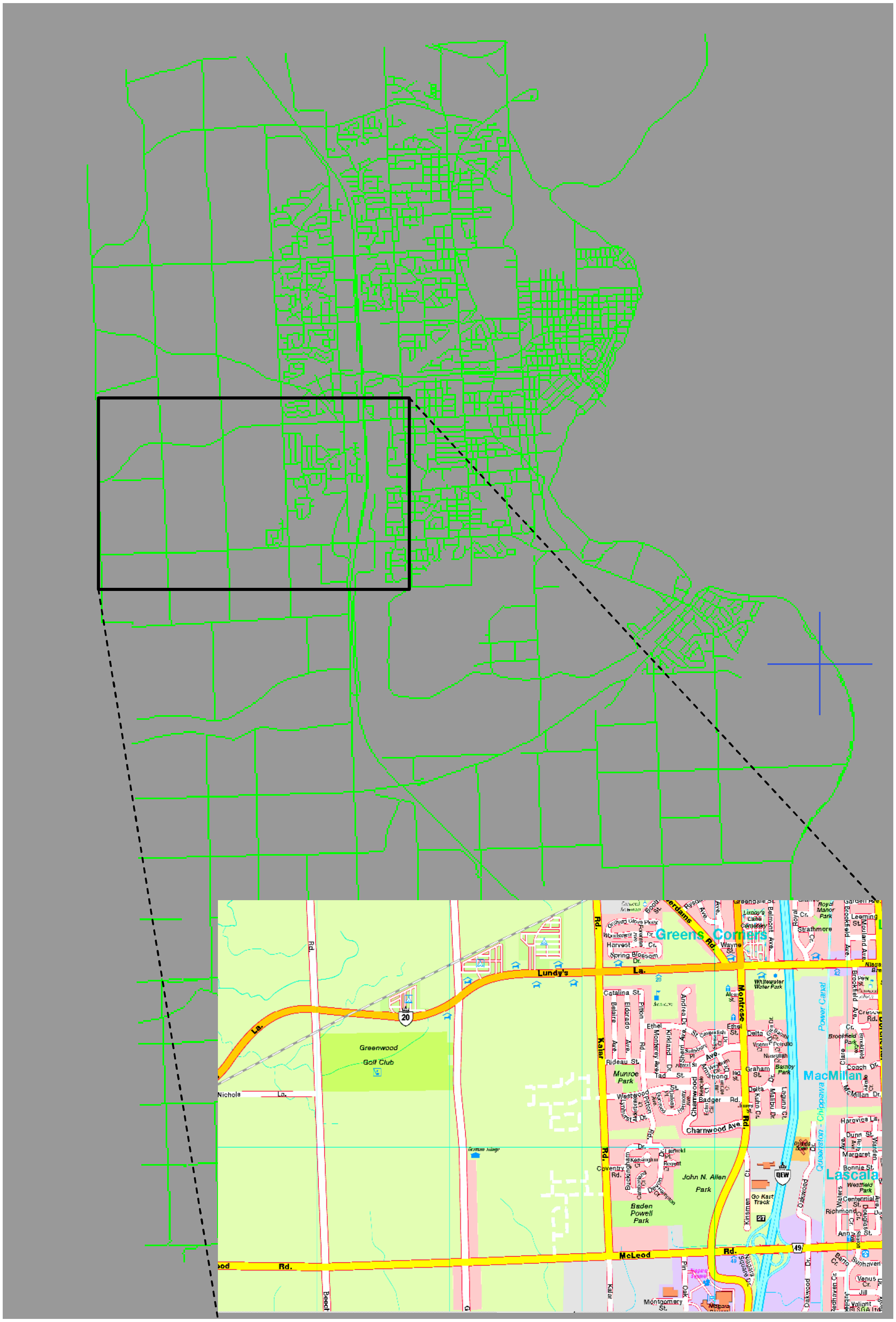

**Figure 2: Screenshot of the Study Area showing screen lines and analyzed intersections**

**Figure 3: Distribution of GEH values for selected links**