Comparisons between MATSim and EMME/2 on the Greater Toronto and Hamilton Area Network

by

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A thesis submitted in conformity with the requirements
for the degree of Master of Applied Science

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University of Toronto

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Your file Votre référence
ISBN: 978-0-494-58928-1
Our file Notre référence
ISBN: 978-0-494-58928-1

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2009

Abstract

The agent-based micro-simulation modelling technique for transportation planning is rapidly developing and is being applied to practice in recent years, thus attracting considerable attention. In contrast to conventional four-step modelling with static assignment theory, this emerging technique employs a dynamic assignment principle. Based on summary of various types of traffic assignment models and algorithms, the thesis elucidates in detail the theories of two models, MATSim and EMME/2, which represent two genres of traffic assignment, i.e., dynamic stochastic stationary state assignment and static deterministic user equilibrium assignment. In the study, the two models are compared and validated based on four indicators of the road network, i.e., travel distance, link volume, travel time and link speed, to reflect both spatial and temporal variation of the traffic flow pattern. The comparison results indicate that numerical outputs produced by MATSim are not only compatible to those by EMME/2 but more realistic from a temporal point of view. Therefore, agent-based micro-simulation models reflect a promising direction of next generation of transportation planning models.

Acknowledgments

At the moment of wrapping up my thesis for the master degree at the University of Toronto, I would like to express my sincere appreciation to all the people who constantly gave me support and encouragement during the course of this hardworking accomplishment.

I am so grateful to Professor Eric Miller, my supervisor for the master’s work, for his both academic guidance and financial sponsorship. Without the precious opportunity he provided, I would not get involved in the cutting-edge research and make such achievement. As well, I appreciate Professor Matthew Roorda for reviewing my thesis and valuable advice during the course of my study.

My special thanks also go to Professor Kai Nagel at TU Berlin, Germany and Professor Kay Axhausen at ETH Zurich, Switzerland for MATSim modelling advice for the research as well as to other MATSim team members including Dr. Michael Balmer at ETH Zurich, Switzerland, Marcel Rieser, Yu Chen and Dominik Grether at TU Berlin, Germany for their various help. Especially, Michael and Marcel’s timely and efficient technical support on MATSim during the course of the research are highly impressive. The work would not be done in such a short time period without the efficient support from the MATSim team.

In addition, many thanks go to the Data Management Group (DMG) at the University of Toronto. All the staff at DMG provided generous help and convenience upon my requests regarding the TTS data and accessibility to EMME/2 and EMME/3.

As well, I would like to express my gratefulness to my peers, James, Jiang, Bryce, Andrew, Ahsan, Marcus and others. I am pleased to have such nice colleagues in the transportation group at the University of Toronto.

My gratitude is also extended to my husband and my daughters for their enormous patience, persistent support and encouragement.

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Chapter 1
Introduction

The interaction between transportation supply and travel demand produces a flow pattern distributed on a network. Traffic assignment models attempt to capture the interactive relationship between these two elements.

Traffic assignment is the core part of transportation planning procedures in which the traffic flow distribution pattern is estimated and overlaid onto the road network according to specified rules and assumptions. In this research, the traffic assignment techniques implemented in two distinctive software applications are applied to the same road network of the Greater Toronto and Hamilton Area (GTHA) for comparisons. Thus, it can be seen that, to what extent, how different they are through comparison of the outcomes from two different models – MATSim and EMME/2.

1.1 Traffic assignment

Traffic assignment is the technique to determine the traffic flow pattern according to specific assumptions for network users' choice behaviour on the road network. Assignment models can be classified in various ways. Based on demand input, there are aggregated OD matrix and agent-based activity chains. According to the users' behaviour choice, there are deterministic and stochastic models. Based on the state of the network, there are equilibrium and non-equilibrium models. Based on the travel time function chosen, there are static and dynamic models.

In the research of traffic assignment, in order to determine the traffic flow pattern on the network, four approaches are explored: mathematical programming, optimal control theory, variational inequality and computer simulation. The first three approaches are facing difficulties to derive efficient solutions for the dynamic stochastic assignment models. The current practical approach to study the assignment issue is to use computer simulation due to its complexity. The details will be discussed in Chapter 2.

1.2 Motivation and Tool Selection

The traditional four-stage model has dominated the transportation planning for many years. It has proved to be an efficient tool for urban transportation development. One example is EMME/2, which is used for operational planning applications in the GTHA. In recent years, with the rapid development of computer techniques, attention has shifted towards dynamic activity-based modelling methods. To model dynamic process of individuals' decision making and mutual interactions, microscopic simulation approach is gaining popularity. One example of this approach is MATSim.

MATSim and EMME/2, representing two genres in traffic assignment research, are selected for the comparisons in the study. They have distinct natures and represent current and future modelling development directions. EMME/2 is an aggregated trip OD matrix-based application, whereas, MATSim is an activity chain agent-based micro-simulation application.

The rationale of EMME/2 assignment is based on a mathematical programming approach, i.e., find a numerical solution to satisfy the objective function subject to certain constraints, thus, making the state of the network reach equilibrium (Wardrop's first principle 1952). On the other hand, the rationale of MATSim simulation employs evolutionary optimization techniques to optimize individual agent's path and departure time choice for a given plan (Balmer 2007).

MATSim is an open source program which is easily accessible for researchers and is an object oriented program which is also easy for further development and extension. As well, the full technical support from the development team in Germany and Switzerland makes it a favourable option for researchers. MATSim has an excellent data input structure design which allows elastic input. This means that MATSim is able to handle a large variety of given input data: from simple one-trip plans to full activity chains.

EMME/2, as a transportation demand modelling tool, has been extensively used among government agencies, non-government organizations and private sectors across Canada. Based on years of practice, it has been proved that EMME/2 is a reliable tool for travel demand forecasting, especially for long-term horizon year forecast. However, EMME/2 does not address the individual behaviour choice in the way MATSim does. Thus, it would be interesting to see how different the assignment results would be from two distinct models. This motivation attracts attentions of researchers.

1.3 Data Source

In order to make sure that the comparison is conducted on the same basis, it is required that the demand input be consistent for two models. In the study, both demand inputs come from the same original data source - TTS (Transportation Tomorrow Survey) database. The original data are manipulated into two formats to feed the models respectively: 24 hourly aggregated trip OD matrices are constructed for the EMME/2 model; activity chain plans for individual agents are constructed for the MATSim model. Both inputs represent the same demand but in different formats. Utilizing the TTS database, a disaggregate data survey, to generate demand inputs for both models guarantees the consistency of aggregated trip OD matrices and activity chain plans for individual agents, thus validating the comparison between EMME/2 and MATSim. The detailed information on the demand generation is described in the Chapter 4.

1.4 Study Area

The study area, the Greater Toronto and Hamilton Area (GTHA), is approximately 8,240 square kilometers, including 5.57 million population, 2.85 million employment and 1.97 million households, based on 2001 census data. It is partitioned into six municipalities namely, City of Toronto, City of Hamilton, regional municipality of Halton, Peel, York and Durham. There are 1717 traffic zones within the study area. Refer to Figure 1.1 and Figure 1.2.

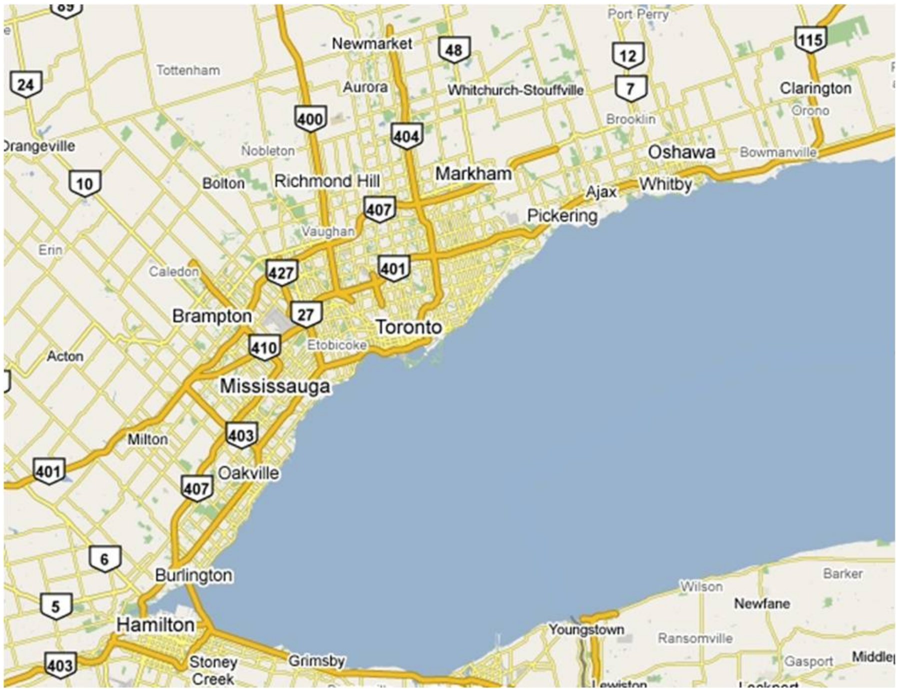

Figure 1.1 Study Area – the Greater Toronto and Hamilton Area (GTHA)

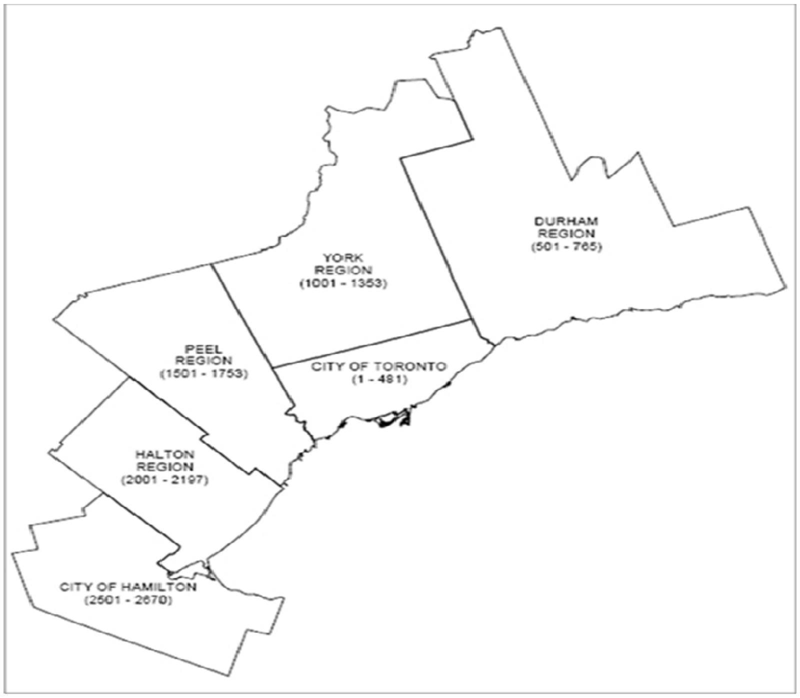

Figure 1.2 2001 Traffic Zones in the GTHA Regional Overview [1]

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[1] Source: http://www.dmg.utoronto.ca, accessed in January 2009

1.5 Conclusion

In the study, four indicators are compared: average travel time, travel distance, link volume and speed. The study indicates that the two models produce comparative traffic assignment outcomes although their algorithms are different. The outputs from two models are statistically consistent and show the same trend as the observed data to some extent. MATSim gives reliable travel distance and link volumes that are similar to EMME/2. MATSim, however has better performance with respect to travel time and link speed to reflect network congestion.

The following chapters describe the theories for traffic assignment algorithms, the two modelling tools, comparison and validation, conclusions and future development.

Chapter 2

Theoretical Concepts

2.1 Definition and Classification

The essence of traffic assignment is to find the traffic flow pattern in which the travel demand could be distributed to the road network based on the assumptions with respect to travel behaviour choice, flow conservation law, capacity restraints and other specific rules, etc. This traffic flow pattern needs to reflect the traffic situation for the current time or the future.

In the past few decades, most modelling attempts place research emphasis on three aspects: (1) path choice, (2) time horizon and (3) the state of network. Although numerous models in various forms were developed or the concepts were proposed since 1950s, all the attention has been concentrated on these three key elements. Looking back at the history, the model development for traffic assignment has gone through a long evolving process, from equilibrium to non-equilibrium (steady-state), from deterministic to stochastic, from static fixed demand to dynamic elastic demand.

All the efforts being made are dedicated to an ultimate purpose which is to construct one accurate model. It is expected to be able to depict the traffic flow pattern over the road network with the capability to show congestion status (delay/queue), the randomness of path choice and departure time choice, and continuous changes of the demand over the time horizon. Such a model would be defined as a dynamic stochastic non-equilibrium model.

It is necessary to clarify the following concepts in order to better understand the nature of a model.

2.1.1 Static vs. Dynamic

The terms static or dynamic refer to whether the system varies over time, i.e. the link volumes, travel cost and demand vary as a function of time.

In a static assignment, the traffic is simultaneously assigned to the path, so that every link on the used path gets the same amount of the traffic, which is not moving along the path over time. Static assignment can be summarized for two features: the traffic assigned will

- simultaneously appear on each link along the path,
- stay on each link over time

The link volume does not reflect the actual traffic volume variation over the time horizon since it is solely the simple aggregation of all the previously assigned traffic volumes on the same link. Although the link cost is the function of link volume, it is a pseudo-change because it does not reflect the actual link cost variation over time. In addition, static assignment also implies that the origin-destination (OD) demand is constant over time.

In dynamic assignment, the traffic is assigned sequentially onto the links along the path, moving from the beginning link to the last link of the path over a time horizon, thus resulting in link cost changes as well over time. It depicts the instantaneous state of the network. Dynamic assignment has three implications:

- The traffic flow is changing since the assigned traffic is moving along the path towards the destination over the time horizon. The instantaneous enter-flow is not necessary equal to exit-flow on the link, thus, the queue builds up and vanishes over time.
- The link cost varies as flow fluctuates. It reflects the actual cost on each link.
- The OD demand varies or fluctuates due to variation of departure time and travel cost.

2.1.2 Equilibrium vs. Non-Equilibrium

Equilibrium or non-equilibrium refers to the state of the network.

Equilibrium refers to the state of the network that satisfies the description in Wardrop's first principle. The definition of equilibrium is usually used to construct the objective function for traffic assignment problem as well as a stop criterion. The Wardrop's first principle states that:

> "Traffic on a network distributes itself in such a way that the travel costs on all paths used from any origin to any destination are equal while all unused paths have equal or greater travel costs".

Non-equilibrium refers to the state of network other than the description in the Wardrop's first principle. However, it is usually assumed that the state of the network gets to a stationary (steady) state or relaxed state without any further improvement through interaction between flows and costs. For instance, the network moves towards a stationary state characterized by the fact that the number of commuters selecting the various choices remains constant over time. This is also described as a Nash Equilibrium in some documentation (Rieser et al 2007).

2.1.3 Deterministic vs. Stochastic

Deterministic or stochastic refers to the different assumptions made for the road users in the choice models. It results in different algorithms for path choice and departure time choice.

Deterministic assignment assumes that all the road users know the actual travel cost on each path and they always decide to minimize their travel cost by taking the shortest path with the least cost. The corresponding assignment algorithm is called a single path all-or-nothing assignment.

All-or-Nothing method assigns the entire traffic demand between each OD pair onto the shortest path (the least cost) connecting that OD pair. No demand is assigned onto the paths other than the shortest path for each OD pair.

Stochastic admits that all the road users are not able to perceive the actual cost but only an estimate of the actual cost for each path. The difference between the estimate and the actual cost is a random error term. In this assumption, each user takes the path with the least cost he/she estimated instead of the actual least cost. Thus, different users may choose different paths between the same origin-destination pair. The corresponding assignment algorithm is called a probabilistic multiple-path algorithm and is generally based on random utility theory (e.g., some form of logit/probit model).

In the random utility method, the choice logit or probit model is used to calculate the probability of the users taking each path for each OD pair based on the travel cost utility. The path flow is obtained by multiplying total OD demand by the probability for each path. In practice, since it is very sophisticated and difficult to calculate the probability directly from logit or probit, Dial's algorithm (1971) was invented to implement the logit calculation in a simplified way and Monte Carlo simulation is used to emulate the probit calculation (Papageorgiou (ed.) 1991).

When similar assumptions are made for the departure time choice, the models are classified as deterministic or stochastic as well.

2.2 Classic Solutions

Based on the ultimate network state, the objective function is constructed. The algorithm is developed to satisfy the objective function and other constraints. In an equilibrium model, the objective function plays two roles, i.e. make sure the equilibrium state of the network will be reached after assignment and the uniqueness of numerical solution; whereas, in a non-equilibrium assignment model, the network will arrive at a stationary state which could be close to equilibrium state in a certain circumstance.

Generally, the algorithm design needs to satisfy three aspects, i.e. objective function, behaviour choice assumptions and convergence. As discussed in the Section 2.1.3 Deterministic vs. Stochastic, because the assumptions for the road users are different, there are two distinct ways to solve the path choice problem, i.e. all-or-nothing or random utility method. Thus, these two algorithms become necessary sub-routines for the model solution.

Most of the traffic assignment models constructed by mathematical programming could not be solved directly by analytical methods and so approximations are used instead. Among others, three classic algorithms are employed.

Frank-Wolfe algorithm was used by LeBlanc (1975) to find the solution for Beckmann's (1956) static deterministic user equilibrium model (Shao (ed.) 2007). It is a linear approximation method used in the iteration process to find the optimal solution for the non-linear objective function of the model. The critical procedure is to calculate the descent step length based on the objective function. It guarantees the optimal solution will be found. In the algorithm, all-or-nothing assignment as a sub-routine is called at each iteration until convergence is reached. The core of EMME/2 is a static deterministic user equilibrium model.

Successive average method is usually used to find the solution for the non-equilibrium model. Its descent step length is 1/n, where n is the number of iterations. However, its convergence speed is very slow and there is no reasonable stopping criterion other than an arbitrary number of iterations. The method resembles the linear approximation method, except that the step size, λ, is arbitrarily fixed to yield a solution in which each of the all-or-nothing flows have the same weight, 1/n (Sheffi 1985).

Incremental method is also used for non-equilibrium models. The OD demand is usually split into n slices. The 1/n OD demand is assigned on the path(s) at each iteration where it depends on the path choice assumptions. The assignment will be performed for n times and no convergence is required. All-or-nothing or logit (probit) as the sub-routine is called n times based on path choice assumption.

In short, for a deterministic model, all-or-nothing is called as a sub-routine in each iteration procedure. For the stochastic model, logit (approximated by Dial) or probit (approximated by Monte Carlo simulation) is called as a sub-routine in each iteration procedure.

2.3 Joint-Concept Models

Various combinations of the concepts described in the previous section are utilized to construct specific models. The name convention will reflect the full features of the model. The features of a model are determined by the joint efforts of all component functions which describe the state of network, behaviour choice assumptions and time horizon. In the literature, the following four models have been extensively exploited or well experimented by researchers and practitioners. They are representatives among others (Papageorgiou (ed.) 1991).

2.3.1 Static Deterministic User Equilibrium Model

This model describes static link flow pattern and deterministic path choice.

Beckmann proposed the mathematical form for this model which was proved to satisfy Wardrop's first principle. About 20 years later, Leblanc applied the Frank-Wolfe algorithm to find the solution for this model.

The static deterministic user equilibrium model reflects the traffic flow pattern under the following assumptions: travel demands and costs are constant over time, the entering flow rate is equal to exiting flow rate on each link at each instant. However, the model cannot capture the fluctuation in congestion level and how the flow pattern changes over time.

The optimal solution for the model can be found by the Frank-Wolfe algorithm. The convergence of the Frank-Wolfe algorithm can be guaranteed by descent step length calculated from the minimized objective function. The descent direction is determined by difference of the previous assigned link flows and the current link flows.

It is important to note two key points that the OD demand is assigned simultaneously on each link of the path, and the link flow is the simple addition of all the path flows which pass through the link. As well, the path choice algorithm is a linear combination of all-or-nothing assignment.

2.3.2 Static Stochastic User Equilibrium Model

This model describes the static link flow pattern and random utility (stochastic) path choice.

Since it is assumed that the travel cost on the path perceived by the road users is different from the actual travel cost, the perceived cost is regarded as a random variable distributed among users.

Based on random utility theory, a logit or probit model is employed to model the stochastic path choice behaviour. (Daganzo and Sheffi 1977)

The model reflects the fact that the OD demand is distributed among all the used paths between each OD pair in a random manner and the flow pattern can be determined by the total OD demand multiplied by the choice probability for each used path. In addition, as the users' perception variance decreases, the stochastic equilibrium state gets closer to the deterministic equilibrium state. If variance is equal to zero ($\sigma=0$), the stochastic equilibrium is equivalent to the deterministic one.

In practice, Dial's algorithm is used for the logit model and a Monte Carlo simulation algorithm for the probit model. The procedure to find a solution for the model is analogous to the method of successive average. Dial's algorithm replaces all-or-nothing in each iteration for stochastic path choice assignment. The descent direction for convergence is determined by the difference of previous assigned link flows and the current ones. The step length is 1/n, where n is the number of iterations.

It is important to note for this type of model that the OD demand is assigned simultaneously on each link of the path and the link flow is the simple addition of all the path flows which pass through the link. As well, path choice algorithm conforms to random utility theory.

2.3.3 Dynamic Deterministic User Optimal Model

This model describes evolution of link flow patterns over time and combined with deterministic path choice at each instant (or discrete interval).

In contrast with the mathematical programming approach, Wie (1988) and Friesz et al (1989) provided a new insight into the problem of dynamic traffic assignment with application of optimal control theory (Papageorgiou (ed.) 1991).

To describe the state of the network, Wie and Friesz summarize a dynamic generalization of Wardrop's first principle:

> "if the instantaneous expected unit travel costs for all the paths that are being used are identical and equal to the minimum instantaneous expected unit path cost at each instant for each origin-destination pair, the corresponding time-varying flow pattern is said to be user optimized."

The network users attempt to minimize individual travel costs at each instant. The instantaneous equilibrium state is characterized by the fact that no users can reduce their costs by unilaterally changing paths. Its solution may be represented by trajectories of link flow rates or densities over a specified time period.

However, Wie and Friesz did not give an operational algorithm for the model. In practice, there is no widely agreed and well established algorithm. The usual solution is to use computer simulation.

To distinguish this type of model, the OD demand is assigned sequentially on each link of the path and the instantaneous path choice algorithm is all-or-nothing.

2.3.4 Dynamic Stochastic Non-Equilibrium Model

This model describes the variation of OD demand, evolution of link flow, cost and congestion over time as well as the randomness of departure time and path choice (Cascetta 1989).

The model simulates the evolution of the network system over time as a stochastic process. The OD demand is sequentially assigned on the network using multinomial logit or probit. The joint utility of path choice and departure time choice is calculated by using a moving average method which represents users' learning and forecasting mechanism from previous experience. This model is able to reflect an instantaneous adaptive routing strategy on a congested transportation network where network users may try to optimize their path decisions on the basis of continually updated traffic information.

In each iteration, as only a fraction of users is allowed to reconsider their choices, the current path flow is the sum of a fraction of the path flow from previous iteration with the path flow resulting from the current choices of the users allowed to change their path.

The system will evolve towards a stationary state characterized by the fact that no users can reduce their perceived disutility by departure earlier or later and/or by choosing different paths. The practical implementation for this type of dynamic model is computer simulation.

To distinguish this type of model, OD demand is assigned sequentially on each link of each path, thus reflecting the moving nature; and a joint utility of path choice and departure time choice is used by random utility model (multinomial logit/probit).

2.3.5 Summary

To some extent, the models in Sections 2.3.1 to 2.3.4 represent the historical course of model development in the area of traffic assignment research. Because of the complexity and sophistication of the mathematical forms of these models, they are not presented in the text. However, they are available in the well documented literature (Papageorgiou (ed.) 1991).

In order to replicate or represent a generic traffic situation at a specific time window, a traffic assignment model needs to address multiple dimensions including demand distribution among departure times, dynamic link flow, cost and congestion as well as path choice etc.

Dynamic link flow, cost and congestion are the indicators reflecting the a spatial evolution of the network system over a temporal horizon. The path and departure time choice are related to behaviour choices. In order to model these phenomena and their relationship, a model usually involves the construction of the mathematical functions including demand conservation equation, link/path flows function, link/path cost function, choice probability function, joint utility function and stop criteria, etc.

In the construction of these functions, the temporal dimension is an important factor to be addressed, thus increasing the complexity and difficulties of the issues. The implementation of these functions needs to resort to computer simulation.

2.4 Simulation Solution

There have been four different approaches to the dynamic traffic assignment problem: mathematical programming, optimal control theory, variational inequality and computer simulation. However, as the first three traditional approaches encounter difficulties for solving dynamic models, researchers increasingly resort to computer simulation as the preferred approach.

Simulation modelling and analysis is becoming an increasingly popular technique for improving or investigating system evolution. It is a cost-effective method for evaluating the performance of traffic operational process. In order to implement dynamic assignment model, simulation is a must because "dynamic" means that the system is changing over time. Computer simulation allows the traffic system to be in motion to reflect temporal and spatial evolution of the traffic flow pattern as well as travel demands and costs updated while the system is in operation. The simulation makes it possible to monitor the solution varying over time. In addition, dynamic assignment requires iterative runs to allow the system reach stationary state.

Traffic simulation models can reflect real-time congestion status and provide the actual travel time to the users. With this information the users select departure time and path alternatives in the next iteration.

The acceleration, deceleration, car-following, lane changing models, queuing algorithms and intersection priority control mechanism, etc. together govern the drivers' behaviour and vehicle movement. The events emulated in the simulation usually include: vehicles loading and running on the link, arriving and queuing at intersection, prioritizing and discharging from the intersection.

The traffic demand may be split into n slices. Based on path choice criterion (deterministic or stochastic), 1/n of OD demand is loaded on the beginning links connecting with origin nodes, and then on the selected path moves towards their destination. As time goes by, the link cost is calculated at every simulation time step to provide dynamic information for the next 1/n loaded vehicles in the same iteration. Multiple iterations need to be executed until convergence is reached. In the simulation, algorithm design can fuse the incremental and the successive average methods together.

There are different ways to classify simulation tools. According to the level of detail the simulation involves, they are classified as microscopic or macroscopic. Microscopic models simulate the movement of individual vehicles, whereas macroscopic simulate a grouping of vehicles and provides link-based aggregated information to indicate traffic states. According to demand input, they can be classified as aggregated trip OD matrix and activity chain individual agent's plan simulation, etc.

Traffic simulation involves sophistication of the mathematical model used along with highly detailed animation graphics. The traffic system is a continuous event system where changes of traffic flow, delay and queue length are always occurring. This means that the status of the system is continuously changing with respect to time. The simulation clock advances in a continuous way instead of in discrete jumps to each event. The continuous event simulation is usually more difficult due to the use of differential equations. On the other hand, traffic simulation often carries a graphical user interface overhead involving the intensive calculations. This means that computing power and graphics displays are the two keys for traffic simulation. Fortunately, the advent of high-powered computers and photorealistic graphics has brought simulation modelling into the acceptance stage.

Validation is the process of ensuring that the simulation model represents reality. It consists of both face validity and statistical validity. Face validity is the continuous process of ensuring that the model, at least on the surface, represents reality. The animation of the system provides sufficient visual fidelity to the actual system. Statistical validity involves an objective and quantitative comparison of the simulation model with the actual system at a given confidence level (Law and Kelton, 2000).

Chapter 3

Modelling Platform

The modelling tools selected for the comparison have distinctive natures and represent different genres in traffic assignment modelling research. Based on literature review and theoretical analysis, EMME/2 is a static deterministic user equilibrium modelling tool, whereas, MATSim is a dynamic stochastic stationary state modelling tool. EMME/2 is mathematical procedure oriented software, whereas, MATSim is the simulation based application package.

3.1 EMME/2

The acronym EMME came from “Equilibre Multimodal, Multimodal Equilibrium” which is aggregated origin-destination trip-based modelling tool. Born in 1970s at the Centre for Research on Transportation (CRT) at the University of Montréal, through nearly 40 years, EMME has grown-up to a brand new application, EMME/3, with a user friendly graphical interface for accessing EMME/2 database and seamless integration with ArcGIS (EMME 2008).

It is a complete commercial platform for travel demand forecasting and transportation planning which contains distinguishing features. It offers tools for implementation of traditional four-step model from travel demand modelling to multimodal equilibration assignment procedures. It can perform many types of traffic assignment, one or multi-class auto assignment with fixed or variable demand as well as disaggregate or multi-path or timetable-based transit assignment. In addition, the interactive graphical interface in EMME/3 is convenient for network editing and result presentation. Its database is designed to allow the simultaneous analysis and direct comparison of multiple scenarios. All the data may be entered into the database interactively or in batch mode.

Behind the graphical user interface, the EMME Prompt drives the modelling and calculation process. The EMME Prompt consists of 50 modules which are subdivided into the following groups: Utilities, Network Editor, Matrix Editor, Function Editor, Assignment Procedures and Results.

The auto assignment implemented in EMME/2 is based on Wardrop's first principle. It is the implementation of a static deterministic user equilibrium model. The typical mathematical form is presented as follows,

Objective Function:

$$\min f(v) = \sum_a \int_0^{v_a} s_a(v)dv \qquad (1)$$

subject to:

$$v_a = \sum_r \sum_s \sum_k h_k^{rs} \delta_{a,k}^{rs}$$

$$q_{rs} = \sum_k h_k^{rs}$$

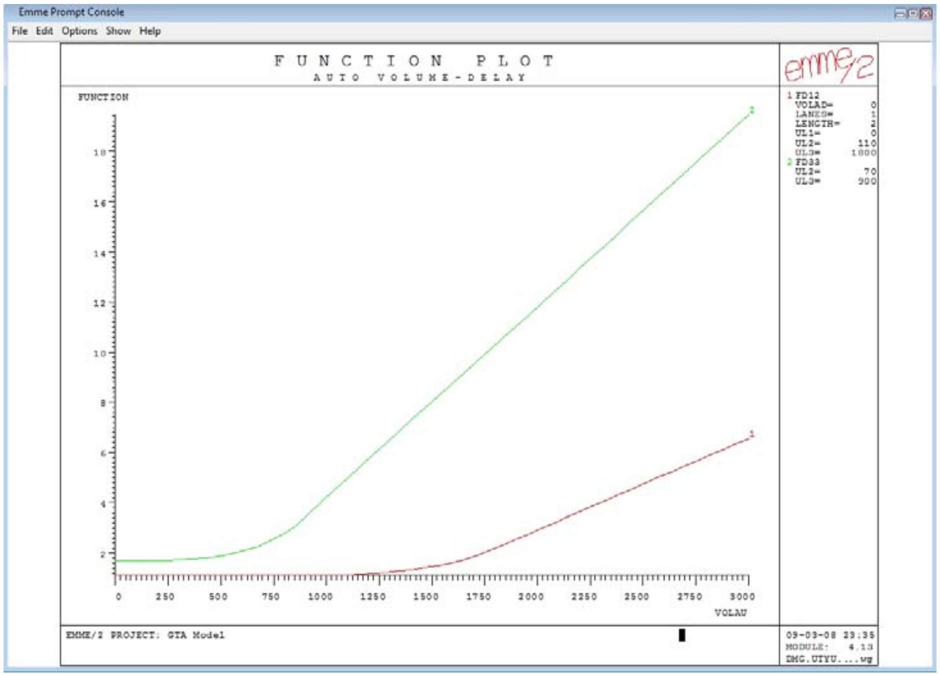
$$h_k^{rs} \geq 0$$

Where,

$s_a(v)$	volume-delay or cost function on link a
v_a	auto volume on link a
h_k^{rs}	flow on path k between origin r and destination s
$\delta_{a,k}^{rs}$	1 if link a belongs to path k from r to s, 0 otherwise
q_{rs}	auto demand from r to s

The equilibrium state of the network is achieved through the continuously mutual interaction between flow and cost via functions associated with each link when an assignment is performed. The objective is to find a set of flows such that all paths used between an origin-destination pair are of equal travel time. The costs are expressed as travel time obtained by evaluating the volume-delay and the turn penalty functions, or as a generalized cost which may represent tolls, fares or some other cost attributes. All the functions are integrated with and used by the assignment procedures. There are five classes of functions, such as volume-delay functions defined for links of the auto network, turn penalty functions defined on turns, transit segment travel time functions, auto demand functions and transit demand functions (EMME 2008).

Model validation and calibration often include an analysis of the functions used to produce the assignment results. In order to assure the proper convergence of assignment results, it is important that volume-delay functions should be monotonically increasing. On the other hand, it is also important that the volume-delay function values do not increase too quickly as the volume on a link approaches and exceeds the link capacity, as this too can cause problems with the convergence of the assignment procedure. The volume-delay functions (VDF) used in the GTHA network is tangent function which is identical to the BPR function for value of (v/c)<1.0; For (v/c)>1.0, a straight line is used with slope equal to BPR slope at (v/c)=1.0. The function plot is shown in Figure 3.1, where, Plot 1 represents VDF of highways and Plot 2 shows VDF of arterial roads.



```
1 FD12
  VOLAD=       0
  LANES=       1
  LENGTH=      2
  UL1=         0
  UL2=       110
  UL3=      1800
2 FD33
  UL2=        70
  UL3=       900
```

```
EMME/2 PROJECT: GTA Model
```

```
09-03-08 23:35
MODULE:   4.13
DMG.UTYU....wg
```

Figure 3.1 Examples of Volume-Delay Function Plot

The algorithm implemented in EMME/2 is the Frank-Wolfe, linear approximation method. The assignment procedure is an iterative process. Three stopping criteria can be specified: (1) maximum number of iteration; (2) relative gap; and (3) normalized gap. The assignment will stop as soon as one of them is met; i.e. the number of iterations reaches the maximum setting or the relative gap or normalized gap is less than or equal to the specified value, whichever occurs first. The relative gap (in %) is the most reliable of the three criteria. The relative gap is an estimate of the difference between the current assignment and a perfect equilibrium assignment. The normalized gap is the difference between the average travel time and the shortest path time.

In EMME/2, the assignment period is generally assumed to be one hour although there is no specific limit. That is, the OD demand matrix used in the assignment is for a specific hour. The volumes resulting from the assignment correspond to those for the assignment period.

3.2 MATSim

The four-stage transportation planning framework only focuses on the study of aggregated OD trips made by individual agent rather than the individual activity itself. However, the trips are the consequence of individual activities.

As individual activities are the source of trips, the attributes of every single trip such as travel mode, departure time, destination and path are closely related to the activities which the individual agents perform during certain time periods. It is argued that an observed flow pattern is a consequence of individuals' participation in activities. Thus, the analysis of travel behaviour should be based on understanding the sequential activities in which people engage.

Since the 1970s, many researchers shifted their attention to the study of individual agent-based activity modelling to complement the four-stage, trip-based modelling framework. Agent-based activity models are microscopic transportation planning models which concentrate on individuals' travel behaviour and decision-making process. MATSim is a laboratory experimental package but also represents a paradigm in the area of agent-based activity plan modelling. It is a microscopic analytical model of travel behaviour using simulation approach in transportation planning.

MATSim stands for "Multi-Agent Transport Simulation" which is a toolbox to implement large-scale agent-based transport simulation. It is open source software which is developed at VSP, TU Berlin, Germany and IVT, ETH Zurich, Switzerland. MATSim contains groups of modules for demand-modelling, agent-based traffic flow simulation, agent-plan evolution as well as methods to analyze the output generated by the modules (MATSim website).

MATSim has distinguishing features including fast dynamic and agent-based traffic simulation, versatile analyses for simulation output, object-oriented modular development, and sophisticated interactive visualizer. New features such as signal systems are also undergoing development.

MATSim consists of four logical groups: MATSim-DATA, MATSim-INI, MATSim-EA and MATSim-ANALYSIS (Balmer 2007). Each group includes multiple modules.

- MATSim-DATA is for data preparation involving census data or aggregated trip matrices.
- MATSim-INI converts raw data to an individual initial activity plan for each agent.
- MATSim-EA implements an iterative evolutionary process to optimize agent's plan.
- MATSim-ANALYSIS compares, validates and visualizes the simulation results.

MATSim-EA is the core of the four groups in that it performs the iterative demand plan evolutionary optimization process. It consists of four parts: MATSim-DB, MATSim-EXEC, MATSim-SCORES and MATSim-STRATEGY. Each part contains multiple functional modules. The MATSim-DB drives the other three parts.

- MATSim-DB keeps initial plans and modified plans for each agent during the iteration process; controls the feedback cycle (iteration) by the following procedures:
    - manage memory for each agent, load initial plan into the memory.
    - send the set of "selected" plans (one for each agent) to the simulator-mobsim by calling MATSim-EXEC.
    - send events resulted from the simulation to each agent to calculate score for each plan by calling MATSim-SCORES.
    - generate new plan by calling MATSim-STRATEGY.
    - based on the random utility, select a plan for each agent for next iteration.
- MATSim-EXEC: executes a stochastic, queue-based agent traffic simulation (mobsim) as described in Cetin et al (2003) and mimics the interaction between agents for the defined time period.

- MATSim-SCORES: evaluate the goodness of fit for each plan per agent by utility function.
- MATSim-STRATEGY: derives new plans for each agent by modifying departure time, path choice and/or mode, etc. in a plan; the dynamic Dijkstra (or Landmarks) shortest path algorithm changes the paths between each pair of activities (path re-planning); the time allocation mutator mutates the departure times and the activity durations (time re-planning).

MATSim executes the traffic assignment through the following procedures: given the individual agents' initial activity plans, loads every agent to mobsim simulator based on the departure time, activity duration and/or path information described in his/her plan; according to the simulation results, calculates a score for the plan based on the utility function (see Equation 2); compares the plan score with those in the agent memory and eliminates the plan with the worse score; partial agents are allowed to evolve the plan by path re-planning module and time re-planning module to modify the path and/or departure time, execute and evaluate the new plan in the next iteration. When each agent's utility, i.e. executed plan score, remains constant over time, the system reaches a relaxed state in which the system average plan score approaches to the system best score. Refer to Figure 3.2 for the procedures described above.

The utility function to calculate the utility ("score") of an executed plan (Rieser et al 2007) is expressed as,

$$U_{plan} = \sum_{i=1}^{n} U_{perf,i} + \sum_{i=1}^{n} U_{travel,i} + \sum_{i=1}^{n} U_{late,i} \tag{2}$$

Where,

n	number of activities
$U_{perf,i}$	logarithmic form of positive utility for performing an activity i
$U_{travel,i}$	linear form of negative utility for time spent traveling
$U_{late,i}$	linear form of negative utility for time being late

Note that the information about time is extracted from agent events, score is interpreted as monetary value and additional terms can be added such as tolls, parking fees, etc.

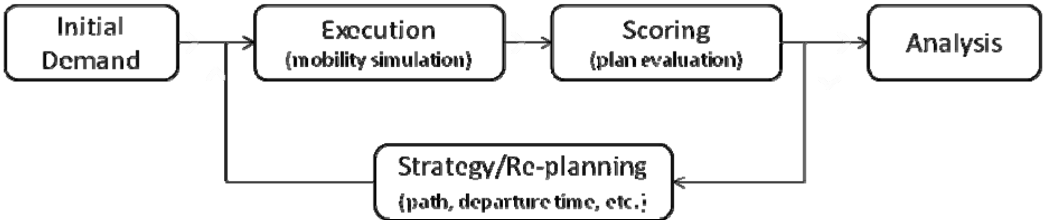


Figure 3.2 Flow Chart of MATSim Simulation

The final traffic assignment results from the interaction of the executed plan of each agent when system reached a stationary state. MATSim has intensive demand for computation power and execution time. For instance, a 50-iteration simulation for the GTHA network with 5.8% population sample data can be done in about half day on a dual core, 4 GB RAM computer.

Chapter 4

Comparison and Validation

The input demand for both MATSim and EMME/2 models are generated from TTS database. Traffic assignment is performed in MATSim and EMME/2 for the same road network of the GTHA respectively. The results from both models and the survey data are mutually compared. Figure 4.1 illustrates the overall process of the implemented work in the study.

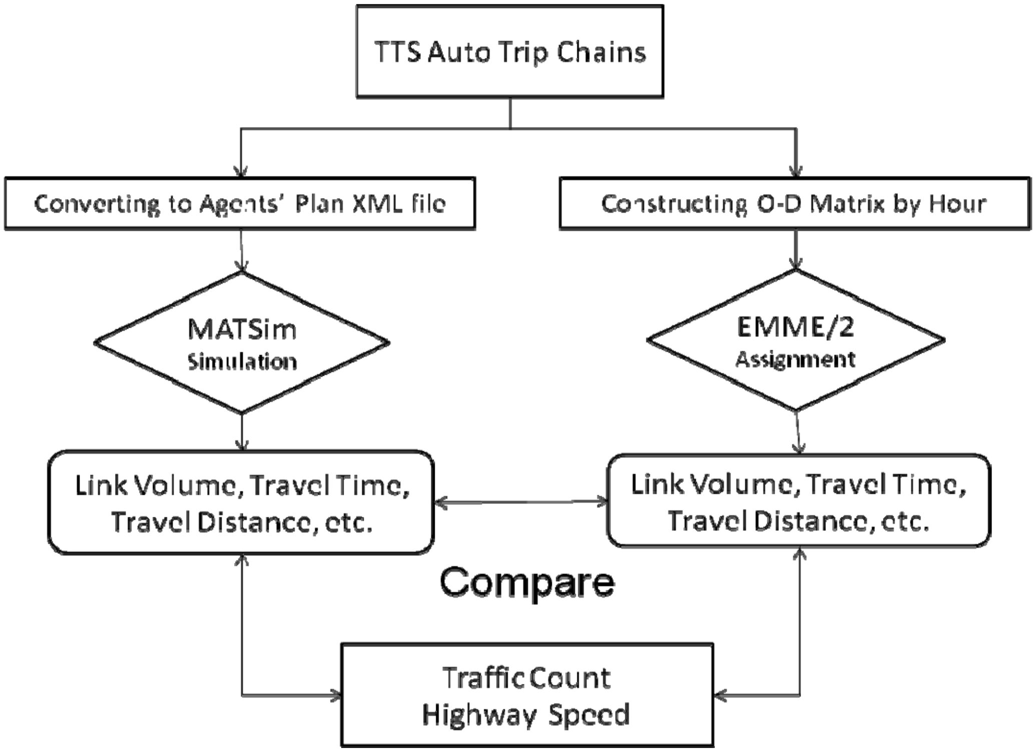


Figure 4.1 Comparison and Validation Flow Chart

4.1 Data Preparation

4.1.1 TTS Data Source

In order to better understand the travel pattern and provide a reliable basis for decision making for road and transit improvement, the Transportation Tomorrow Survey (TTS) has been conducted since 1986. It is a comprehensive travel survey conducted in the Greater Toronto and Hamilton Area (GTHA) once every five years. This is a factual survey that collects information on how members of a household use the transportation system on a weekday. The resulting information is widely used in hundreds of transportation planning studies.

The TTS database contains well organized survey data records. It aims to represent a 5% random sample of households throughout the survey area and associated persons' trips in the GTHA and surrounding area (DMG 2003A). The beauty of the TTS database is the richness in individual trip records which reflect the individuals' activities on both temporal and spatial dimensions explicitly. TTS is not only often used for aggregation trend analysis, but also makes it possible to provide activity chain input for emerging agent-based models. In addition, sensitivity analysis of individuals' reaction to policy is becoming feasible.

The demand inputs for two models are generated from TTS 2001 survey which actually contains 5.8% household samples in the GTHA. The auto mode trips are solely considered for demand input in the study. There are three types of trips by auto mode in the database, which are (1) Auto all way trips, (2) Auto access/egress to/from GO rail trips and (3) Auto access/egress to/from Subway trips. They are cleaned in Access to fit the data requirement. Table 4.1 shows the data cleaning results.

Table 4.1 Data Cleaning Results

	TTS Records	Cleaned Data[1]	Percentage
Household	113,608	87,145	76.7%
Persons (Agents)	315,202	134,519	42.7%
Trips	678,669	439,327	64.7%

The cleaned data set consists of household ID, person ID, trip number, trip start time, trip purpose, origin and destination zones. The purposes of trips in the data set (DMG 2003B) are listed as follows,

C - Second and subsequent school trips
D - Daycare
F - Facilitate passenger
H - Home
M - Marketing
O - Other
R - Second and subsequent work trips
S - First school trip of the day
W- First work trip of the day
9 - Unknown

---

[1] Only associated with auto trips

4.1.2 Demand Generation

A program, GenerateOD, is utilized to generate 24 hourly OD matrices for EMME/2. The matrices are created by aggregating individual trips from the cleaned data set according to the trip start time and origin-destination. Figure 4.2 shows the trip distribution of input demand by time of day.

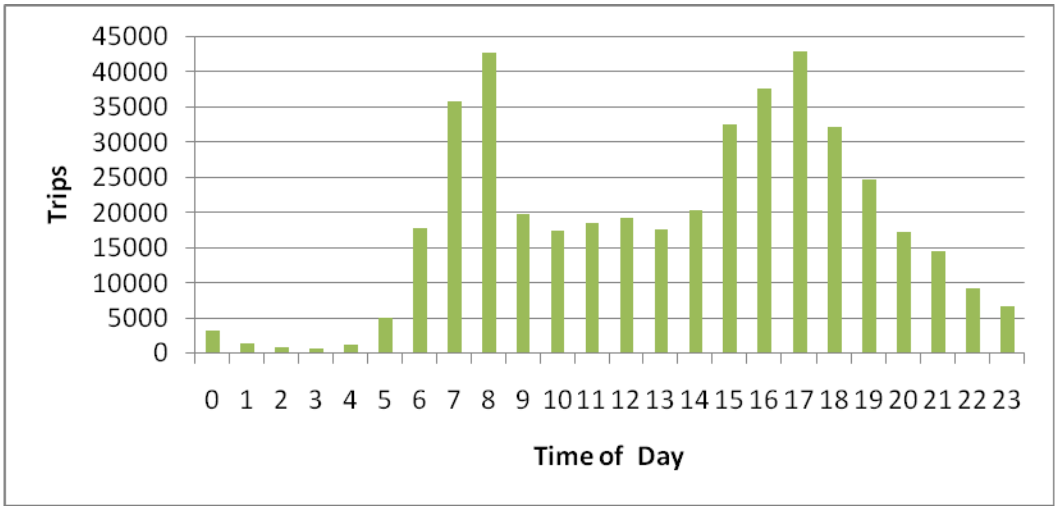


Figure 4.2 Trip Distribution by Time of Day

MATSim Converter program is utilized to create initial agents' trip plans from the cleaned data set and assign coordinates for activity locations.

The individual trips in the data set start from and end to traffic zones represented by centroids. However, MATSim requires each trip start and end at a link. Thus, each zone-based trip needs to be transformed to a link-based trip. First, a pair of random coordinates (x, y) is generated for an activity within a circle area around centroid. The radius of the circle area is defined as 0.7 times the distance from the centroid to a nearest centroid. The factor 0.7 has been proved to be a good coverage of the circle areas with low overlaps (Rieser et al 2007). Then, the activity coordinates are mapped to the nearest link. Figure 4.3 shows a graphical overview how links are mapped with activity locations.

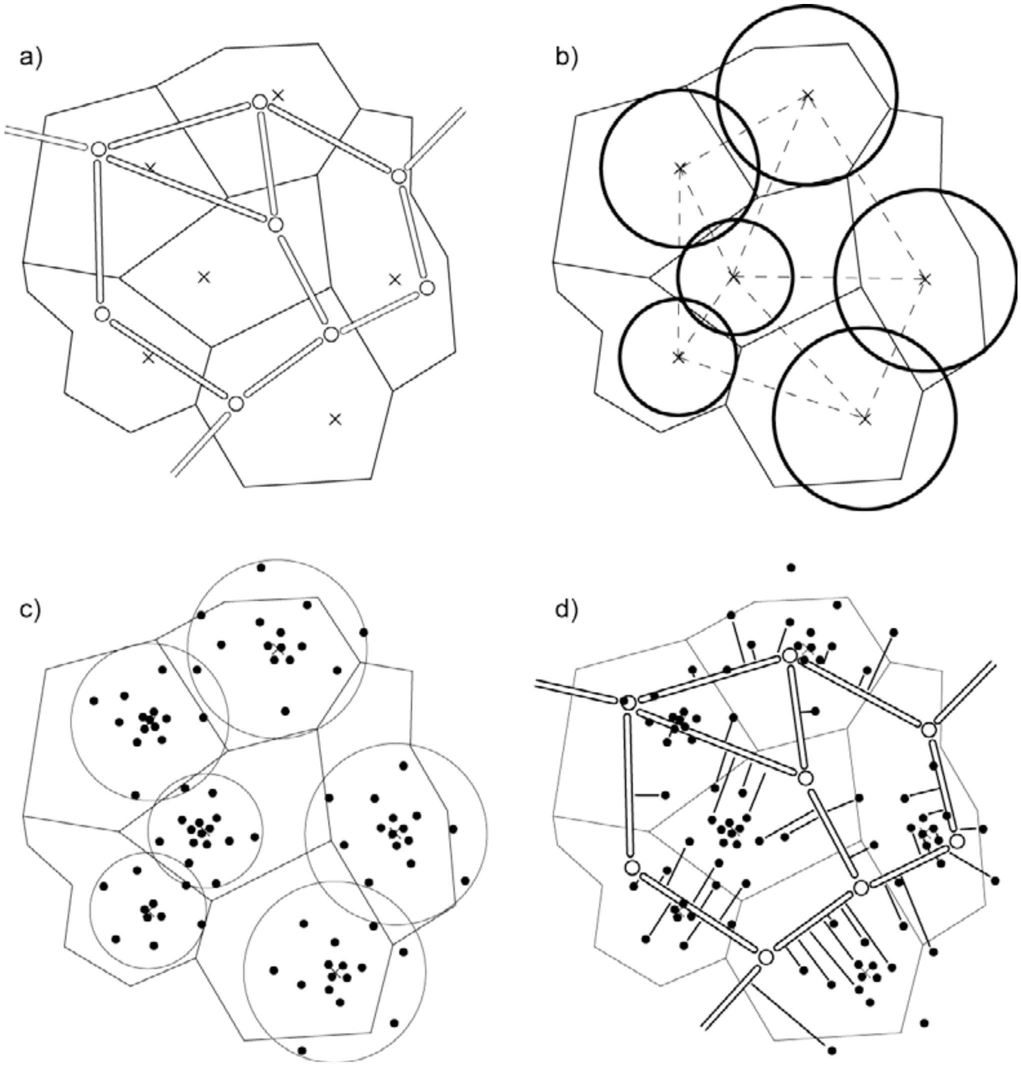


Figure 4.3 Mapping activity locations to links[1]

a) Network with nodes and links, and traffic zones represented by a centroid (x)

b) Circles around centroids with defined radius

c) Randomly generated coordinates for activity locations within the circle for each zone.

d) Mapping activity locations to nearest link

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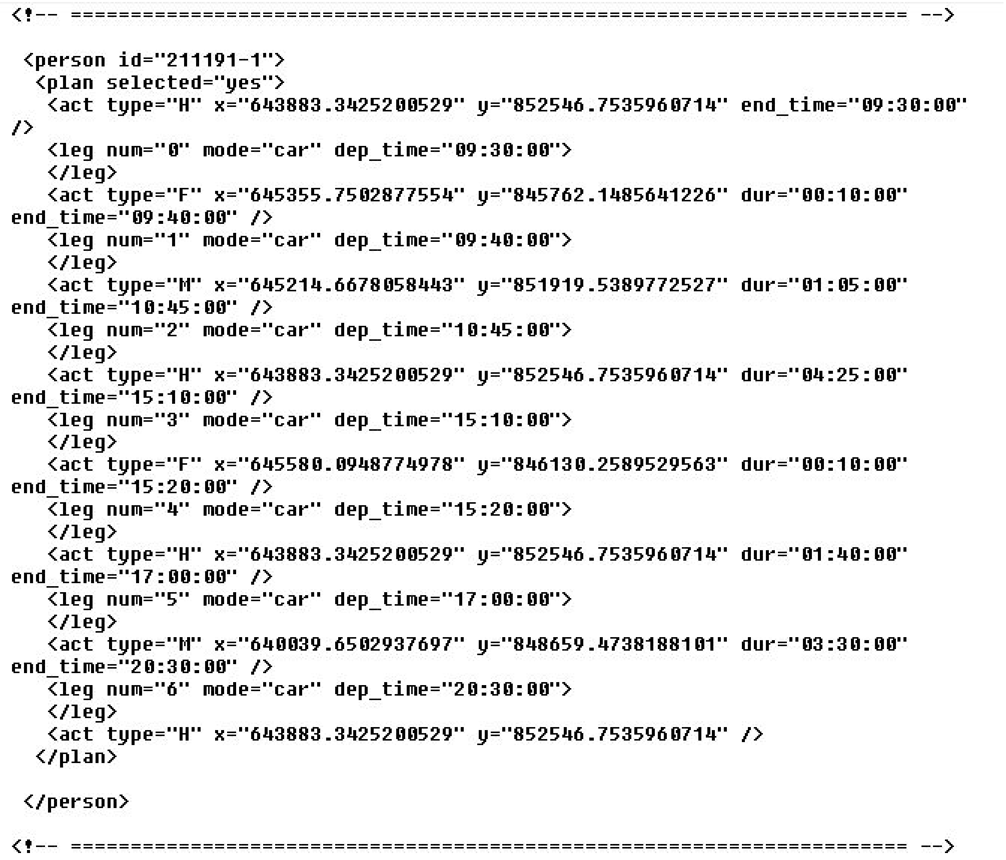
[1] Source: Rieser et al (2007)

Figure 4.4 shows an example of an agent’s plan.



```
<!-- ======================================================================= -->

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  <plan selected="yes">
   <act type="H" x="643883.3425200529" y="852546.7535960714" end_time="09:30:00"
/>
   <leg num="0" mode="car" dep_time="09:30:00">
   </leg>
   <act type="F" x="645355.7502877554" y="845762.1485641226" dur="00:10:00"
end_time="09:40:00" />
   <leg num="1" mode="car" dep_time="09:40:00">
   </leg>
   <act type="M" x="645214.6678058443" y="851919.5389772527" dur="01:05:00"
end_time="10:45:00" />
   <leg num="2" mode="car" dep_time="10:45:00">
   </leg>
   <act type="H" x="643883.3425200529" y="852546.7535960714" dur="04:25:00"
end_time="15:10:00" />
   <leg num="3" mode="car" dep_time="15:10:00">
   </leg>
   <act type="F" x="645580.0948774978" y="846130.2589529563" dur="00:10:00"
end_time="15:20:00" />
   <leg num="4" mode="car" dep_time="15:20:00">
   </leg>
   <act type="H" x="643883.3425200529" y="852546.7535960714" dur="01:40:00"
end_time="17:00:00" />
   <leg num="5" mode="car" dep_time="17:00:00">
   </leg>
   <act type="M" x="640039.6502937697" y="848659.4738188101" dur="03:30:00"
end_time="20:30:00" />
   <leg num="6" mode="car" dep_time="20:30:00">
   </leg>
   <act type="H" x="643883.3425200529" y="852546.7535960714" />
  </plan>

 </person>

<!-- ======================================================================= -->
```

Figure 4.4 Example of An Agent’s Plan

4.1.3 2001 GTHA Network

The EMME/2 original network contains following elements: 1812 centroids, 13681 regular nodes and 45892 links (including transit lines). The nodes in total are 15493. The centroids include 1717 internal zones, 31 external zones, 14 Subway centroids and 50 GO (rail) centroids.

In order to prepare the road network input for MATSim, two procedures are followed. First, a program E2M is used to extract the links only with car mode from the original EMME/2 network, thus resulting in 38391 links. Then, NetworkCleaner cleans up the network to satisfy MATSim input requirement. It ensures that each link in the network can be reached by any other link. Links that have no connection with other links are removed from the network. Nodes without incoming or outgoing links are removed as well from the network. The network after cleaning contains 14103 nodes with all centroids remained and 38391 links.

In order to implement the same turn restrictions as the EMME/2 network, a program Maneuvers is utilized to add 716 prohibited turns into the cleaned network. The network is modified and ends up with 16350 nodes and 41560 links.

4.2 Parameter Specification

Since running MATSim with 100% capacity network requires significant computation power, the network with scaled link capacities is used for the study. A proper scale factor needs to be determined so that the network with scaled capacity produces the same results as the one with full capacity.

4.2.1 Settings for EMME/2

As the link capacity plays the key role for traffic assignment in EMME/2, it is the only scaled element in the experiments. Four scenarios with different scale factor for the link capacity are tested in EMME/2. The other attributes of the network remain the same in all the scenarios. Because demand input from TTS database represents approximately 5.8% of GTHA population, the scale factor is chosen as 0.05, 0.06 and 0.07 for experiments. The expansion factor, one of the household attributes, is applied to the demand input from TTS database to construct 24 hourly full trip matrices for the full capacity network.

The travel time from the network with three different scale factors is compared with the one from the full capacity network respectively. It is found that the 24 hourly average travel times with scale factor 0.06 shows the best match to the ones with the full capacity. It indicates that it is appropriate to use 0.06 capacity scenario with sample demand to represent full capacity scenario with weighted demand.

Twenty-four auto assignments are conducted for each scenario and the average trip travel time by time of day are shown in Figure 4.5.

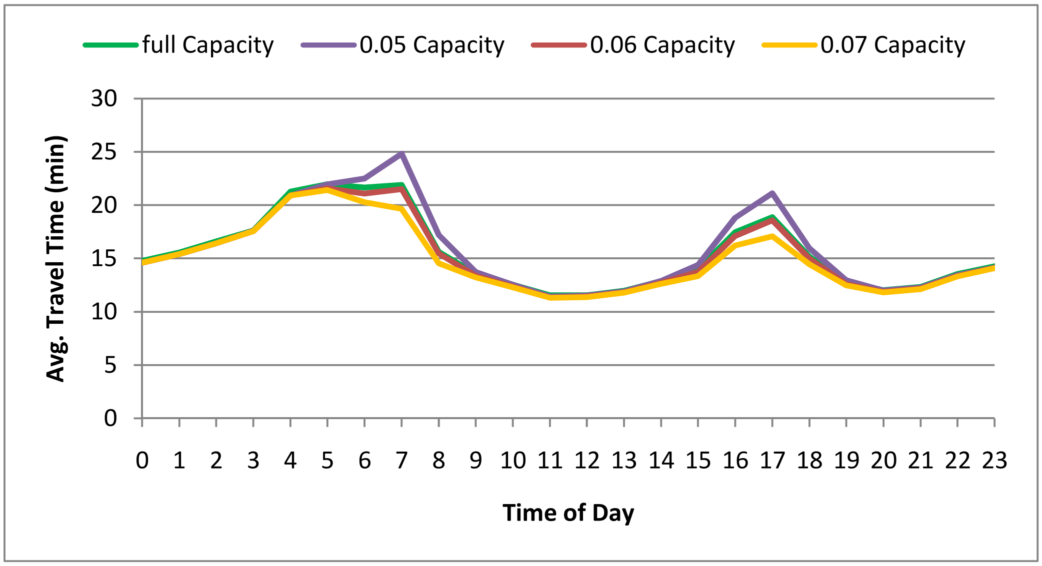


Figure 4.5 Travel Time with Scaled Capacity in EMME/2

4.2.2 Settings for MATSim

MATSim simulation configurations in this study are listed in Appendix A. All required parameters are specified in one configuration file. The typical parameters are locations of input data, file formats and function parameters, etc.

There are two key factors that need to be specified in MATSim,

1) Flow Capacity Factor (FCF) denotes the scale of link capacity;
2) Storage Capacity Factor (SCF) denotes the scale of vehicle storage length on a link.

They have global effect on the simulation. SCF is the empirical factor which is suggested by MATSim development team between 0.1 and 0.3 to adapt to approximate 5% population. FCF is set to be 0.05, 0.06 and 0.07 respectively while SCF is set to be 0.2 for experiments.

Figure 4.6 and Figure 4.7 show the average trip travel time for different FCF/SCF simulation runs. It can be seen that FCF shows the dominant influence on the model relative to SCF. On the other hand, unlike EMME/2, MATSim generates significantly different travel time during AM/PM peak period using different scales of link capacity. This phenomenon can be well explained by the algorithm used in MATSim, i.e. queue-based assignment is more sensitive to network capacity changes. The longer trip travel times at certain time of day resulting from higher SCF's can be interpreted that more vehicles that are allowed in a link may cause longer queues for congested roads. Based on this analysis, FCF 0.06 and SCF 0.2 are used for the model comparison with EMME/2.

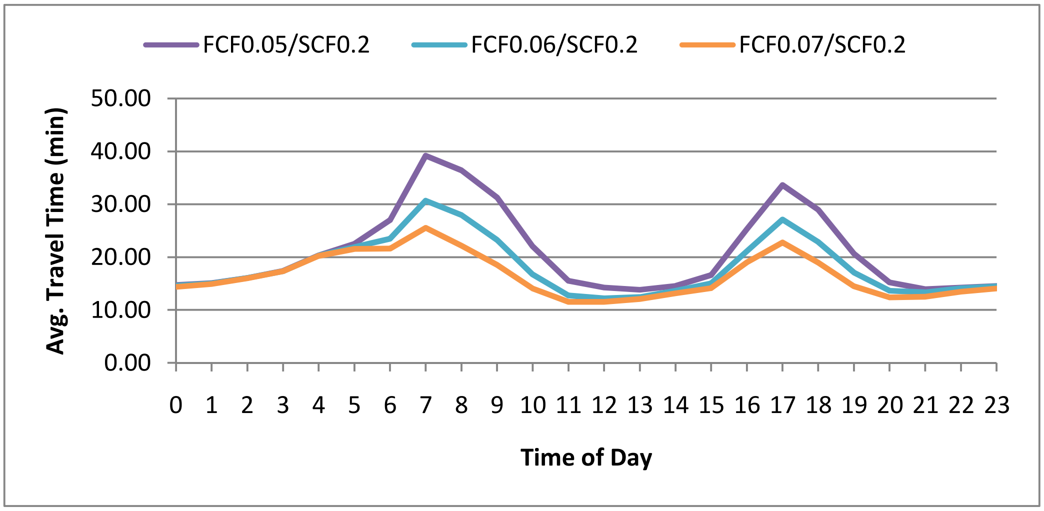


Figure 4.6 Travel Time with Different FCF in MATSim

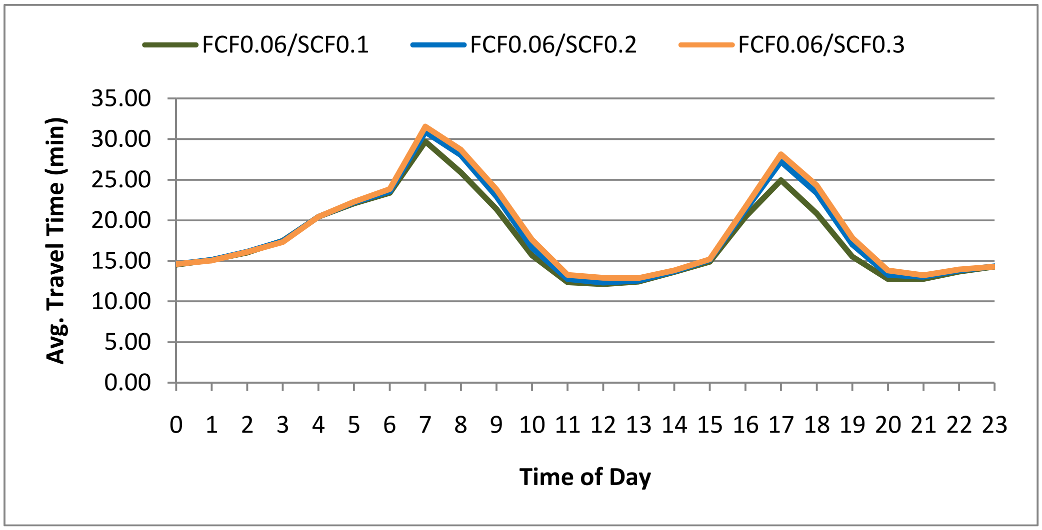


Figure 4.7 Travel Time with Different SCF in MATSim

To calculate scores (utilities) for each executed plan, the typical activity time and duration are set as constraints for each type of activity based on common sense. Refer to Appendix A for detailed information.

The strategy module includes Re-Route and Time Allocation Mutator which derive new plans for each agent by modifying path choice and departure time respectively. In order to keep the hourly demand in MATSim consistent with the demand in EMME/2, the Time Allocation Mutator is not activated in the study. The maximum number of plans for each agent is set to four plans. This number results from the scenario size in conjunction with computer memory limitations.

The route finding strategy ReRoute_Landmarks is used in parameter identification process. Because Landmarks is much faster than Dijkstra in finding the shortest route (Lefebvre et al 2007), 50-iteration run (134,519 agents) takes less than 9 hours using Landmarks while almost 12.5 hours using Dijkstra on dual core, 4 GB RAM computer. However, Landmarks is restricted to Euclidean distance between two nodes; whereas, Dijkstra is a generic algorithm on the problem of finding a shortest path between two nodes. Therefore, ReRoute_Dijkstra is used in model comparison process.

4.2.3 Stop Criteria and Convergence

The convergence of auto assignment in both models is addressed according to difference criteria. The stop mechanism in EMME/2 auto assignment is governed by one of three criteria, number of iterations, normalized gap (0.5min) and relative gap (0.5%). So far, MATSim stop is controlled by number of iterations.

The convergence is determined by a rather fuzzy definition of system relaxed state in MATSim. The system relaxed state could be characterized by the fact that certain indicators remain constant over time.

Two indicators, average travel time and travel distance, are used to identify convergence. Figure 4.8 indicates that the system reaches a stable state after 30 iterations since travel time and travel distance remain constant.

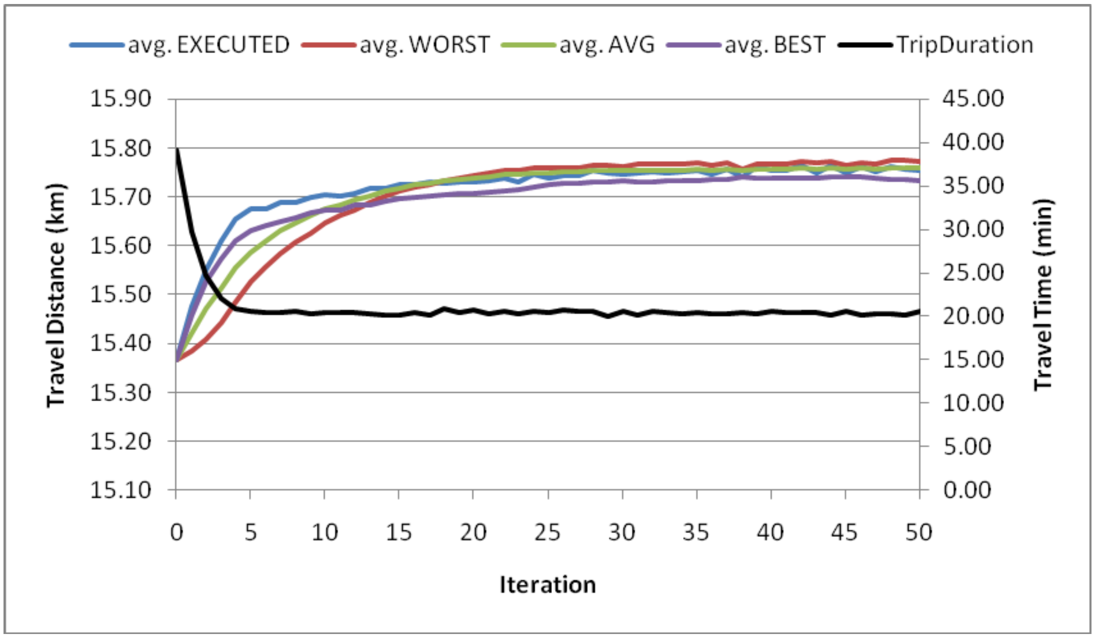


Figure 4.8 Iteration Evolution – Travel Time and Travel Distance

As well, the plan score can be used to identify convergence. The score curves shown in Figure 4.9 reach convergence since no agents could make any improvement for their executed plan score.

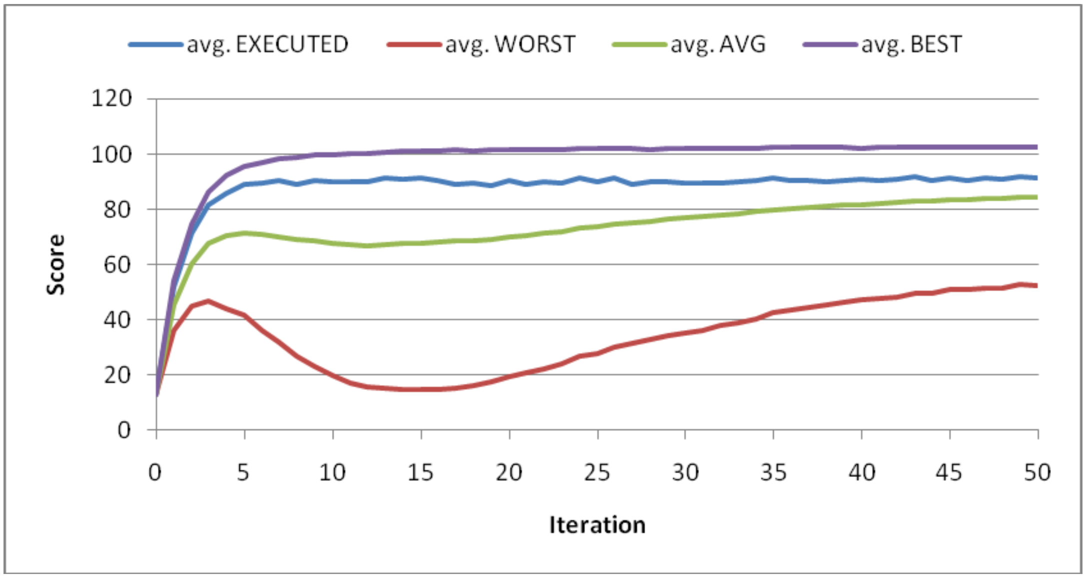


Figure 4.9 Iteration Evolution - Score

Through all the experiments, it is determined that the 0.06 capacity scenario in EMME/2 and FCF 0.06/SCF 0.2 parameters in MATSim are employed for the following comparisons between two models.

4.3 Comparison and Validation

Since the assignment output from EMME/2 is aggregated, whereas, the output from MATSim is agent-based events that occurred during the simulation, some post-simulation processes are carried out for MATSim output to get aggregated statistics. These processes are performed using specific programs or using MATSim standard statistical output. In addition, some EMME/3 graphical features are utilized in the study.

Numerical comparisons between MATSim and EMME/2 are conducted from the following perspectives,

1) Trip Distribution by 24 hours
2) Travel Time: 24 hourly average travel time and inter-zonal travel time weighted by trips
3) Travel Distance: 24 hourly average trip length
4) Link Volume: compare with traffic counts at screenline level
5) Link Speed: compare harmonic mean of speed on major highways with surveyed speed

4.3.1 Graphic Presentation

Generally, agent-based simulation models are quite different from conventional four-stage models in both algorithms and graphical presentation. It can be seen from the following figures that the conventional models show aggregate quantity, whereas, agent-based models show individual agents and their mutual interaction on the network.

Figures 4.10 and 4.11 present auto assignment results for different times of day from a MATSim simulation. In Figure 4.10 and Figure 4.11, green, red and yellow cars on links represent free flow traffic, congested traffic and saturated traffic respectively.

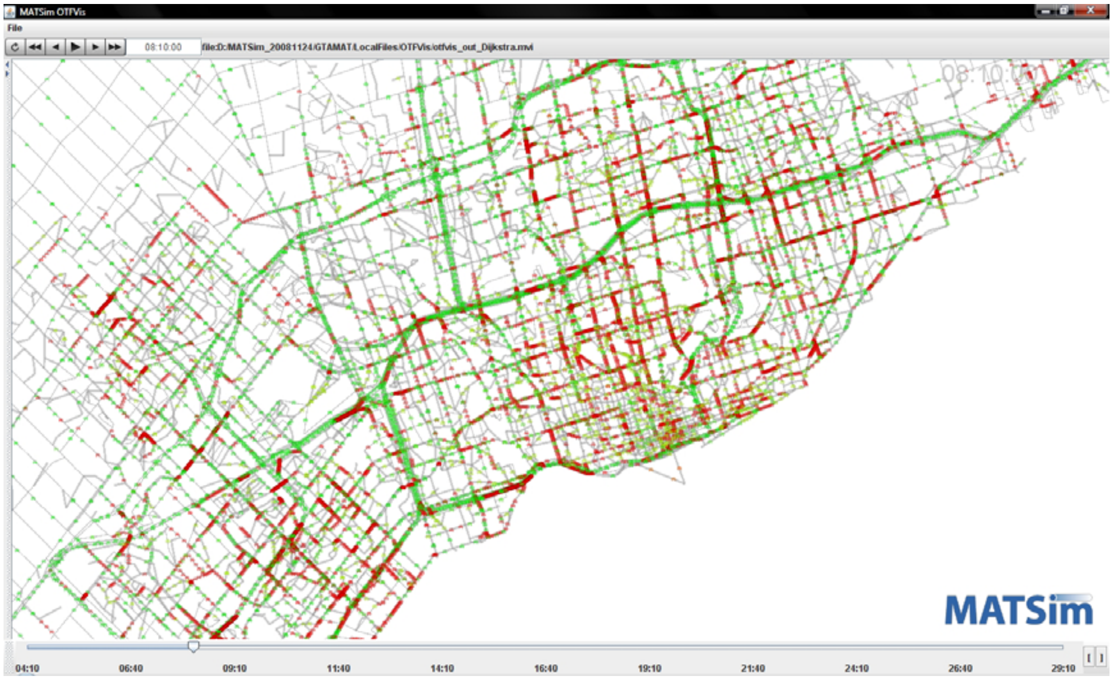


Figure 4.10 Traffic Flow at 8:10am by MATSim

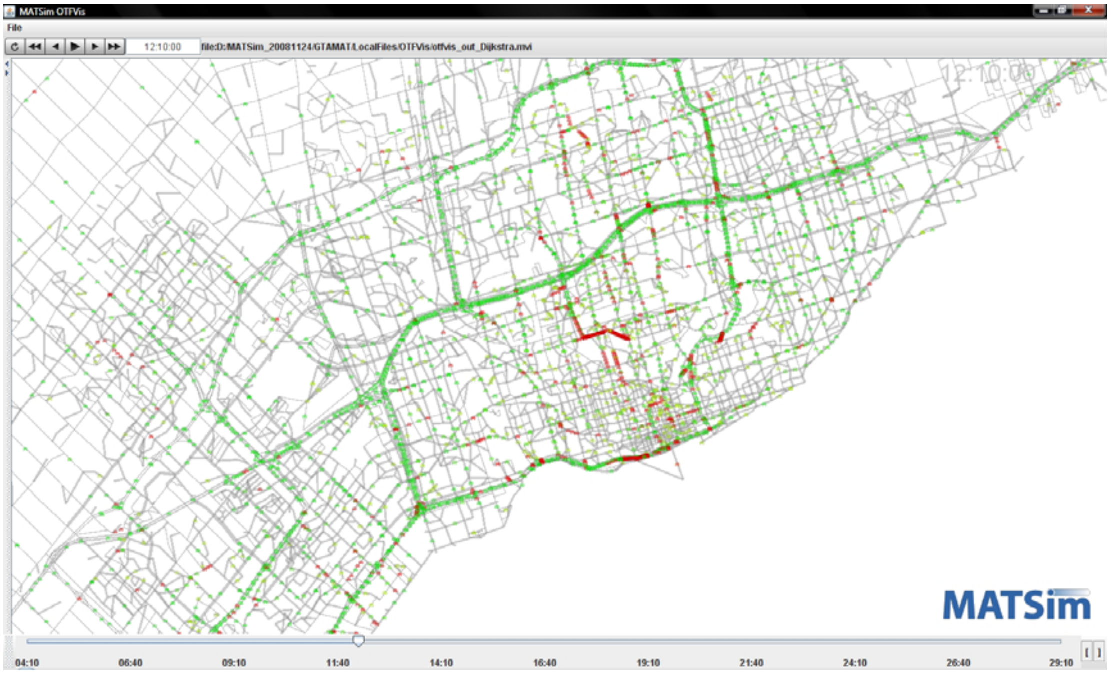
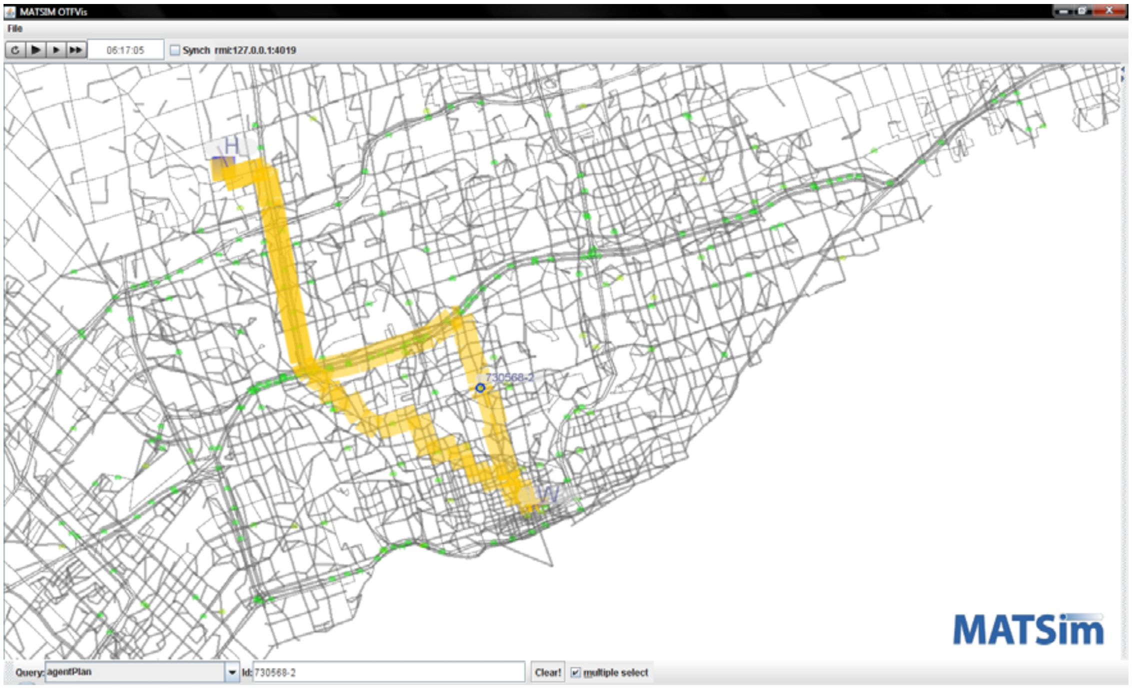


Figure 4.11 Traffic Flow at 12:10am by MATSim

MATSim has the ability to visualize the agents' trip paths and associated activities on the road network during real-time simulation, but it requires extreme large memory computer. Figure 4.12 shows H-W-H trip path chosen by an agent who lives in north of Toronto and works in downtown Toronto.



06:17:05

☐ Synch rmi:127.0.0.1:4019

Query: agentPlan

Id: 730568-2

☑ multiple select

Figure 4.12 Path Chosen by an Agent

Figures 4.13 and 4.14 present auto assignment results for different time of day from EMME/2. The volumes shown in both figures are at the same scale.

Figure 4.13 Traffic Flow at 8:00-9:00am period by EMME/2

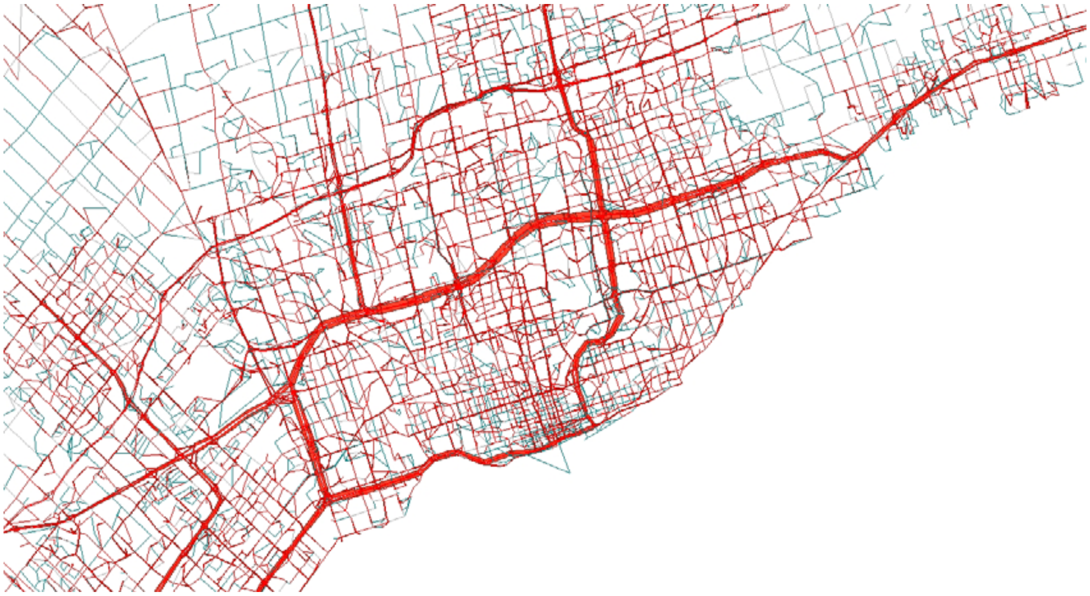


Figure 4.14 Traffic Flow at 12:00-13:00 period by EMME/2

4.3.2 Trip Distribution

As EMME/2 does not consider the link space constraint, all the demand can be loaded onto the network. However, as MATSim is a microscopic simulation model, the agents loaded onto the links are constrained by the physical space of the links. It can be seen from Figure 4.15, the hourly departures are slightly less than demand input trips during day time. Figure 4.16 shows a finer trip distribution and indicates that the demand input trips aggregated from TTS database all start at a particular time, i.e., surge at hourly, half-hourly and quarter-hourly. This may cause the problem that some agents cannot be loaded onto the links due to congestion in MATSim.

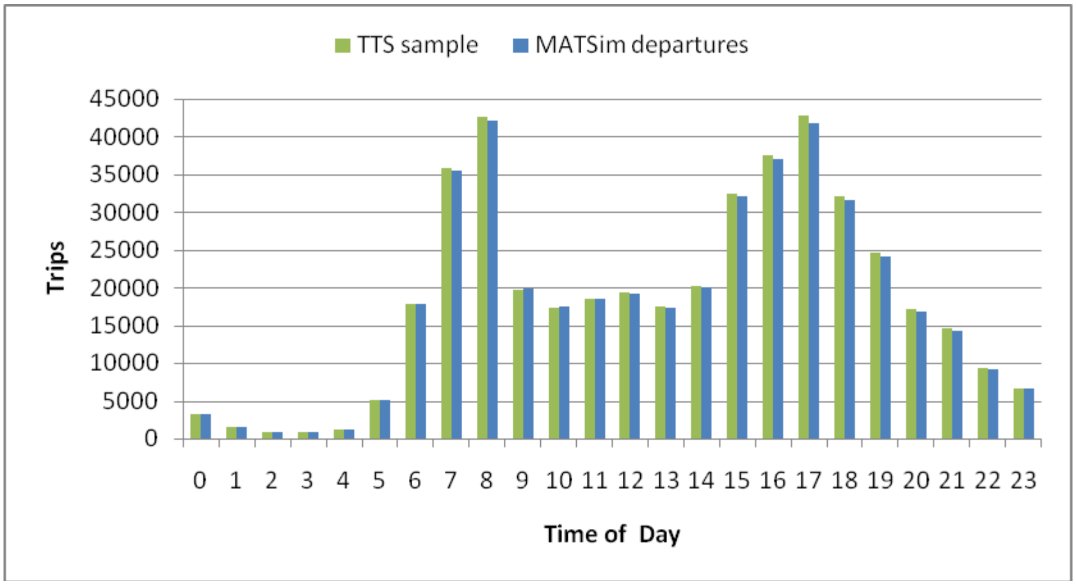


Figure 4.15 Trip Distribution Comparison

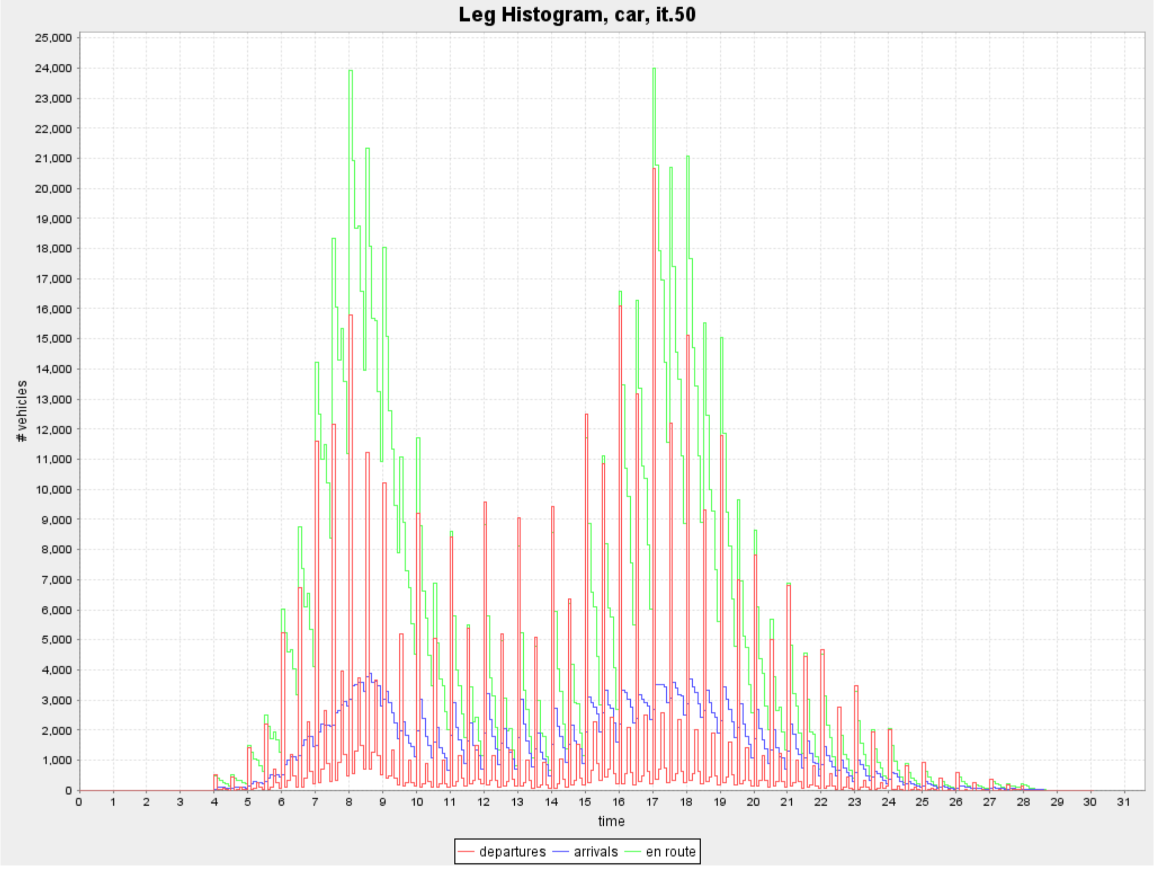


Figure 4.16 Trip Distribution in MATSim (5 minutes interval)

4.3.3 Travel Time

24 hourly average trip travel times are calculated for both models. Figure 4.17 shows the comparison between MATSim and EMME/2. Both models generate similar travel time for night and mid-day off peak times. However, the travel time in MATSim is much higher than that in EMME/2 at both AM and PM peak periods. This indicates that MATSim captures fluctuating congestion on the network by time of day while EMME/2 is less sensitive to congestion.

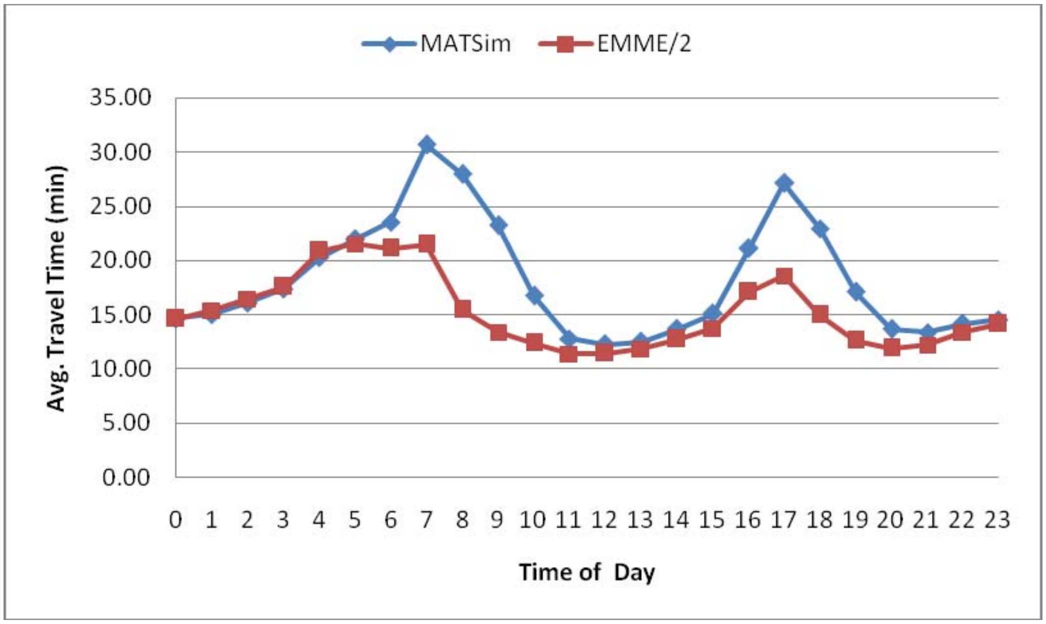


Figure 4.17 Average Trip Travel Time Comparison

Moreover, the detailed inter-zonal travel time weighted by trips is calculated for 24 hours. The inter-zonal travel time matrices for each hour from both models are compared. The results are illustrated in Appendix B and summarized in Table 4.2.

Table 4.2 Mean of Inter-Zonal Travel Time Comparison

Time of Day	Mean of Travel Time		Difference %	Time of Day	Mean of Travel Time		Difference %
	EMME/2	MATSim			EMME/2	MATSim	
0	14.15	14.61	-3%	12	10.32	11.78	-12%
1	14.99	15.20	-1%	13	10.90	12.28	-11%
2	16.06	16.24	-1%	14	11.89	13.49	-12%
3	17.30	17.50	-1%	15	12.24	14.51	-16%
4	20.49	20.51	0%	16	15.94	19.44	-18%
5	21.20	21.78	-3%	17	17.26	22.61	-24%
6	20.25	21.84	-7%	18	13.98	19.30	-28%
7	20.38	22.05	-8%	19	11.79	15.16	-22%
8	13.67	19.37	-29%	20	11.13	12.73	-13%
9	12.37	17.61	-30%	21	11.49	13.02	-12%
10	11.52	14.24	-19%	22	12.80	13.75	-7%
11	10.27	11.92	-14%	23	13.61	14.34	-5%

It can be seen in Table 4.2, the mean of inter-zonal travel time in MATSim is much longer than one in EMME/2 at AM /PM peak hour. This result corresponds to the average trip travel time comparison in Figure 4.17.

4.3.4 Travel Distance

Another trip characteristic – average travel distance is also calculated for both models. In addition, one of TTS data attributes – straight trip distance is extracted from TTS database and compared with the travel distance from two models.

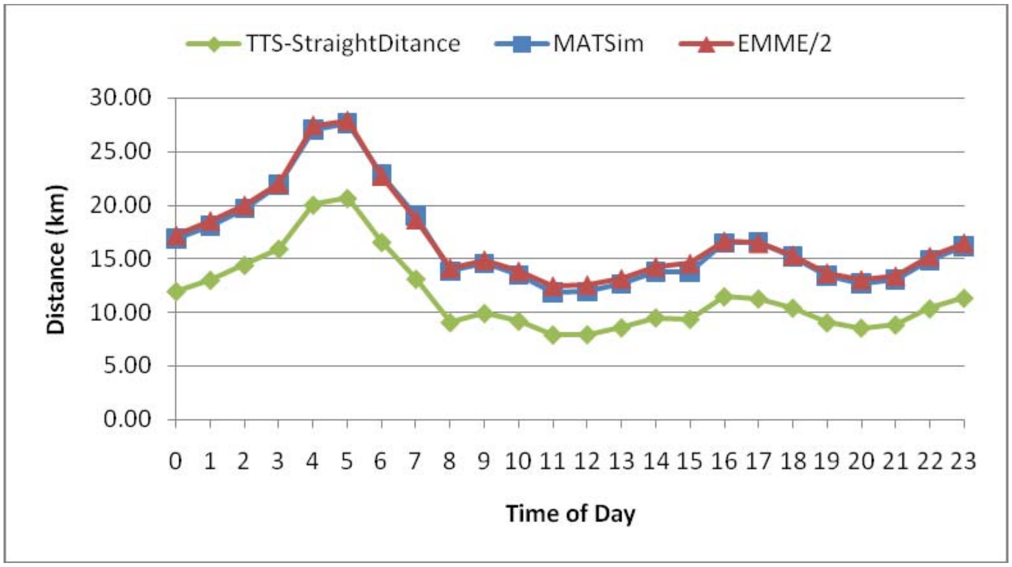


Figure 4.18 Average Travel Distance Comparison

As shown in Figure 4.18, MATSim and EMME/2 give almost the same average travel distance by hour except for mid-day at which time most short trips occur. It is speculated that, in MATSim, a trip starts at a random point on a link and does not include the travel length of start link into travel distance. As most short trips occur during mid-day, the omitted travel length on the start link seems to be significant in comparison with the long trips. For instance, the average trip length in MATSim is lower than the one in EMME/2 by 4.5% for a 13.4 km trip between 11:00 to 15:00. On the other hand, EMME/2 calculates travel distance between origin and destination centroids. Compared to TTS straight trip distance, both MATSim and EMME/2 have plausible trends.

4.3.5 Link Volume

In this study, link volumes are compared to traffic counts at the screenline level in order to monitor auto traffic flow movement between regions within the Greater Toronto Area (GTA) and into/out of different city sectors in the City of Toronto.

Cordon Count data are used for the comparison. The Cordon Count is a periodic counting program involving over a thousand counting stations across the GTA starting in 1975 (DMG 2003C). The Cordon Count program represents a one-day “snapshot” of persons and vehicles passing each counting station. The counting stations have been organized into screenlines at the boundaries of and at key locations within, the Regional Municipalities of Halton, Peel, and York, Durham, and the City of Toronto. The counting process involves classifying every vehicle by type and occupancy.

Since only trips associated with the auto mode are included in this study, the auto vehicular counts in year 2001 are extracted from the Cordon Count database for comparison purpose. The data were collected in the period of May and June in 2001.

A screenline is a linear group of counting stations designed to capture all or most of the movement across it. The major GTA regional screenlines and screenlines in the City of Toronto are shown in Figure 4.19 and Figure 4.20 respectively.

Figure 4.19 Screenlines in the GTA [1]

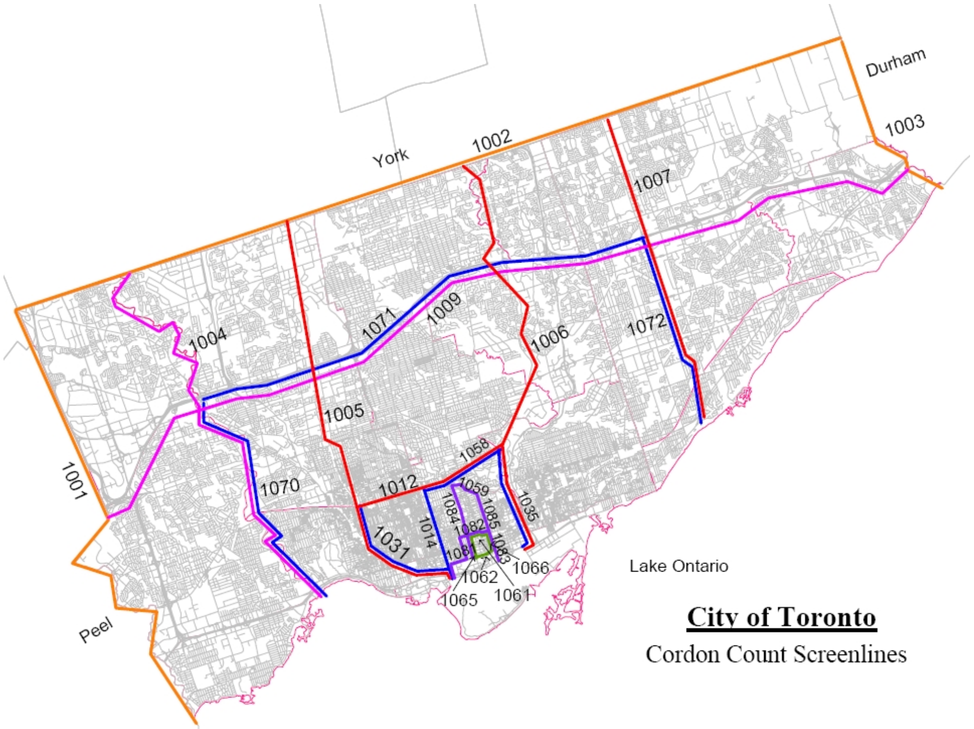


Figure 4.20 Screenlines in the City of Toronto[1]

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[1] Source: http://www.dmg.utoronto.ca, accessed in January 2009

In total, twelve screenlines are chosen for link volume comparison. The typical morning (6:00 to 10:00 AM) and evening (3:00 to 7:00 PM) time windows are used to represent the peak periods of travel and to provide a common frame for comparison.

Eight screenlines are chosen in the GTA at regional level,

1) Halton West Boundary
2) Halton – Peel Boundary
3) Peel – York Boundary
4) Peel – Toronto Boundary
5) Toronto – York Boundary
6) Toronto – Durham Boundary
7) York – Durham Boundary
8) Durham East Boundary

Four screenlines are chosen in the City of Toronto,

1) Metro Boundary – 1001, 1002, 1003
2) Suburban – 1070, 1071, 1072
3) Central Area – 1014, 1058, 1035
4) Downtown Core – 1061, 1062, 1065, 1066

Before the comparison between model link volumes and Cordon Count data, a weight factor has to be determined to factor up the model link volumes. The expansion factor, one of the TTS household attributes, is used to factor up sample trips to reflect the full population in the GTHA. Table 4.3 shows the weight factors derived from weighted trips over sample trips by time of day. In order to simplify the calculation and correspond to the 0.06 capacity of the network, the average weight factor 16.93 is applied to all link volumes from both models.

Table 4.3 Weight Factor by Time of Day

Time of Day	Weighted Trips	Sample Trips	Weight Factor	Time of Day	Weighted Trips	Sample Trips	Weight Factor
0	55435	3260	17.00	12	323958	19319	16.77
1	25762	1508	17.08	13	294292	17535	16.78
2	15948	931	17.13	14	342021	20269	16.87
3	14018	810	17.31	15	546112	32515	16.80
4	21223	1226	17.31	16	636112	37611	16.91
5	89278	5147	17.35	17	723450	42765	16.92
6	306048	17819	17.18	18	542701	32168	16.87
7	606556	35756	16.96	19	415465	24624	16.87
8	711758	42663	16.68	20	290994	17230	16.89
9	329168	19712	16.70	21	244711	14545	16.82
10	289158	17365	16.65	22	156721	9295	16.86
11	309415	18577	16.66	23	112889	6677	16.91
Total	Weighted Trips: 7403193			Sample Trips: 439327			
Average Weight Factor: 16.93							

The comparison results of traffic volumes at all screenlines are presented in the Figure 4.21, 4.22, 4.23 and 4.24.

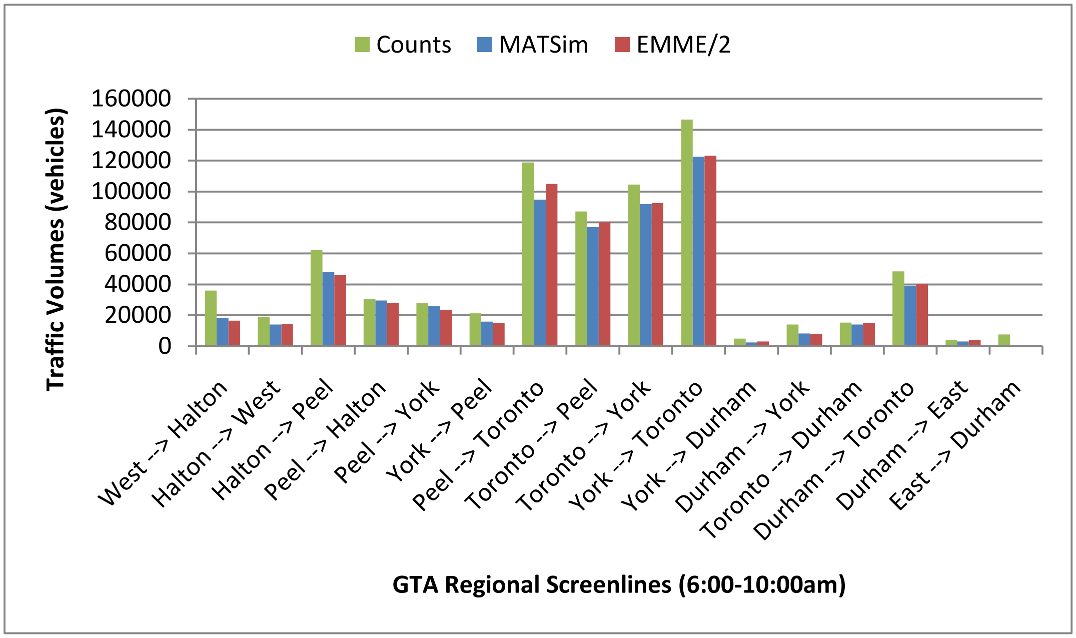

Figure 4.21 GTA Regional Screenlines Comparison at AM Period

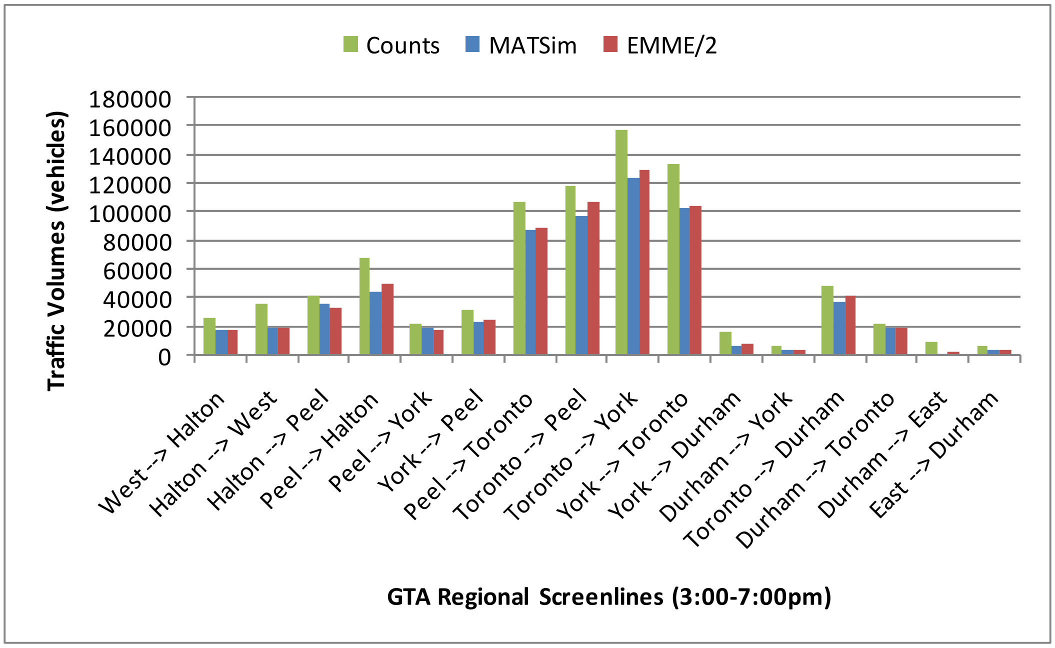

Figure 4.22 GTA Regional Screenlines Comparison at PM Period

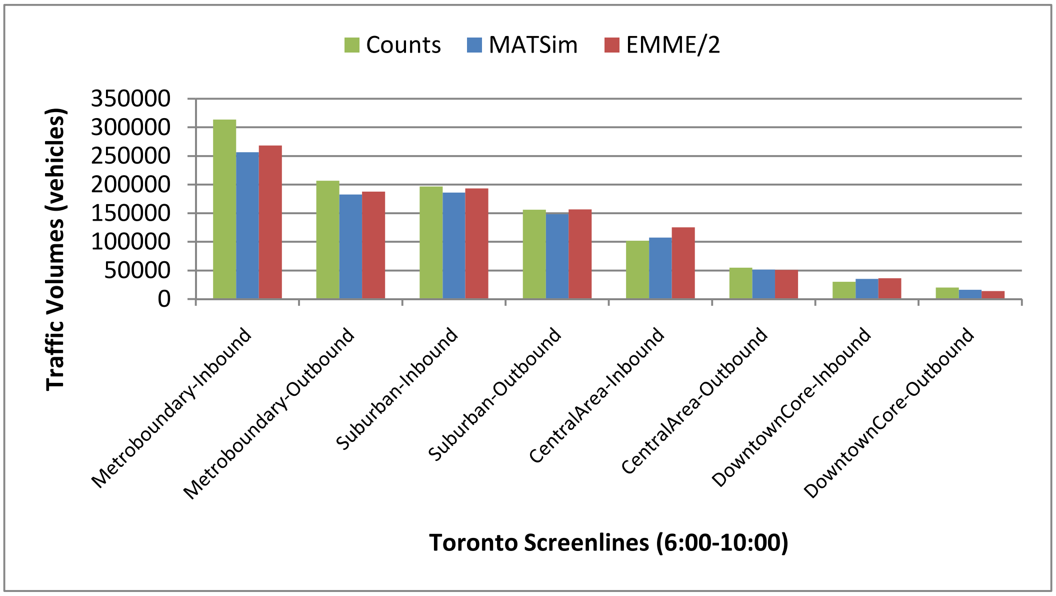

Figure 4.23 City of Toronto Screenlines Comparison at AM Period

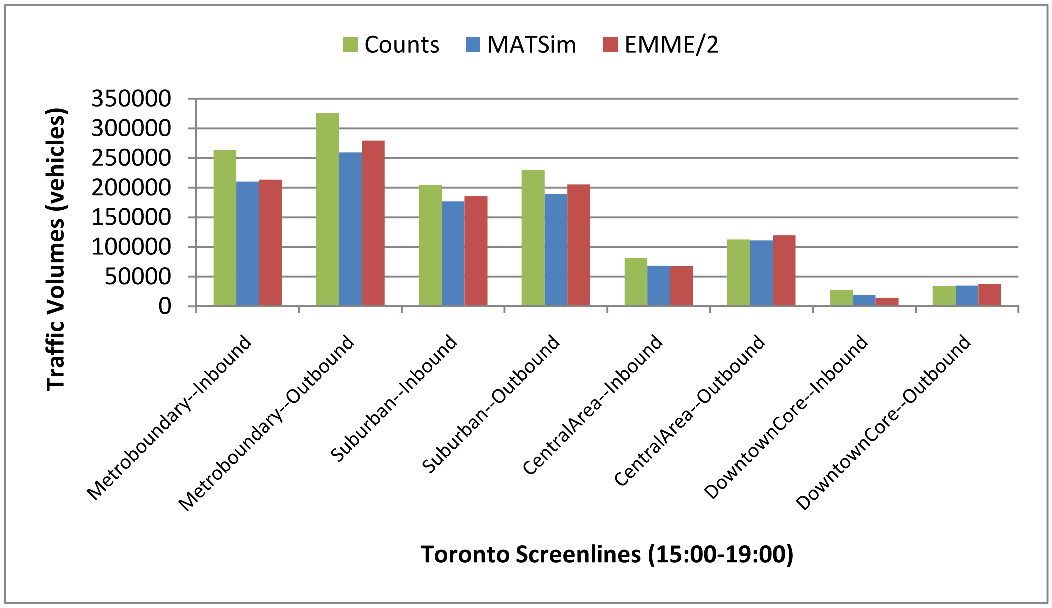

Figure 4.24 City of Toronto Screenlines Comparison at PM Period

As can be seen in above four figures, the link volumes of two models follow the similar variation of Cordon Count at screenline level. This result indicates that both models generate realistic traffic flow patterns on the network. The link volumes from both models do not well match the auto counts at regional boundaries, but match the counts at the inner City of Toronto screenlines.

One possible reason might be due to the TTS data source. TTS data excludes most into/out and through trips around GTHA, but captures well trips within the City of Toronto. This result can be further explained by the fact that TTS data has a finer description of trips across traffic zones (TZ) within the City of Toronto. The number of TZ in the GTHA is shown in Table 4.4.

Table 4.4 Number of TZ in the GTHA Network

Region	Toronto	Durham	York	Peel	Halton	Hamilton	External
No. of TZ	481	265	353	253	196	169	31

Note: all TZ are represented as centroids in the GTHA network.

The occurrence that auto counts in Cordon Count are higher than those in two models is due to the fact that Cordon Count includes all traffic, while TTS only includes households, but not business or goods movement trips in cars.

It is clear that the link volumes between two models are close at the screenline level. However, the volumes from MATSim are slightly less than those from EMME/2 in total. As discussed in Section 4.3.2, this is because agents' departure times are not randomly distributed across each hour but concentrate at due hour or half hour so that trips cannot be fully loaded onto the network in MATSim simulation due to high congestion. Therefore, it results in some lost of link volumes in the simulation. The percentage differences of link volumes of MATSim vs. Counts, EMME/2 vs. Counts and MATSim vs. EMME/2 are calculated and exhibited in Appendix C.

In addition, the Percent Root Mean Square Error (RMSE) is calculated for eight regional screenlines at counting stations between two models. It is also calculated for four inner screenlines at counting stations in the City of Toronto for the mutual comparison of the two models and the Cordon Count.

Percent Root Mean Square Error is a common indicator in traffic assignment calibration process to determine if modeled volumes match traffic counts. When comparing model flows versus counts, sometimes a straight aggregate sum by link group can be misleading. The sum of all traffic counts for a particular link group may be close to the sum of the corresponding traffic flows, but individual link flows may still be very different than their corresponding link count. The Percent Root Mean Square Error calculation on the link group, however, lets one determine individual link differences. This will usually give a better measure for determining the "fitness" between counts versus model flows. The Percent RMSE calculation is described by the following equation:

$$\%RMSE = \frac{\sqrt{\sum_j (Model_j - Count_j)^2 / (NumberofCounts - 1)}}{\sum_j Count_j / NumberofCounts} * 100 \qquad (3)$$

Where, j represents the individual counting station

When applied to model flows versus counts, RMSE values are usually between 10% and 100%. 10% usually describes flows that are very similar to the counts on a link-by-link basis, while 100% usually describes flows that are very different from the counts.

The RMSE comparison results are shown in Table 4.5 and Table 4.6. The median of all RMSEs between the two models is 31%.

Table 4.5 RMSE between MATSim and EMME/2 at Regional Screenlines in the GTA

Screenline		Direction		No. of Stations	RMSE	
					AM	PM
1	Halton West Boundary	Hamilton --> Halton	E	6	18%	5%
		Halton --> Hamilton	W	6	15%	11%
2	Halton-Peel Boundary	Halton --> Peel	E	17	19%	29%
		Peel --> Halton	W	17	38%	31%
3	Peel-York Boundary	Peel --> York	E	12	38%	45%
		York --> Peel	W	12	52%	15%
4	Peel-Toronto Boundary	Peel --> Toronto	E	18	45%	37%
		Toronto --> Peel	W	18	12%	26%
5	Toronto-York Boundary	Toronto --> York	N	40	33%	30%
		York --> Toronto	S	40	20%	34%
6	York-Durham Boundary	York --> Durham	E	35	44%	56%
		Durham --> York	W	35	61%	48%
7	Toronto-Durham Boundary	Toronto --> Durham	E	5	12%	29%
		Durham --> Toronto	W	5	4%	5%
8	Durham East Boundary	Durham --> East	E	21	68%	42%
		East --> Durham	W	21	88%	18%

Note: E - Eastbound; W - Westbound; N - Northbound; S - Southbound

Table 4.6 RMSE at Screenlines in Toronto

Screenlines		Direction	No. of Stations	MATSim vs. Survey		EMME2 vs. Survey		MATSim vs. EMME/2	
				AM	PM	AM	PM	AM	PM
1	Metro Bundary	I	63	60%	48%	44%	44%	35%	35%
		O	63	43%	36%	45%	44%	24%	29%
2	Suburban	I	36	30%	26%	36%	40%	27%	31%
		O	37	28%	34%	47%	33%	32%	23%
3	Central Area	I	31	52%	59%	78%	63%	31%	20%
		O	31	55%	52%	59%	64%	30%	35%
4	Downtown Core	I	16	39%	45%	52%	56%	43%	58%
		O	17	63%	36%	86%	59%	52%	39%

Note: I - Inbound; O - Outbound

4.3.6 Speed Comparison

Detailed link speed comparisons between MATSim, EMME/2 and surveyed speed are performed in the study. The harmonic mean of speeds on major highway sections is calculated based on average travel time on each link generated by two models. The analysis is carried out to find more detailed difference between MATSim and EMME/2 as well as to validate the models against survey data.

In the fall of 2002, the Ministry of Transportation Ontario undertook a travel time survey on many of the major provincial highways in the GTHA. Travel time samples were collected in each direction for the identified highway sections in each of the three time periods defined as:

- 6:30 to 9:30 for the AM peak period
- 12:00 to 14:00 for the midday period
- 15:30 to 18:30 for the PM peak period

In the study, the periods of 7:00 to 9:00 and 16:00 to 18:00 are chosen as the common periods for both models and survey for AM peak and PM peak respectively. Therefore, the harmonic mean of speeds in the survey is recalculated accordingly.

The speed mentioned in the study refers to the harmonic mean of speed. The equation of harmonic mean is expressed as,

$$H = \frac{n}{\sum_{i=1}^{n} \frac{1}{x_i}} \tag{4}$$

Where,

H the harmonic mean of x

x_i the i^{th} observation value

n the number of observations

For instance, if a car travels at the speed of R km/h from A to B between 7:00-8:00am and again at the speed of S km/h between 8:00-9:00am, the average speed between A and B at AM period (7:00-9:00am) is the harmonic mean of R and S.

Six 400-series highways and two rural highways are selected for the speed comparison. The description of the selected highways is summarized in Table 4.7.

Table 4.7 The Description of Selected Highways

Highway		Section	Obs. Segment	Direction	Length (km)	Link Length (km)
400-Series	400	Hwy 401 / Hwy 9	10	Northbound	35.3	35.4
				Southbound	35.3	35.7
	401 express	Hwy 6 North / Winston Churchill Blvd *Halton Region*	8	Eastbound	36.2	37.2
				Westbound	36.2	37.0
		Winston Churchill Blvd / Hwy 427 *Peel Region*	6	Eastbound	18.4	19.1
				Westbound	18.4	19.4
		Hwy 427 / Toronto-Durham Bdy *Toronto Municipality*	26	Eastbound	41.2	40.3
				Westbound	41.2	40.3
		Toronto-Durham Bdy / Newtonville Rd *Durham Region*	22	Eastbound	54.9	55.7
				Westbound	54.9	55.3
	403	QEW / Hwy 401 *Peel Region*	9	Northbound	20.3	20.9
				Southbound	20.3	21.4
		Hwy. 2 / QEW *Hamilton Municipality*	7	Eastbound	22.0	22.8
				Westbound	22.0	22.9
	410	Hwy 401 / Bovaird Dr	8	Northbound	12.8	12.8
				Southbound	12.8	12.6
	427	QEW / Hwy 7	12	Northbound	19.0	19.2
				Southbound	19.0	19.6
	QEW	Casablanca Blvd.* / Burlington St. *Hamilton Municipality*	5	Toronto-Bound	16.0	18.3
				Niagara-Bound	16.0	18.5
		Burlington St. / Winston Churchill Blvd. *Halton Region*	18	Eastbound	33.6	34.3
				Westbound	33.6	34.2
		Toronto-Miss. Bndy / Winston Churchill Blvd *Peel Region*	6	Eastbound	13.5	13.2
				Westbound	13.5	13.1
Rural Highways	50	Hwy 427 / Hwy 9	15	Northbound	31.9	31.9
				Southbound	31.9	31.9
	KING ST (RR #9) / KING RD (RR #11)	Winston Churchill Blvd South / Hwy 400	16	Eastbound	40.4	40.4
				Westbound	40.4	40.4

* It is Christie St. in models' network.

Note that in Table 4.7, Length (km) refers to the survey travel length, whereas, Link Length (km) refers to link distance from the models.

All selected highways are shown in Figure 4.25 of the GTHA network.

Figure 4.25 Selected Major Highways for Speed Comparison

In order to find out systematic difference on the speed among two models and survey, the scatter plots of speeds on 400-series highway sections are drawn in Figure 4.26 and 4.27.

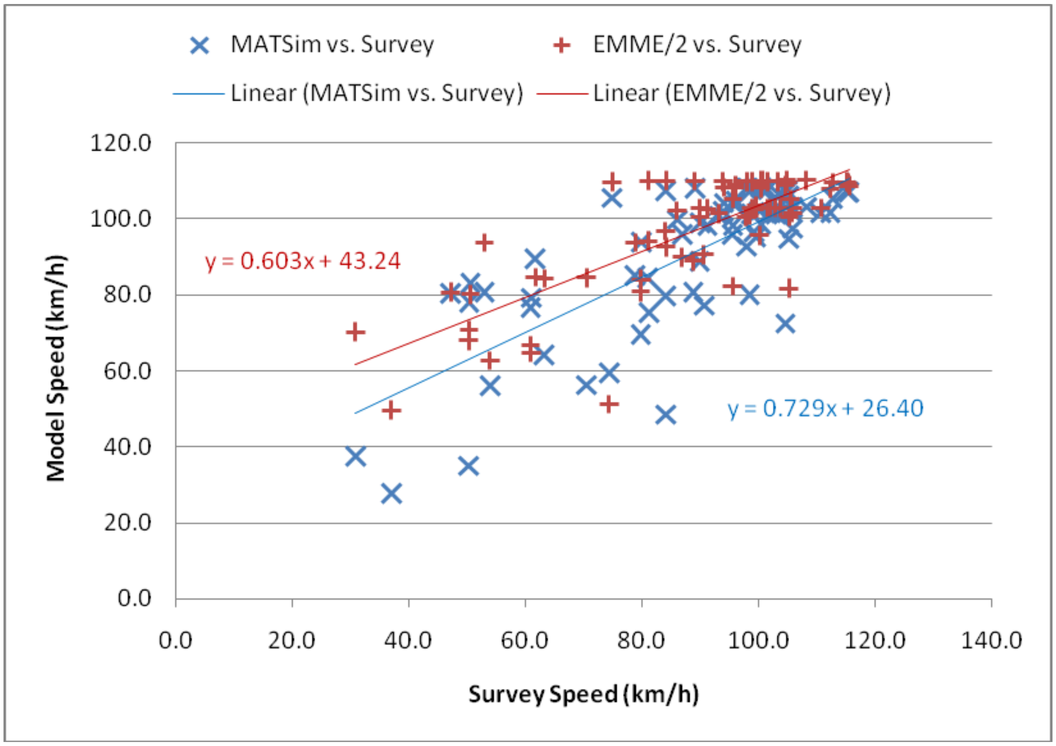

Figure 4.26 Model vs. Survey, Scatter Plot of 400-Series Highway Speed

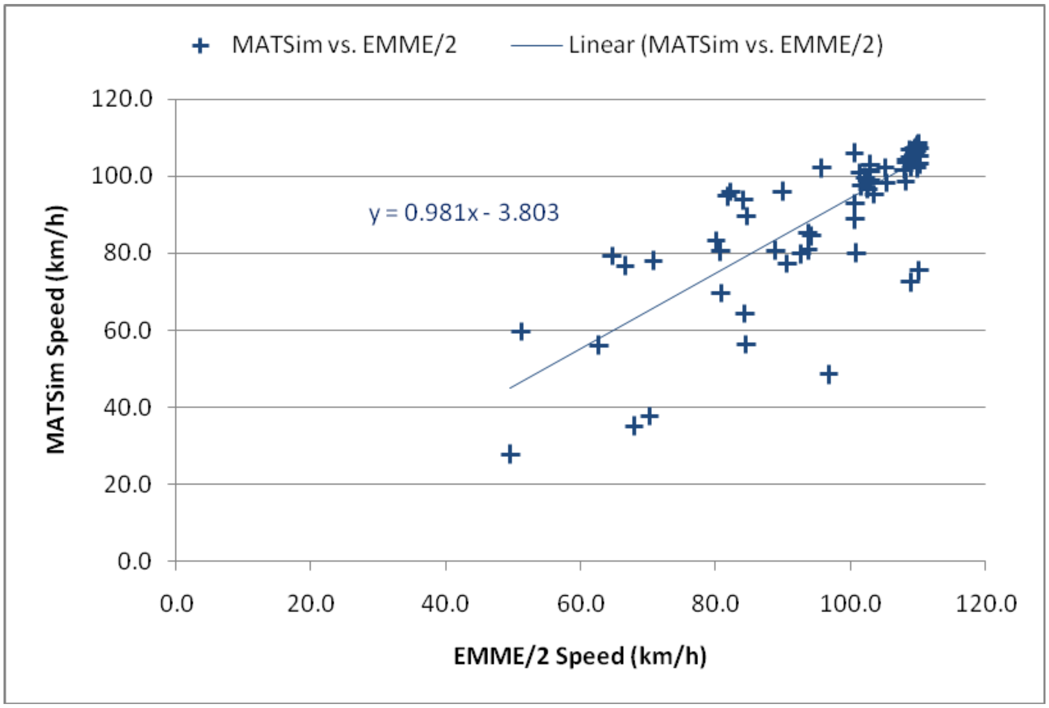

Figure 4.27 MATSim vs. EMME/2, Scatter Plot of 400-Series Highway Speed

From above two scatter plots, three linear relationships can be identified. Furthermore, the regression analysis is carried out for each comparison. The key statistics are listed in Table 4.8.

Table 4.8 Regression Statistics

MATSim vs. Survey	Observations: 72			
	Adjusted R Square: 0.578			
		Coefficients	*t Stat*	*P-value*
	Intercept	26.41	3.941	1.90E-04
	Survey	0.729	9.913	5.74E-15
EMME/2 vs. Survey	Observations: 72			
	Adjusted R Square: 0.610			
		Coefficients	*t Stat*	*P-value*
	Intercept	43.24	8.329	4.52E-12
	Survey	0.603	10.58	3.63E-16
MATSim vs. EMME/2	Observations: 72			
	Adjusted R Square: 0.620			
		Coefficients	*t Stat*	*P-value*
	Intercept	-3.803	-0.427	0.671
	EMME/2	0.981	10.80	1.46E-16

As can be seen from Table 4.8, all Adjusted R Squares from three regressions are around 0.6. It implies that the goodness-of-fit of all regression models are acceptable, i.e., 60% of the variation in the data points can be captured by the corresponding regression line.

The intercepts of M-S (MATSim vs. Survey) and E-S (EMME/2 vs. Survey) are positive which imply that predicted speeds in models are higher than in the survey. This result is reasonable because only auto trips are assigned in the two models, whereas, the survey speed is measured when auto vehicles are running in mixed modes traffic flow on highways.

The slope of M-S is closer to 1 than the slope of E-S even though M-S data are more scattered. It indicates that the link speeds in MATSim are closer to survey speeds and more realistic than those in EMME/2. The link speeds in EMME/2 are much higher than observed survey speeds.

On the other hand, the negative intercept in M-E (MATSim vs. EMME/2) further indicates that the speed in MATSim is lower than the one in EMME/2, but this difference is not significant at

95% confidence level. Moreover, the slope of M-E approximates to 1. It can be concluded that the link speeds in MATSim and EMME/2 are statistically not different.

In addition, the rural highway speed comparison is exhibited in Figure 4.28.

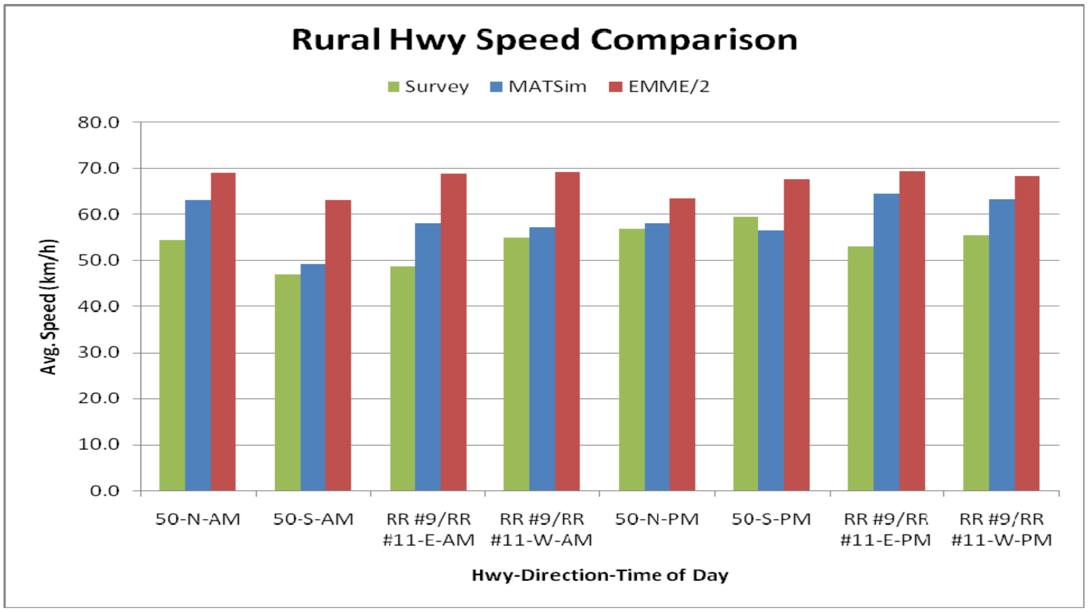

Figure 4.28 Rural Highway Speed Comparison by Direction at AM and PM Peak

It is clear that the rural highways' average speed in EMME/2 is the highest one compared to those in MATSim and survey at all circumstances. The speed in MATSim is higher than survey in general. The survey speed is the lowest one because the survey vehicles are running in the mixed multiple modes on roads in the real world.

The scatter plot of the speeds on observation segments along Hwy 401 Expressway in Toronto section is presented in Figure 4.29 and Figure 4.30. The description of the Toronto section is listed in Table 4.9.

The reason of choosing Hwy 401 is that Hwy 401 is the busiest highway in North America which carries approximately 500,000 vehicles every day. It is the main trade, commuting and recreational corridor in Ontario

Toronto is the largest city and economic capital in Canada as well as the heart of Ontario. Besides those demographic and economic features, Hwy 401 – Toronto section holds the most observation segments in all highway sections.

Table 4.9 The Description of Hwy 401 Express –Toronto Section

Eastbound		Length (km)	Link Length (km)	Westbound		Length (km)	Link Length (km)
1	Hwy 427			27	Toronto-Durham Bdy		
2	Dixon Rd	2.3	1.59	26	Hwy 2A	1.2	1.13
3	Hwy 409	2.0	2.07	25	Hwy 2	0.6	0.82
4	Islington Ave	0.6	0.32	24	Meadowvale Rd	1.2	1.15
5	Weston Rd	1.4	1.34	23	Morningside Ave	2.5	1.92
6	Hwy 400	1.3	1.1	22	Neilson Rd	1.5	1.61
7	Keele St	3.2	3.38	21	Hwy 48	1.8	2.19
8	Dufferin St	2.0	1.57	20	McCowan Rd	1.7	1.73
9	Allen Rd	0.8	0.89	19	Brimley Rd	0.8	0.78
10	Bathurst St	1.4	2.05	18	Kennedy Rd	1.6	1.63
11	Avenue Rd	1.1	0.82	17	Warden Ave	1.7	1.67
12	Hwy 11 - Yonge St	1.7	1.42	16	Victoria Park Ave	1.3	1.26
13	Bayview Ave	2.0	2.33	15	Hwy 404	1.5	1.74
14	Leslie St	2.0	2.06	14	Leslie St	2.0	1.9
15	Hwy 404	2.0	1.97	13	Bayview Ave	2.0	1.83
16	Victoria Park Ave	1.5	1.4	12	Hwy 11 - Yonge St	2.0	2.06
17	Warden Ave	1.3	1.38	11	Avenue Rd	1.7	1.8
18	Kennedy Rd	1.7	1.58	10	Bathurst St	1.1	1.12
19	Brimley Rd	1.6	1.51	9	Allen Rd	1.4	1.68
20	McCowan Rd	0.8	0.96	8	Dufferin St	0.8	0.39
21	Hwy 48	1.7	1.68	7	Keele St	2.0	1.99
22	Neilson Rd	1.8	2.24	6	Hwy 400	3.2	3.09
23	Morningside Ave	1.5	1.64	5	Weston Rd	1.3	1.49
24	Meadowvale Rd	2.5	2.08	4	Islington Ave	1.4	1.3
25	Hwy 2	1.2	0.93	3	Hwy 409	0.6	0.43
26	Hwy 2A	0.6	0.86	2	Dixon Rd	2.0	2.08
27	Toronto-Durham Bdy	1.2	1.16	1	Hwy 427	2.3	1.53
	TOTAL	41.2	40.33		**TOTAL**	41.2	40.32

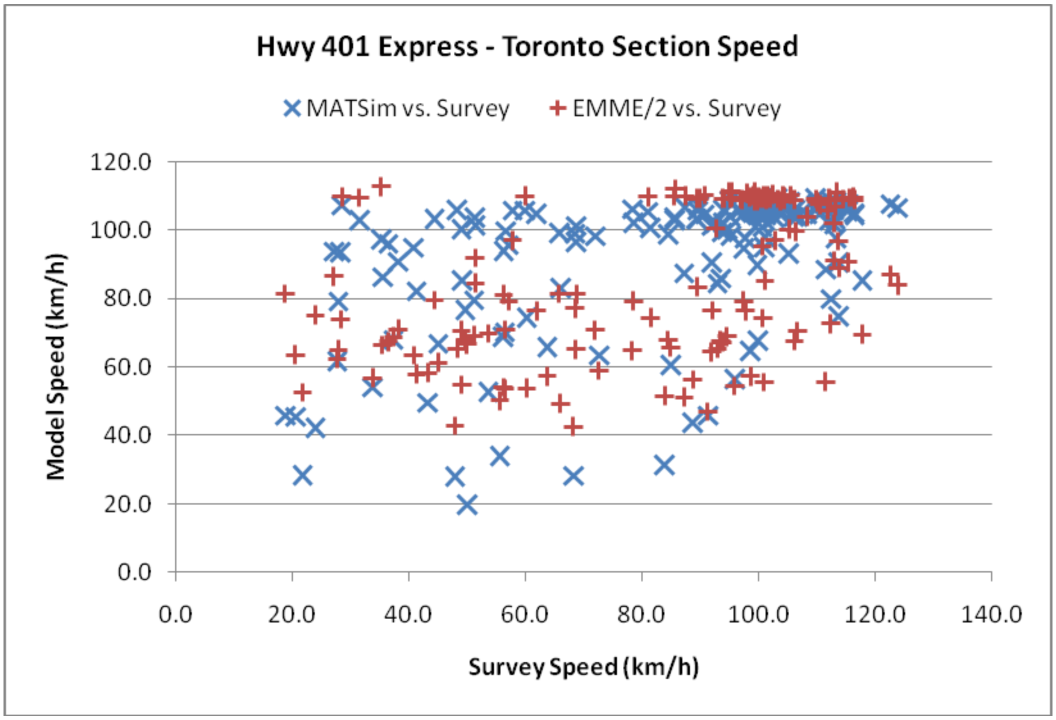

Figure 4.29 Model vs. Survey, Scatter Plot of Hwy 401 Express - Toronto Section Speed

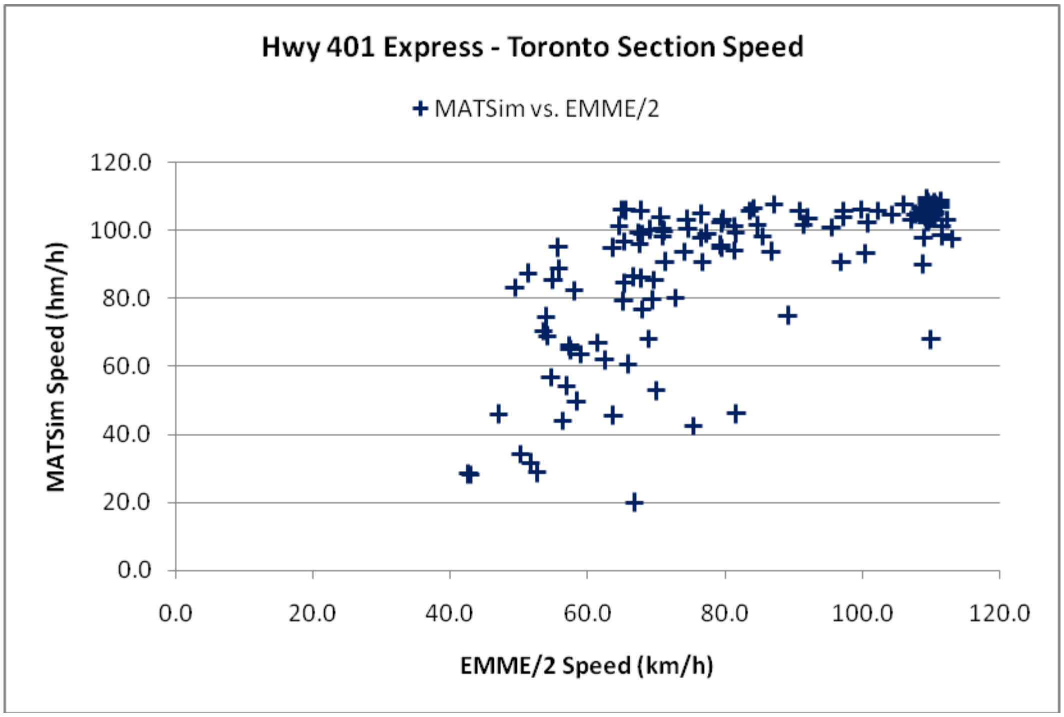

Figure 4.30 MATSim vs. EMME/2, Scatter Plot of Hwy 401 Express - Toronto Section Speed

Unfortunately, no linear pattern can be observed in both scatter plots, although M-S is more scattered again. The analysis is performed from another perspective at this stage. The average speeds at segments are plotted for both models and survey at AM, Mid-Day and PM period respectively. Refer to Figure 4.31, 4.32, 4.33, 4.34, 4.35 and 4.36.

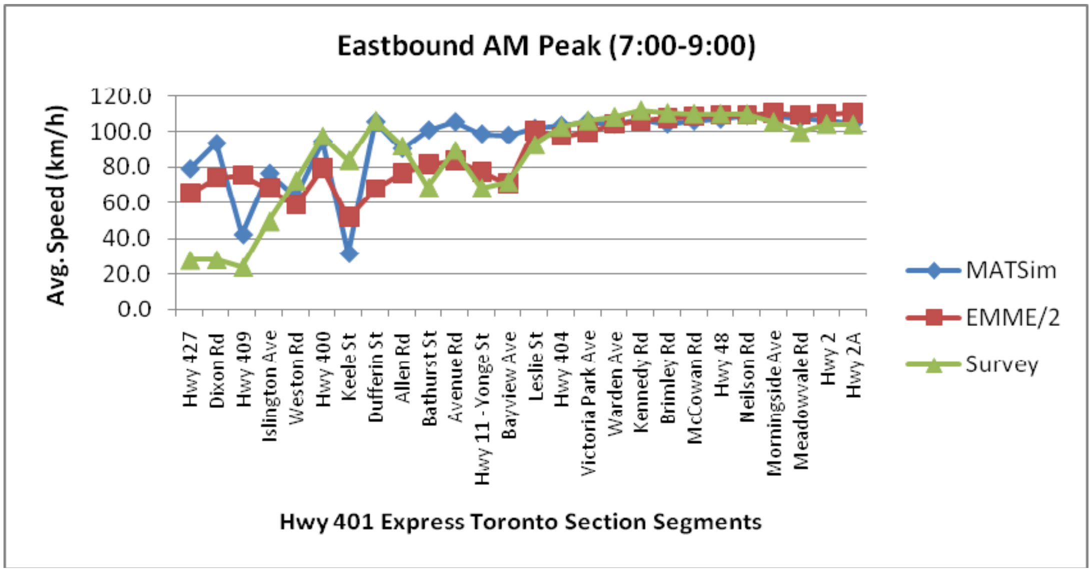

Figure 4.31 Hwy 401 Express – Toronto Eastbound Speed at AM Peak

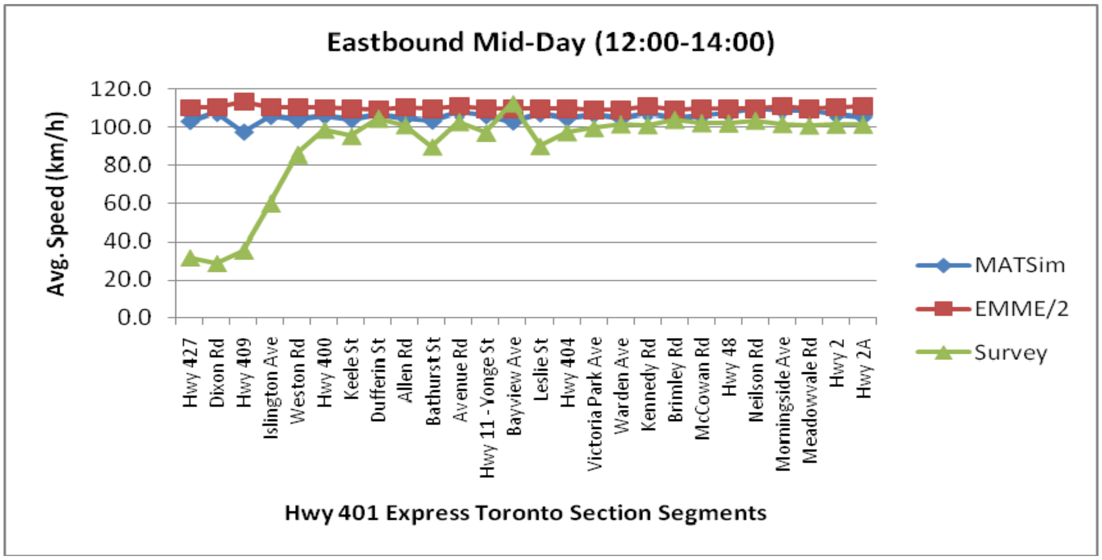

Figure 4.32 Hwy 401 Express – Toronto Eastbound Speed at Mid-Day

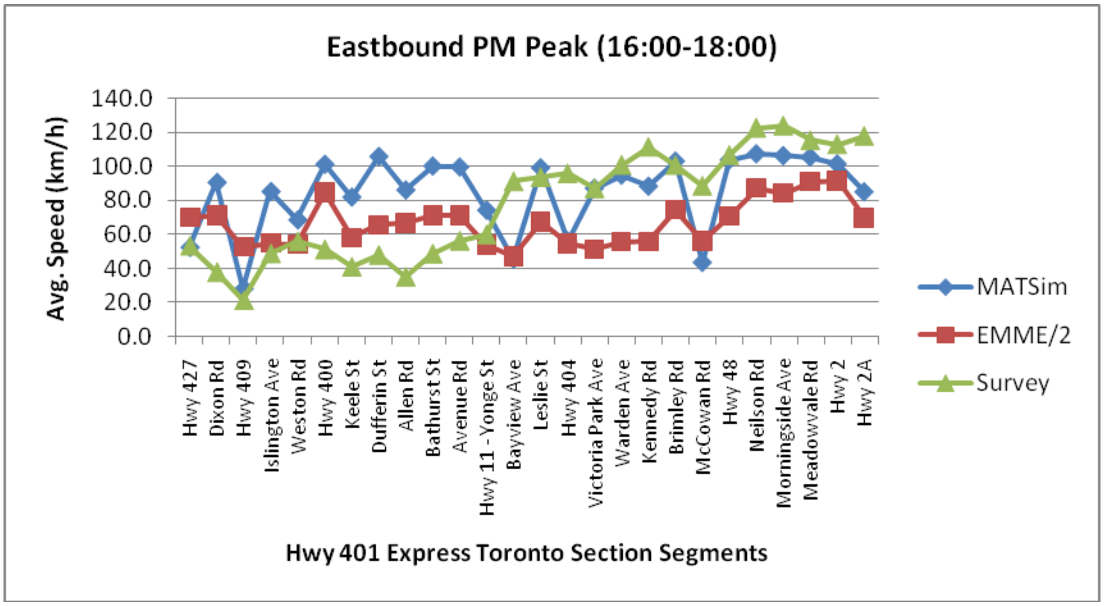

Figure 4.33 Hwy 401 Express – Toronto Eastbound Speed at PM Peak

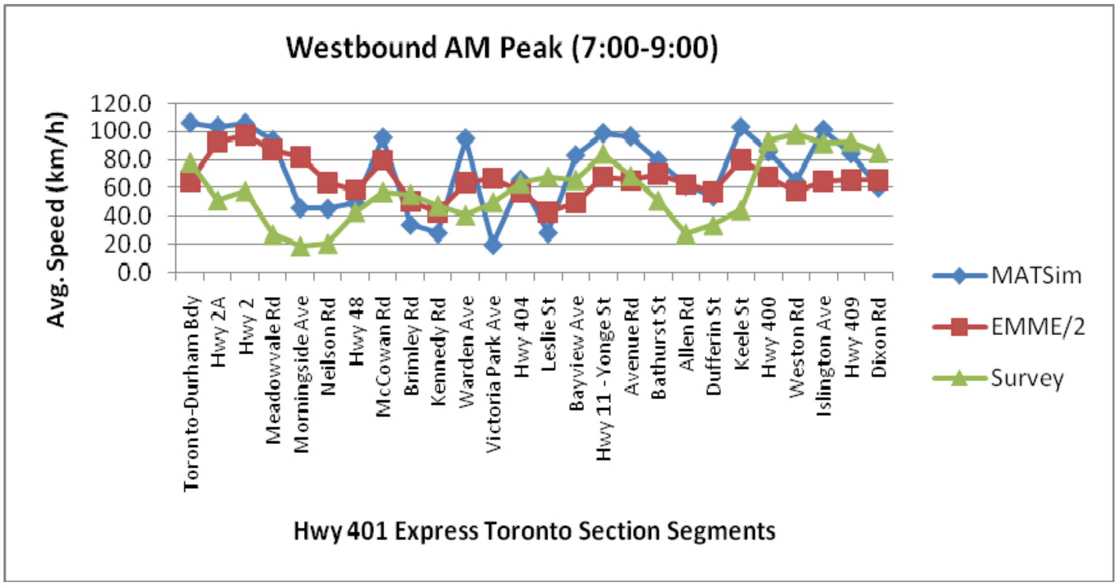

Figure 4.34 Hwy 401 Express – Toronto Westbound Speed at AM Peak

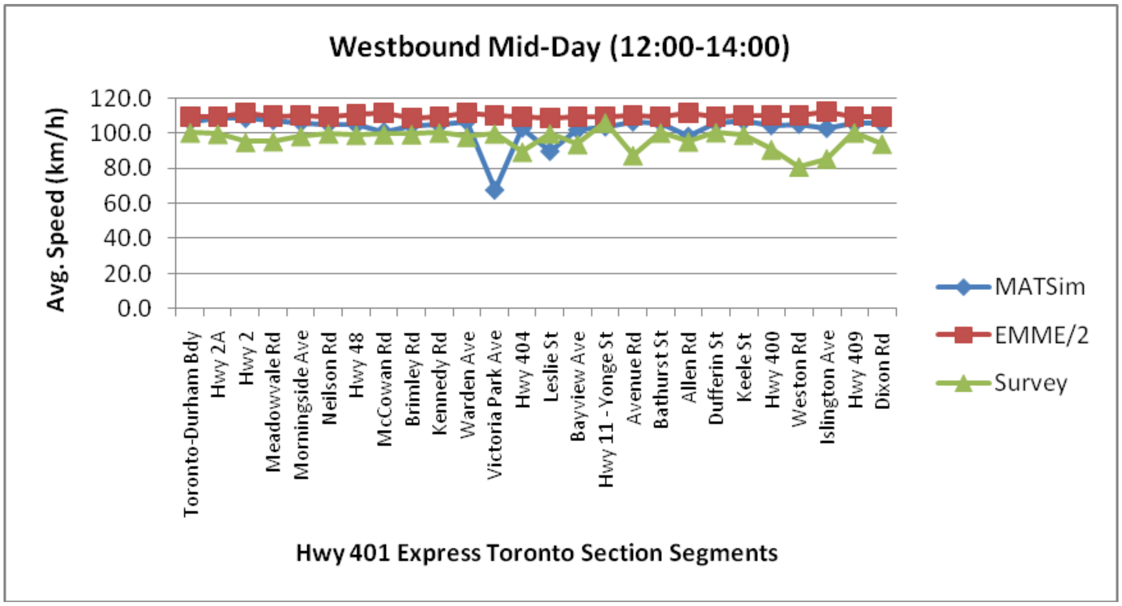

Figure 4.35 Hwy 401 Express – Toronto Westbound Speed at Mid-Day

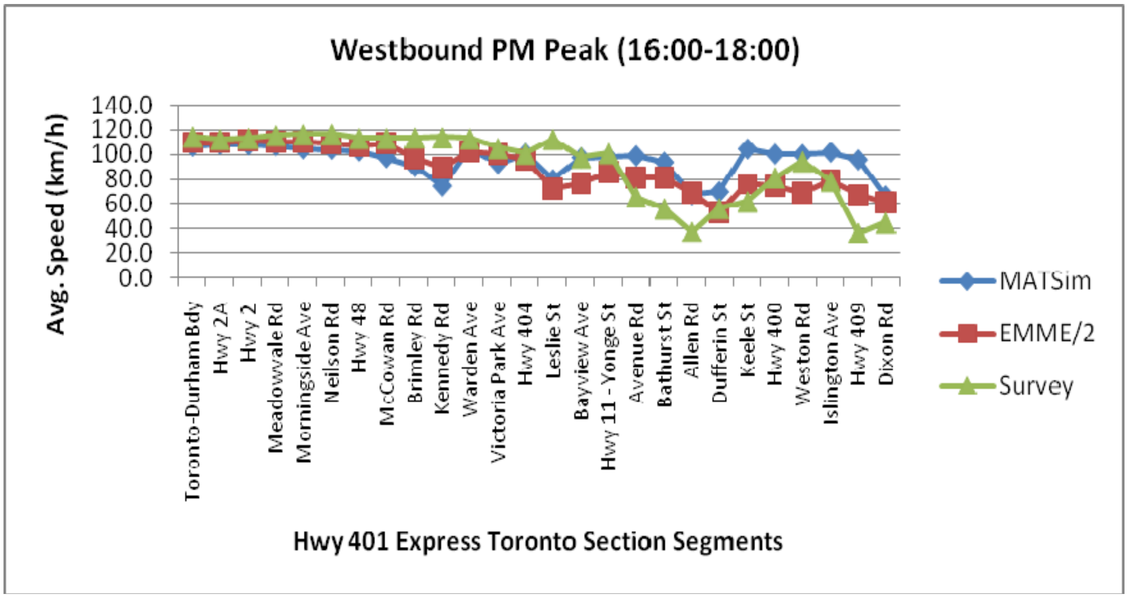

Figure 4.36 Hwy 401 Express – Toronto Westbound Speed at PM Peak

The presentations of the figures are encouraging in terms of the speed fluctuation along the segments of Toronto section. In general, the link speeds of MATSim and EMME/2 show the similarity of fluctuation as in the Survey.

The westbound PM speed pattern is a flip of the eastbound AM speed. Some congestion starting points can be relatively identified from Figure 4.31 and Figure 4.36 for these two peak periods.

In contrast, the spread congestion can be observed in Figure 4.33 and Figure 4.34. The drastic change of the speeds of both models and survey at the eastbound PM peak and westbound AM peak is captured by Figure 4.33 and Figure 4.34 respectively.

Both eastbound and westbound Mid-Day speeds are similar. Also, Figure 4.32 and Figure 4.35 show that the speeds in EMME/2 is the highest one compared with MATSim and Survey.

In addition, the speed comparisons along Hwy 400 section are exhibited in Appendix C. Hwy 400 is the key north-south connection in southern Ontario and usually dominated by auto vehicles for commuting and recreational purpose. Appendix C shows the similar trends as Hwy 401 Express – Toronto section but less fluctuation as well as generally less difference between predicted speeds and survey speeds.

Chapter 5
Conclusion and Outlook

In this study, MATSim and EMME/2, as distinguishing representatives of two traffic modelling paradigms in transportation planning research, are selected for the comparisons from both temporal and spatial perspectives. EMME/2 is an aggregated trip-based application, whereas, MATSim is an agent-based micro-simulation application.

Both models are travel demand models without micro-features of network such as signal system[1]. In the comparative study, both models use the same demand input and road network. Four indicators from both spatial and temporal perspectives are selected for comparison: average travel time, travel distance, link volume and speed.

Average Travel distance

MATSim and EMME/2 produce almost the same hourly travel distance. As well, compared with the TTS straight line trip length, the distributions of travel distances from both models consistently approximate to 1.45 times of the TTS straight line trip length in average.

Link volume

The two models show similar results at screenline level. The absolute percentage of differences between MATSim and EMME/2 are in the range of 0 to 29% at 12 screenlines for two directions. The RMSEs between two models are in the range of 4% to 88% at 12 screenlines which contains 602 counting stations for two directions.

The link volumes from the two models show the similar variation of Cordon Count at screenline level. This result indicates that both models generate realistic traffic flow patterns on the network. However, the link volumes from both models do not well match the auto counts at regional

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[1] Signal system in MATSim was not available in the version for this study, but is currently developed and available in the new version.

boundaries screenlines, but approximately match the counts at the inner screenlines in the City of Toronto.

Average travel time

Both models generate similar travel time for night and mid-day off peak time. However, the travel time in MATSim is much higher than that in EMME/2 at both AM and PM peak periods. It indicates that MATSim captures fluctuated congestion on the network by time of day while EMME/2 is less sensitive to congestion.

The inter-zonal travel time matrices for each hour from both models are compared. The mean of inter-zonal travel time in MATSim is much longer than that of EMME/2 at AM /PM peak periods.

Link Speed

Link speeds at major highway sections are compared between the models and the survey. Between the two models, the speeds estimated in MATSim are lower than those of EMME/2, but the difference is not significant at 95% confidence level.

On the other hand, the predicted speeds from both models are generally higher than survey speed. This result is reasonable because only auto trips are assigned in the two models, whereas, the survey speeds are measured when auto vehicles are running in mixed modes traffic flow on highways. The link speeds in MATSim are closer to survey and more realistic while EMME/2 generates higher link speeds which are much different from survey speeds. For the comparison at single segment level, the link speeds from MATSim and EMME/2 show analogous fluctuation patterns as survey speeds at corresponding time periods.

Overall, through the comparative study, it can be concluded that, even though the algorithms behind two models are quite different, the outputs from two models are consistent to some extent although differences exist. MATSim gives similar reliable travel distance and link volumes to EMME/2. MATSim has better performance with respect to travel time and link speed than EMME/2, because it reflects network congestion level in a more realistic way. EMME/2 is less sensitive to demand variation by time of day.

The conclusions are important for future development and policy analysis using agent-based models to complement conventional models in terms of dynamic features.

Future Work

MATSim is an agent-based simulation package which is a promising direction of dynamic stochastic models. Currently, MATSim agent plan evolutionary mechanism includes time allocation mutator and re-route module. Non-car mode is available for agent plans, but is not supported in the mobility simulation. The travel cost by non-car mode is assumed to be as twice much as that by car mode at free speed (Rieser et al 2009). The mode choice module as one of the re-planning mechanism should be implemented in the future. The feature to emulate no-car mode, especially transit mode, should be included in the traffic simulation.

TASHA (Travel/Activity Scheduler for Household Agents) is an agent-based activity micro-simulator developed at the University of Toronto (Miller and Roorda 2003). It can generate a set of activity plans for individual agents including mode choice decision (Roorda et al 2006). Thus, it is possible to integrate TASHA with MATSim in the future development from the perspective of activity plan generation and modification involving location choice, departure time choice and activity duration etc.

In the current study, the EMME/2 model includes the toll scheme in the volume-delay function associated with Highway 407, whereas, the MATSim model does not employ the toll scheme. From an econometric point of view, the toll scheme in MATSim is considered as a part of the utility function to calculate scores for agent plans (Rieser et al 2008). The toll scheme for Highway 407 shall be implemented in the MATSim model in the future research. As well, the two models can be used for sensitivity analysis for road pricing policy.

References

Balmer, M. (2007) Travel demand modelling for multi-agent transport simulations: algorithms and systems, Ph.D. dissertation at ETH Zurich, Switzerland.

Bell, M. G. H. (1997) Transportation network analysis, J. Wiley, New York

2001 Canadian Census, Statistics Canada, http://www12.statcan.ca, accessed in March 2009.

Cascetta, E. (1989) A stochastic process approach to the analysis of temporal dynamics in transportation networks, Transportation Research B23, 1-17.

Cetin, N. and K. Nagel (2003) Parallel queue model approach to traffic micro-simulations, paper presented at the 82th Annual Meeting of the Transportation Research Board, Washington, D.C., 2003.

Charypar, D., K. Nagel and K.W. Axhausen (2007) An event-driven queue-based microsimulation of traffic flow, Transportation Research Record, 2003, 35–40.

Chung, C. A. (2004) Simulation Modelling Handbook, A Practical Approach, Industrial and Manufacturing Engineering Series, CRC Press.

Daganzo, C. F. and Y. Sheffi (1977) On stochastic models of traffic assignment, Transportation Science 11, 253-274.

Data Management Group at the University of Toronto website, http://www.dmg.utoronto.ca, accessed during July 2008 – March 2009.

Data Management Group (DMG) (2003A) Transportation Tomorrow Survey Reports: 2001 Transportation Tomorrow Survey: Design & Conduct of the Survey, January 2003.

Data Management Group (DMG) (2003B) Transportation Tomorrow Survey Reports: 2001 Transportation Tomorrow Survey: Data Guide, January 2003.

Data Management Group (DMG) (2003C) Cordon Count Reports: 2001 GTA Cordon Count - Transportation Trends (1991 - 2001), March 2003.

EMME (2008) Users' Guide, Reference Manual, Prompt Manual v3.0; EMME/2 (1994) User's Manual, INRO Inc.

Florian, M. A., M. Gendreau and P. Marcotte (Eds.) (2002) Transportation and network analysis: Current trends: Miscellanea, Kluwer Academic, London.

Griesenbeck, B. and G. Garry (2007) Comparison of activity-based tour model to four-step model as a tool for metropolitan transportation planning. Proceedings of the National Transportation Planning Applications Conference, May 6-10, Daytona Beach, Florida.

Law, A.M. and D.W. Kelton (2000) Simulation modelling and analysis, 3rd Edition, McGraw-Hill, New York

Lefebvre, N. and M. Balmer (2007) Fast shortest path computation in time-dependent traffic networks, http://www.ivt.ethz.ch, accessed in March 2009.

MATSim website, http://www.matsim.org, accessed during July 2008 – March 2009.

Miller, E. J. and M. J. Roorda (2003) A prototype model of 24 hour household activity scheduling for the Toronto Area. Transportation Research Record, 1831, 114–121.

Papageorgiou, M. (ed.) (1991) Concise encyclopedia of traffic & transportation systems, Pergamon Press, New York.

Raney, B. and K. Nagel (2004) Iterative route planning for large-scale modular transportation simulations, Future Generation Computer Systems, 20 (7) 1101–1118.

Raney, B. and K. Nagel (2003) Truly agent-based strategy selection for transportation simulations, paper presented at the 82th Annual Meeting of the Transportation Research Board, Washington, D.C., 2003.

Rieser, M., U. Beuck, M. Balmer and K. Nagel (2008) Modelling and simulation of a morning reaction to an evening toll, https://svn.vsp.tu-berlin.de, accessed in March, 2009.

Rieser, M., D. Grether and K. Nagel (2009) Adding mode choice to multiagent transport simulation, paper presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.

Rieser, M., K. Nagel, U. Beuck, M. Balmer and J. Rümenapp (2007) Truly agent-oriented coupling of an activity-based demand generation with a multi-agent traffic simulation. Transportation Research Record, 2021, 10–17.

Roorda, M.J., E.J. Miller and N. Kruchten (2006) Incorporating within-household interactions into a mode choice model using a genetic algorithm for parameter estimation, paper presented at the 85th Annual Meeting of the Transportation Research Board, Washington, D.C., 2006.

Shao, C. F. (ed) (2007) Traffic Planning, China Railway Publishing House, Beijing.

Sheffi, Y. (1985) Urban transportation networks: Equilibrium analysis with mathematical programming methods, Prentice-Hall, N.J.

Appendices

Appendix A Configuration Used in the Study for MATSim Simulation

```
<?xml version="1.0" ?>
<!DOCTYPE config SYSTEM "http://www.matsim.org/files/dtd/config_v1.dtd">
<config>

        <module name="global">
                <param name="randomSeed" value="4711" />
                <param name="outputTimeFormat" value="HH:mm:ss" />
                <param name="coordinateSystem" value="Atlantis" />
        </module>

        <module name="network">
                <param name="inputNetworkFile"
value="D:/MATSim_20081124/GTAMAT/LocalFiles/Maneuvers/output_network_716.xml.gz" />
        </module>

        <module name="plans">
                <param name="inputPlansFile"
value="D:/MATSim_20081124/GTAMAT/LocalFiles/Converter/plans_1216.xml.gz" />
        </module>

        <module name="controler">
                <param name="outputDirectory"
value="D:/MATSim_20081124/GTAMAT/LocalFiles/Controler/ManeuversNetwork/Dijkstra/0.06_0.2_716" />
                <param name="firstIteration" value="0" />
                <param name="lastIteration" value="50" />
        </module>

        <module name="simulation">
                <!-- "start/endTime" of MobSim (00:00:00 == take earliest activity time/ run as long as active
vehicles exist) -->
                <param name="startTime" value="00:00:00" />
                <param name="endTime" value="00:00:00" />
                <param name="flowCapacityFactor" value="0.06" />
                <param name="storageCapacityFactor" value="0.2" />


                <param name = "snapshotperiod"    value = "00:10:00"/> <!-- 00:00:00 means NO snapshot
writing -->
                <param name = "snapshotFormat"   value = "oftvis"/> <!-- netvis, googleearth, transims, oftvis -->
        </module>

        <module name="planCalcScore">
                <param name="learningRate" value="1.0" />
                <param name="BrainExpBeta" value="2.0" />

                <param name="lateArrival" value="-18" />
                <param name="earlyDeparture" value="-0" />
                <param name="performing" value="+6" />
                <param name="traveling" value="-6" />
                <param name="waiting" value="-0" />
```

```
        <param name="activityType_0"           value="H" /> <!-- home -->
        <param name="activityPriority_0"       value="1" />
        <param name="activityTypicalDuration_0" value="12:00:00" />
        <param name="activityMinimalDuration_0" value="" />

        <param name="activityType_1"           value="W" /> <!-- first work trip of the day -->
        <param name="activityPriority_1"       value="1" />
        <param name="activityTypicalDuration_1" value="08:00:00" />
        <param name="activityMinimalDuration_1" value="" />
        <param name="activityOpeningTime_1"     value="06:00:00" />
        <param name="activityLatestStartTime_1" value="" />
        <param name="activityEarliestEndTime_1" value="" />
        <param name="activityClosingTime_1"     value="18:00:00" />

        <param name="activityType_2"           value="C" /> <!-- second and subsequent school trips -->
        <param name="activityPriority_2"       value="2" />
        <param name="activityTypicalDuration_2" value="06:00:00" />
        <param name="activityMinimalDuration_2" value="" />

        <param name="activityType_3"           value="D" /> <!-- daycare -->
        <param name="activityPriority_3"       value="2" />
        <param name="activityTypicalDuration_3" value="01:00:00" />
        <param name="activityMinimalDuration_3" value="" />

        <param name="activityType_4"           value="F" /> <!-- facilitate passenger -->
        <param name="activityPriority_4"       value="3" />
        <param name="activityTypicalDuration_4" value="08:00:00" />
        <param name="activityMinimalDuration_4" value="" />

        <param name="activityType_5"           value="M" /> <!-- marketing -->
        <param name="activityPriority_5"       value="3" />
        <param name="activityTypicalDuration_5" value="8:00:00" />
        <param name="activityMinimalDuration_5" value="" />

        <param name="activityType_6"           value="O" /> <!-- other -->
        <param name="activityPriority_6"       value="4" />
        <param name="activityTypicalDuration_6" value="12:00:00" />
        <param name="activityMinimalDuration_6" value="" />

        <param name="activityType_7"           value="R" /> <!-- second and subsequent work trips -->
        <param name="activityPriority_7"       value="2" />
        <param name="activityTypicalDuration_7" value="06:00:00" />
        <param name="activityMinimalDuration_7" value="" />

        <param name="activityType_8"           value="S" /> <!-- first school trip of the day -->
        <param name="activityPriority_8"       value="1" />
        <param name="activityTypicalDuration_8" value="08:00:00" />
        <param name="activityMinimalDuration_8" value="" />
        <param name="activityOpeningTime_8"     value="09:00:00" />
        <param name="activityClosingTime_8"     value="15:00:00" />

        <param name="activityType_9"           value="9" /> <!-- unknown -->
        <param name="activityPriority_9"       value="4" />
        <param name="activityTypicalDuration_9" value="08:00:00" />
        <param name="activityMinimalDuration_9" value="" />

</module>
```

```
    <module name="strategy">
            <param name="maxAgentPlanMemorySize" value="4" /> <!-- 0 means unlimited -->

            <param name="Module_1" value="SelectExpBeta" />
            <param name="ModuleProbability_1" value="0.8" />

            <!--<param name="Module_2" value="ReRoute_Landmarks" />-->
            <param name="Module_2" value="ReRoute_Dijkstra" />
            <param name="ModuleProbability_2" value="0.2" />

            <!--<param name="Module_3" value="TimeAllocationMutator" />-->
            <!--<param name="ModuleProbability_3" value="0.1" />-->

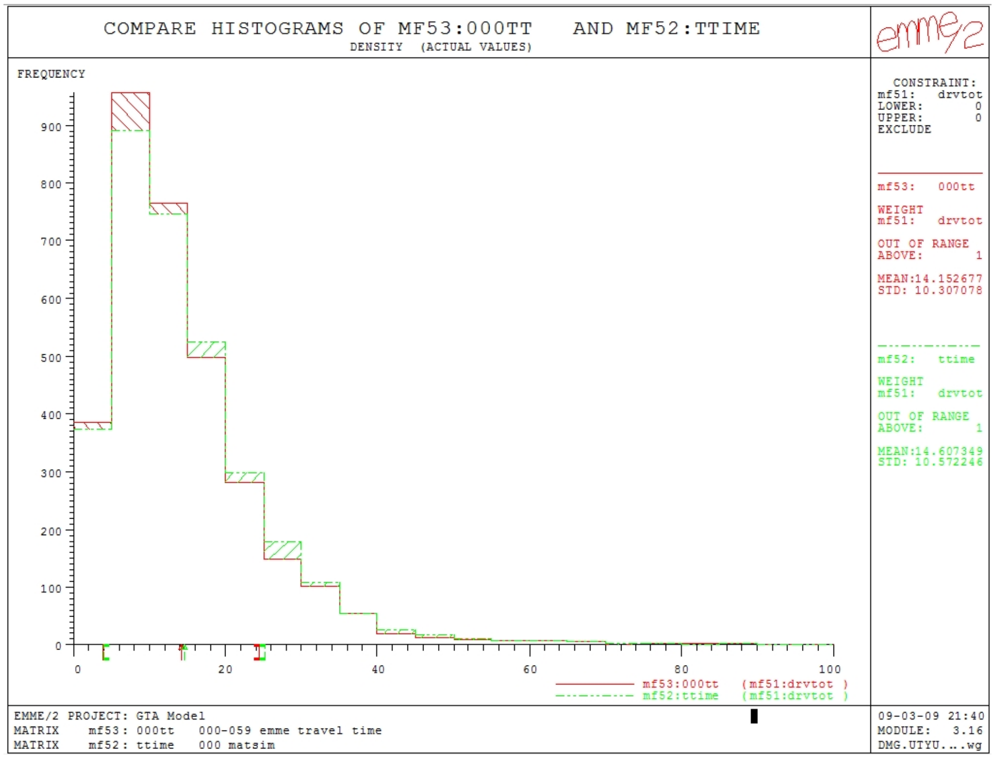


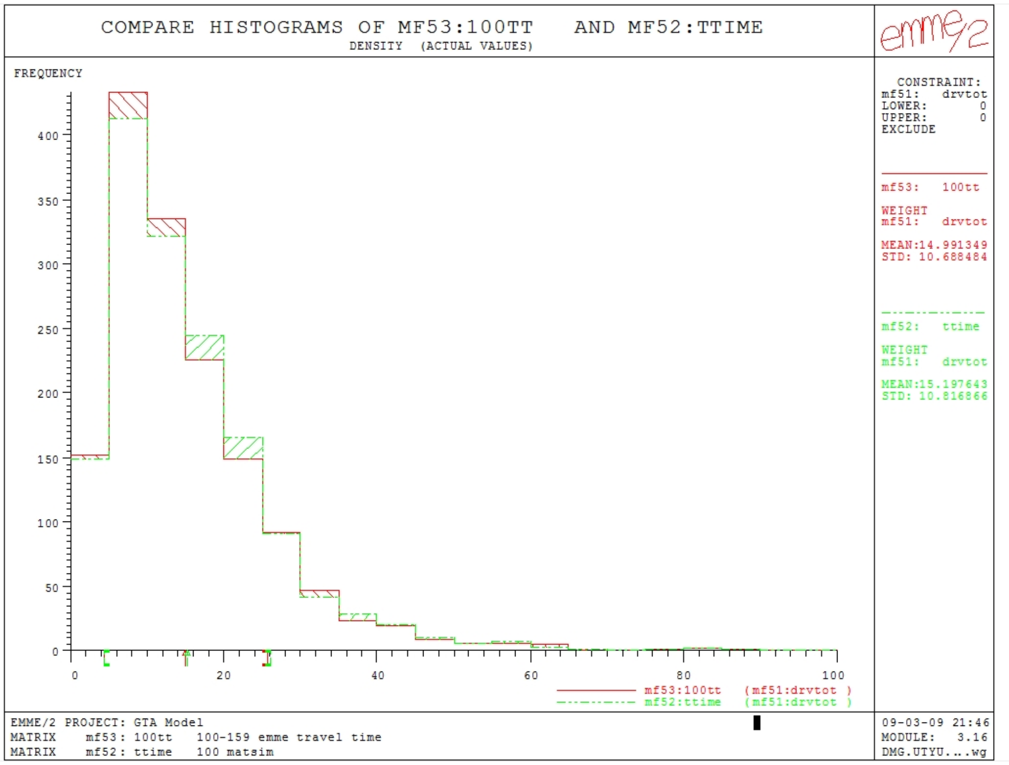
    </module>

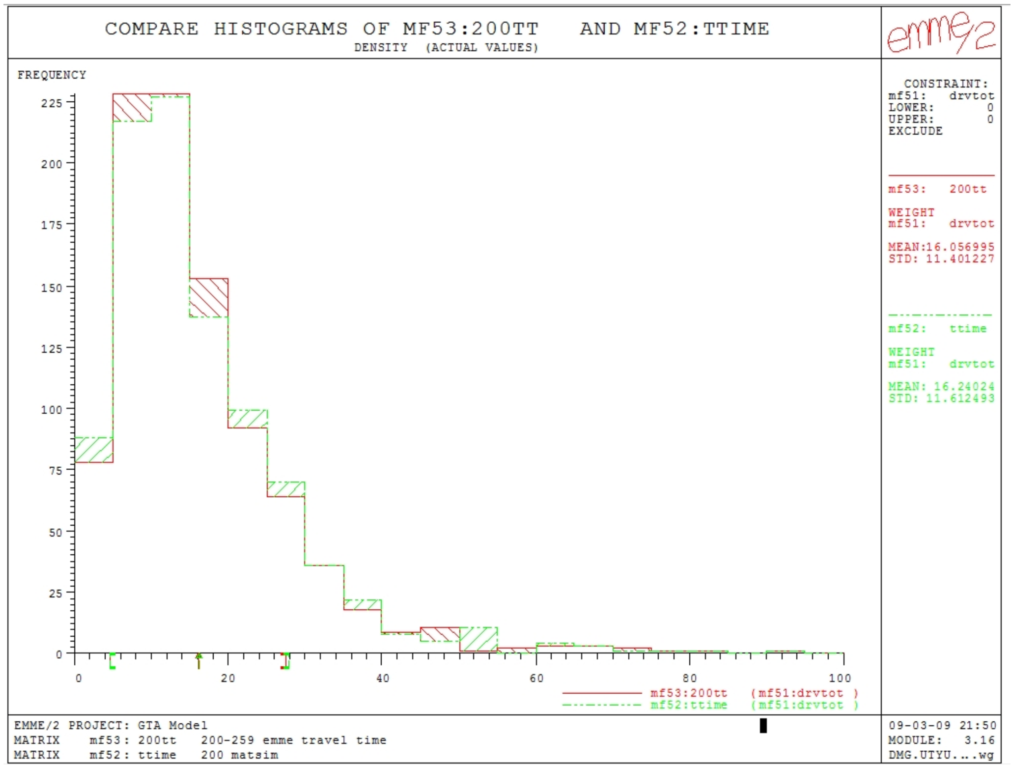


</config>
```

Appendix B 24 Hourly EMME/2 and MATSim Inter-Zonal Travel Time Distribution Comparison Histogram (Weighted by Trips)



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150
125
100
75
50
25
0
0
20
40
60
80
100
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mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 200tt
WEIGHT
mf51: drvtot
MEAN:16.056995
STD: 11.401227
mf52: ttime
WEIGHT
mf51: drvtot
MEAN: 16.24024
STD: 11.612493
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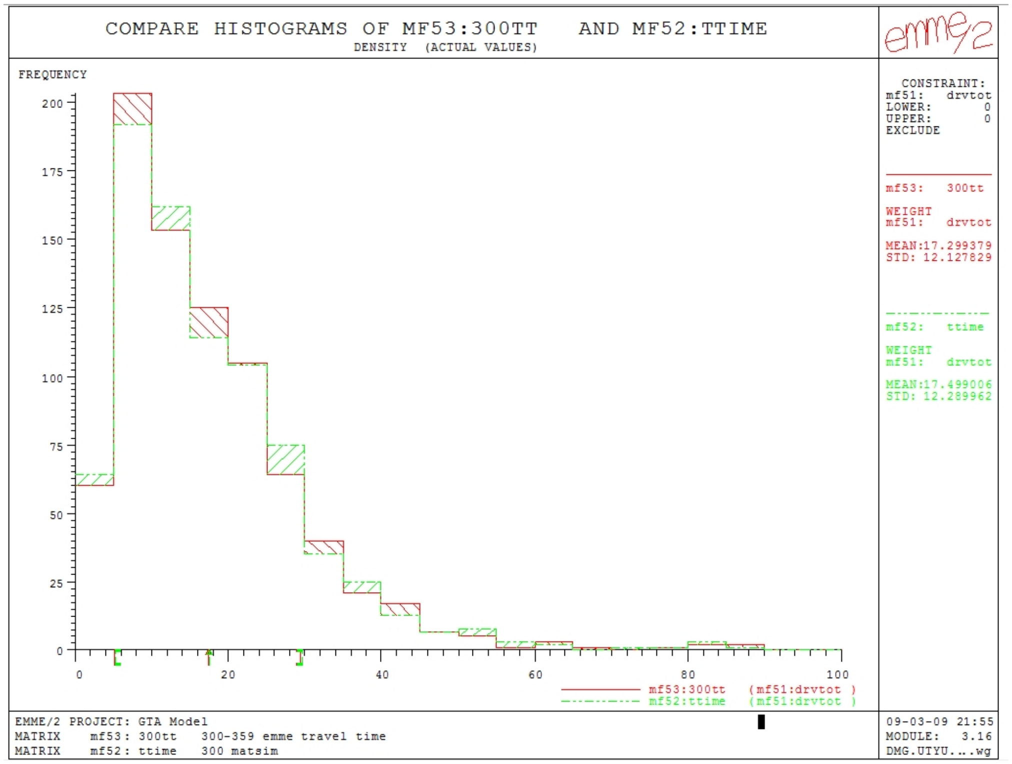
MATRIX mf53: 200tt 200-259 emme travel time
MATRIX mf52: ttime 200 matsim
09-03-09 21:50
MODULE: 3.16
DMG.UTYU....wg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DENSITY (ACTUAL VALUES)
emme/2
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175
150
125
100
75
50
25
0
0
20
40
60
80
100
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mf52:ttime (mf51:drvtot)
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LOWER: 0
UPPER: 0
EXCLUDE
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WEIGHT
mf51: drvtot
MEAN:17.299379
STD: 12.127829
mf52: ttime
WEIGHT
mf51: drvtot
MEAN:17.499006
STD: 12.289962
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MATRIX mf52: ttime 300 matsim
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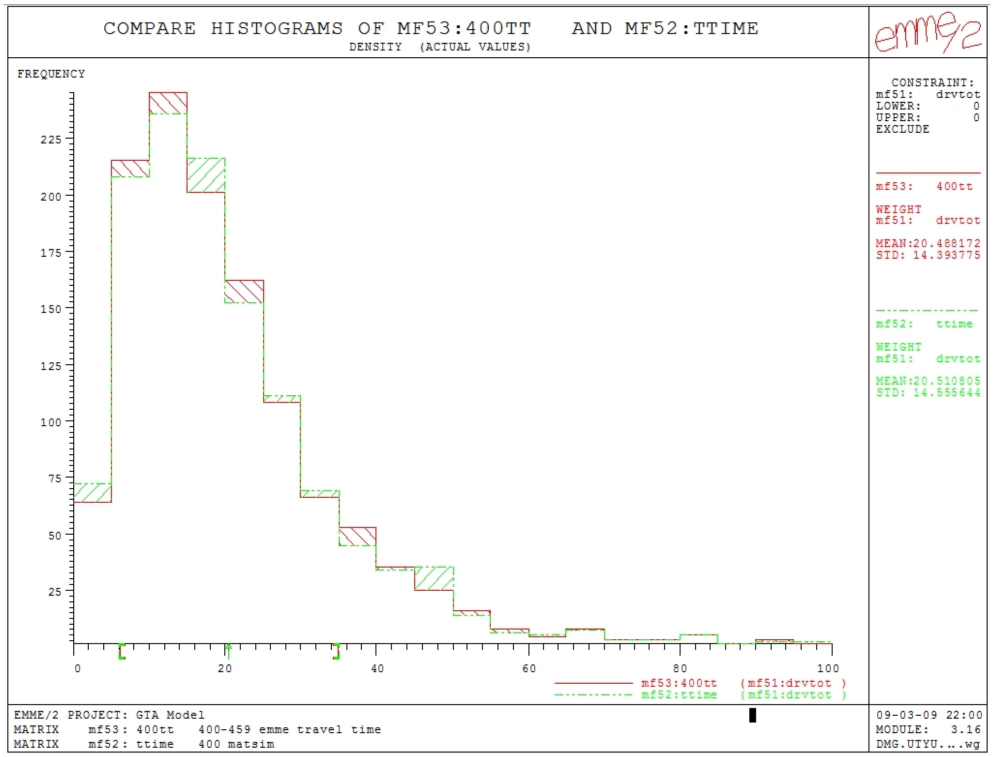
MODULE: 3.16
DMG.UTYU....wg



```
CONSTRAINT:
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UPPER:       0
EXCLUDE

mf53:    400tt

WEIGHT
mf51:   drvtot

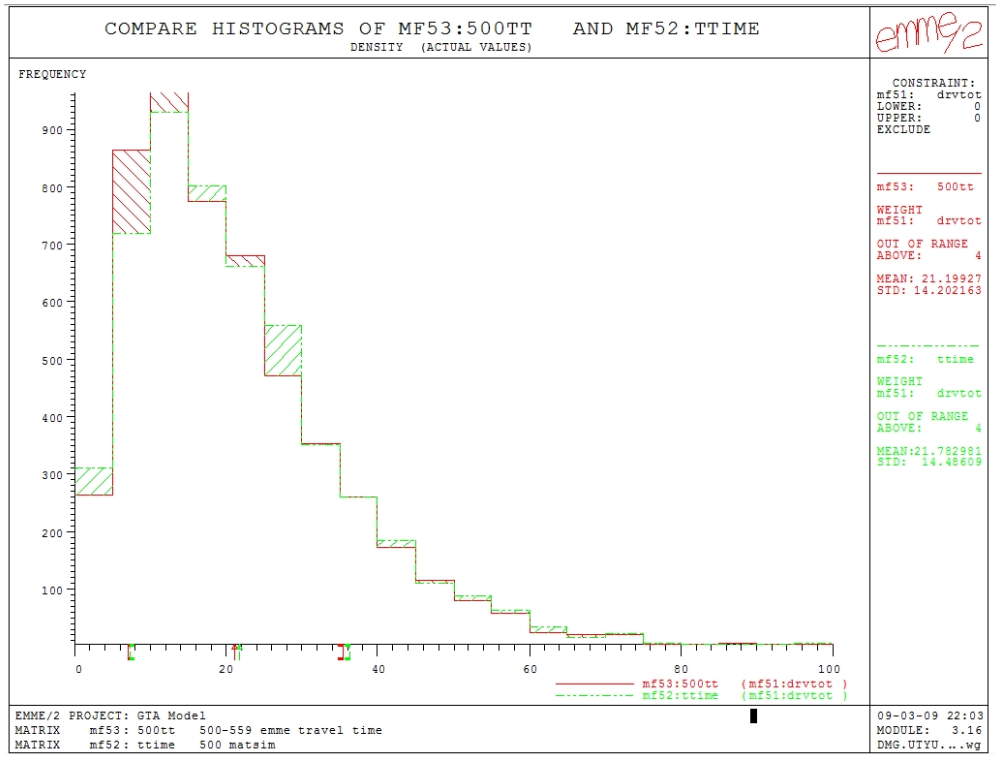
MEAN:20.488172
STD: 14.393775

mf52:    ttime

WEIGHT
mf51:   drvtot

MEAN:20.510805
STD: 14.555644
```

```
EMME/2 PROJECT: GTA Model                                     09-03-09 22:00
MATRIX    mf53: 400tt    400-459 emme travel time             MODULE:   3.16
MATRIX    mf52: ttime    400 matsim                           DMG.UTYU....wg
```



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UPPER:       0
EXCLUDE

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WEIGHT
mf51:   drvtot

OUT OF RANGE
ABOVE:       4

MEAN: 21.19927
STD: 14.202163

mf52:    ttime

WEIGHT
mf51:   drvtot

OUT OF RANGE
ABOVE:       4

MEAN:21.782981
STD:  14.48609
```

```
EMME/2 PROJECT: GTA Model                                     09-03-09 22:03
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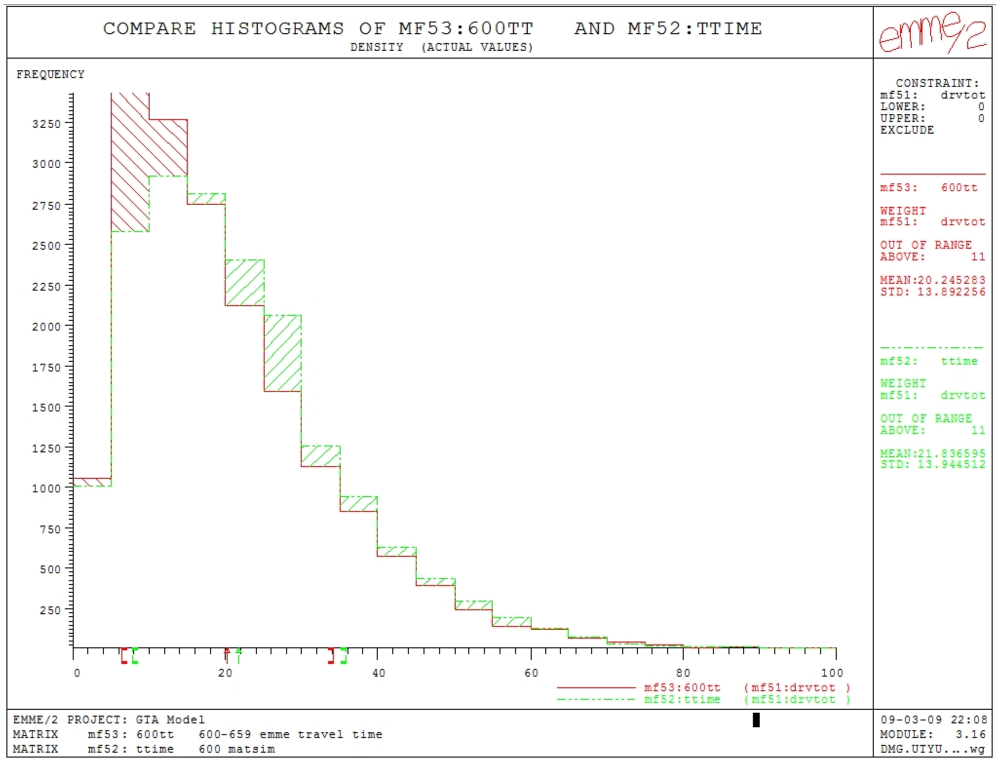
MATRIX    mf52: ttime    500 matsim                           DMG.UTYU....wg
```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2250
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500
250
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20
40
60
80
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mf53:600tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 600tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 11
MEAN:20.245283
STD: 13.892256
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 11
MEAN:21.836595
STD: 13.944512
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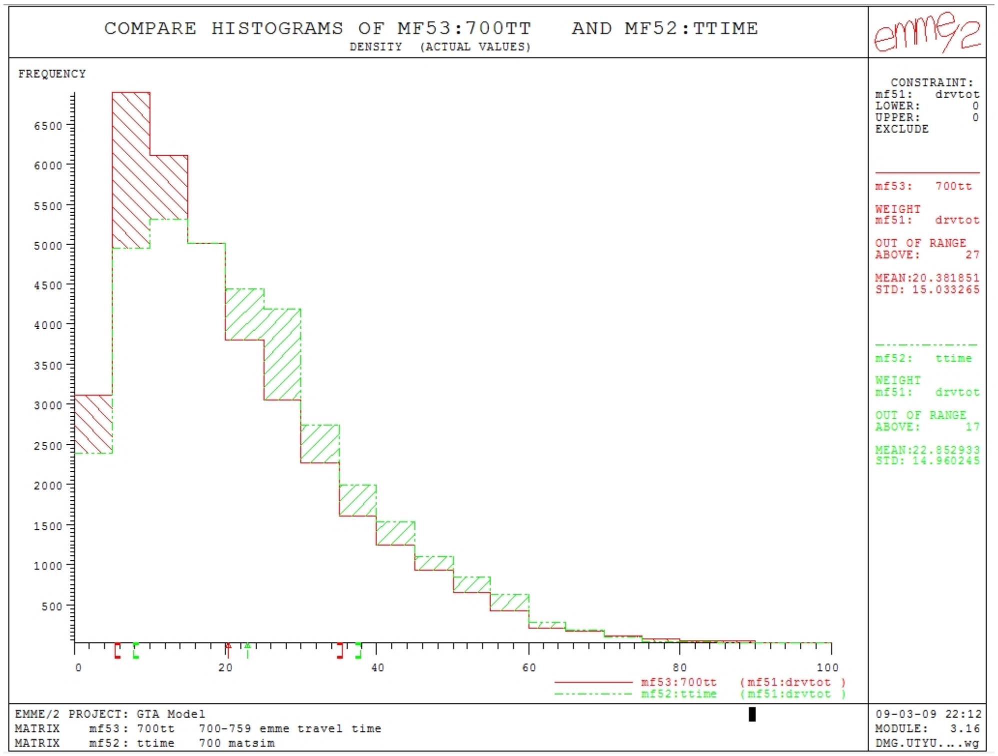
MATRIX mf53: 600tt 600-659 emme travel time
MATRIX mf52: ttime 600 matsim
09-03-09 22:08
MODULE: 3.16
DMG.UTYU....wg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DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
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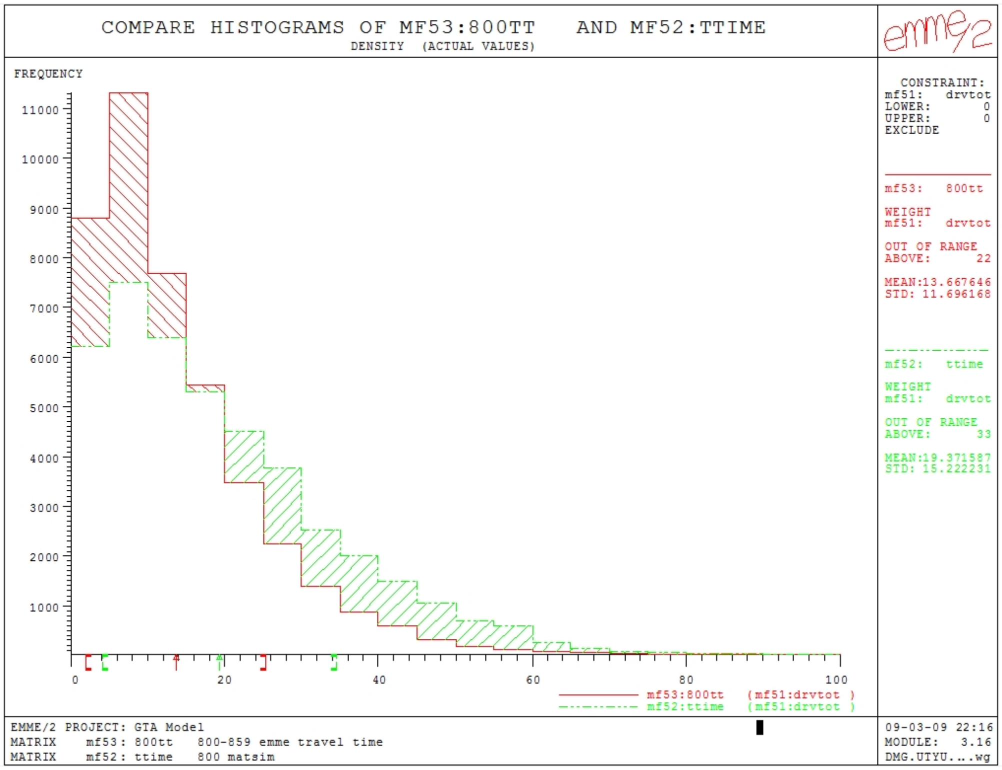
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
20
40
60
80
100
mf53:700tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 700tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 27
MEAN:20.381851
STD: 15.033265
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 17
MEAN:22.852933
STD: 14.960245
EMME/2 PROJECT: GTA Model
MATRIX mf53: 700tt 700-759 emme travel time
MATRIX mf52: ttime 700 matsim
09-03-09 22:12
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:800TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
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20
40
60
80
100
CONSTRAINT:
mf51: drvtot
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UPPER: 0
EXCLUDE
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WEIGHT
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OUT OF RANGE
ABOVE: 22
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WEIGHT
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ABOVE: 33
MEAN:19.371587
STD: 15.222231
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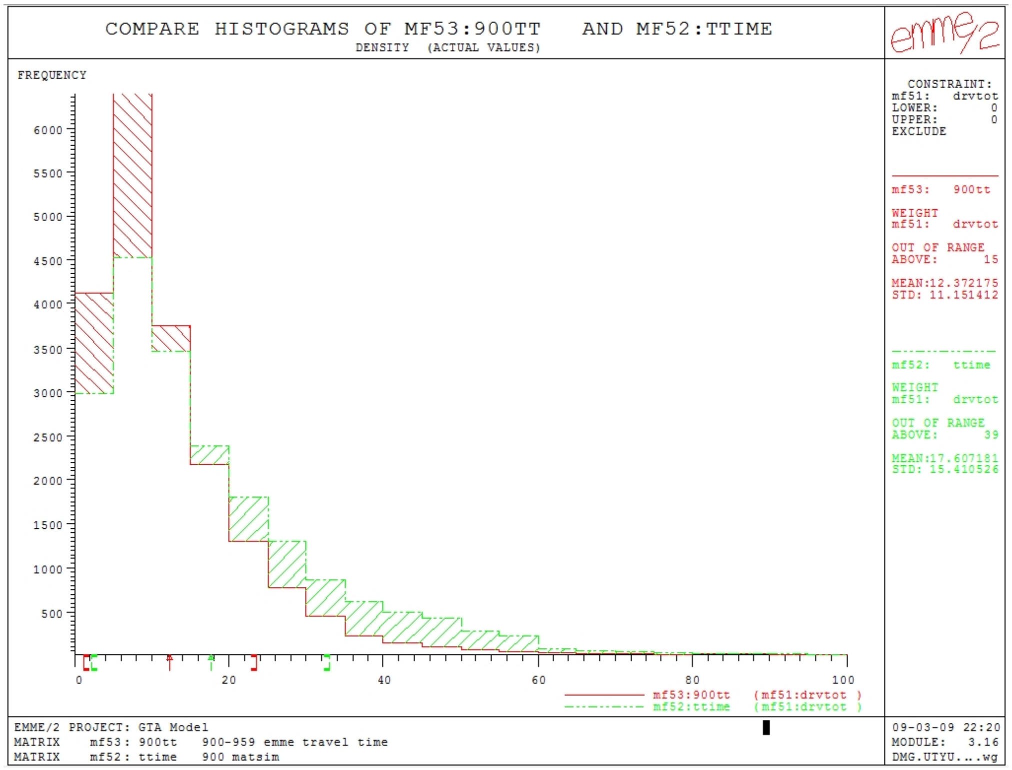
MATRIX mf52: ttime 800 matsim
09-03-09 22:16
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:900TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
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4500
4000
3500
3000
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2000
1500
1000
500
0
20
40
60
80
100
CONSTRAINT:
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UPPER: 0
EXCLUDE
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WEIGHT
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OUT OF RANGE
ABOVE: 15
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WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 39
MEAN:17.607181
STD: 15.410526
mf53:900tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
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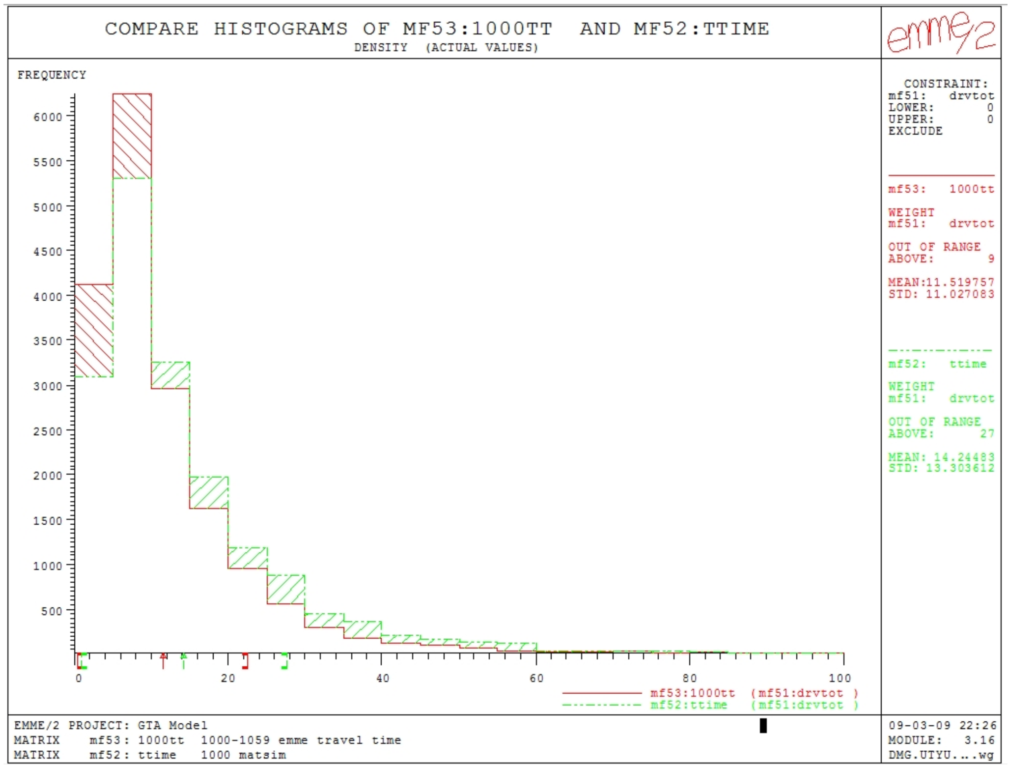
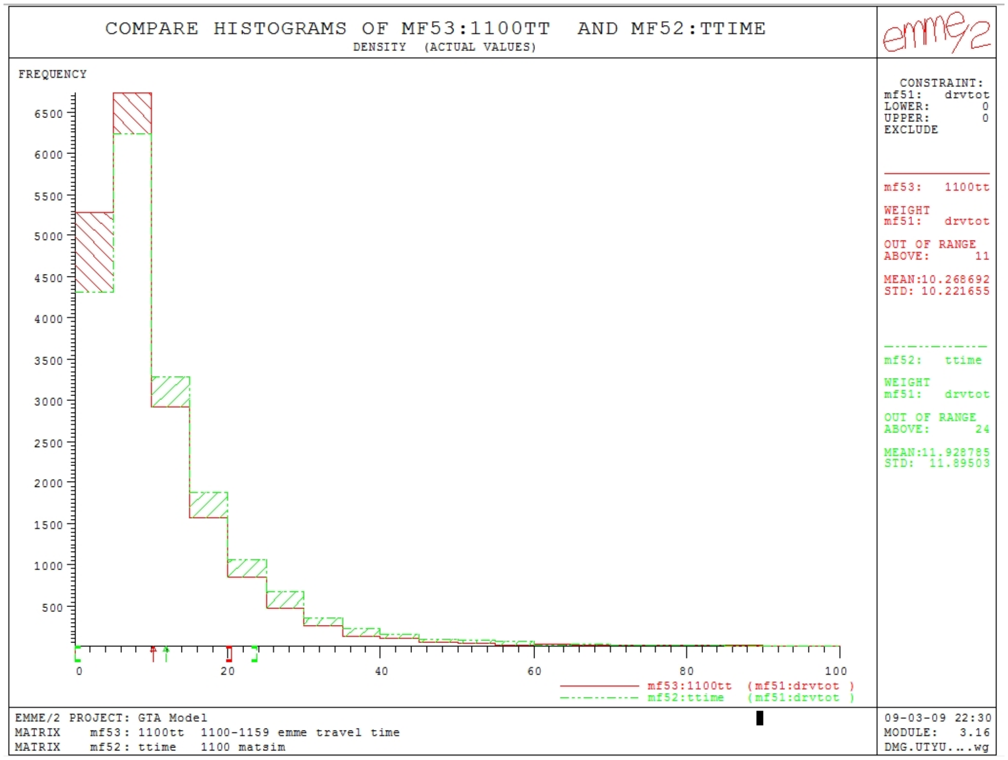
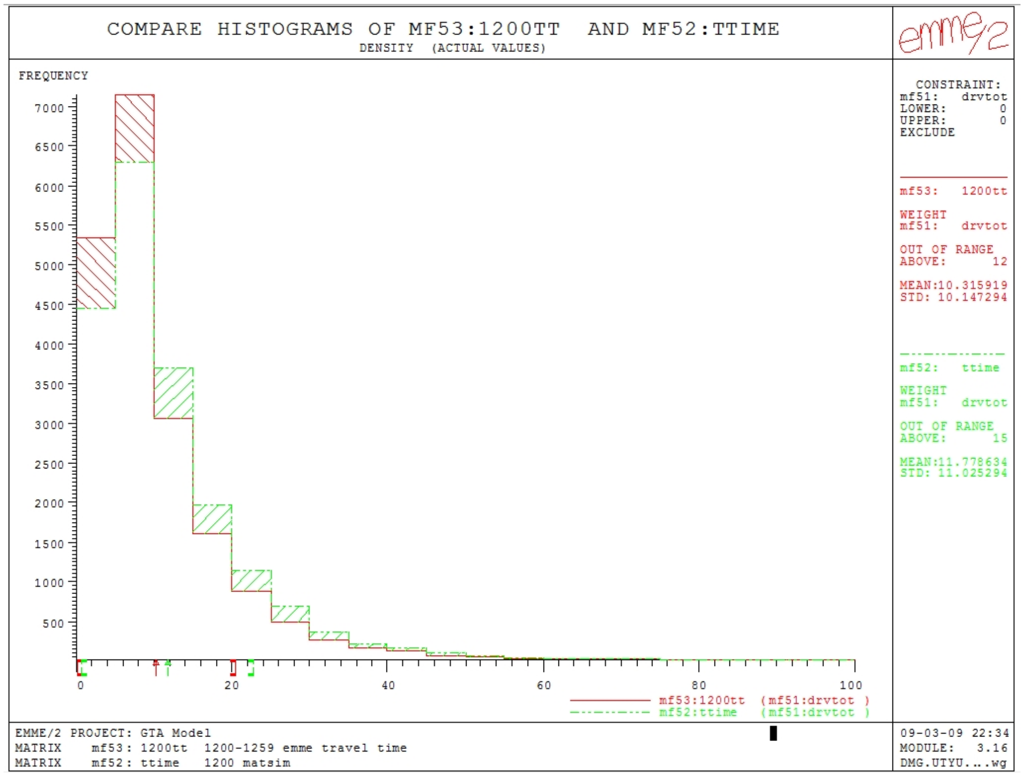
MATRIX mf53: 900tt 900-959 emme travel time
MATRIX mf52: ttime 900 matsim
09-03-09 22:20
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:1000TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
20
40
60
80
100
mf53:1000tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 1000tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 9
MEAN:11.519757
STD: 11.027083
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 27
MEAN: 14.24483
STD: 13.303612
EMME/2 PROJECT: GTA Model
MATRIX mf53: 1000tt 1000-1059 emme travel time
MATRIX mf52: ttime 1000 matsim
09-03-09 22:26
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:1100TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
20
40
60
80
100
mf53:1100tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 1100tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 11
MEAN:10.268692
STD: 10.221655
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 24
MEAN:11.928785
STD: 11.89503
EMME/2 PROJECT: GTA Model
MATRIX mf53: 1100tt 1100-1159 emme travel time
MATRIX mf52: ttime 1100 matsim
09-03-09 22:30
MODULE: 3.16
DMG.UTYU....wg



COMPARE HISTOGRAMS OF MF53:1200TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)

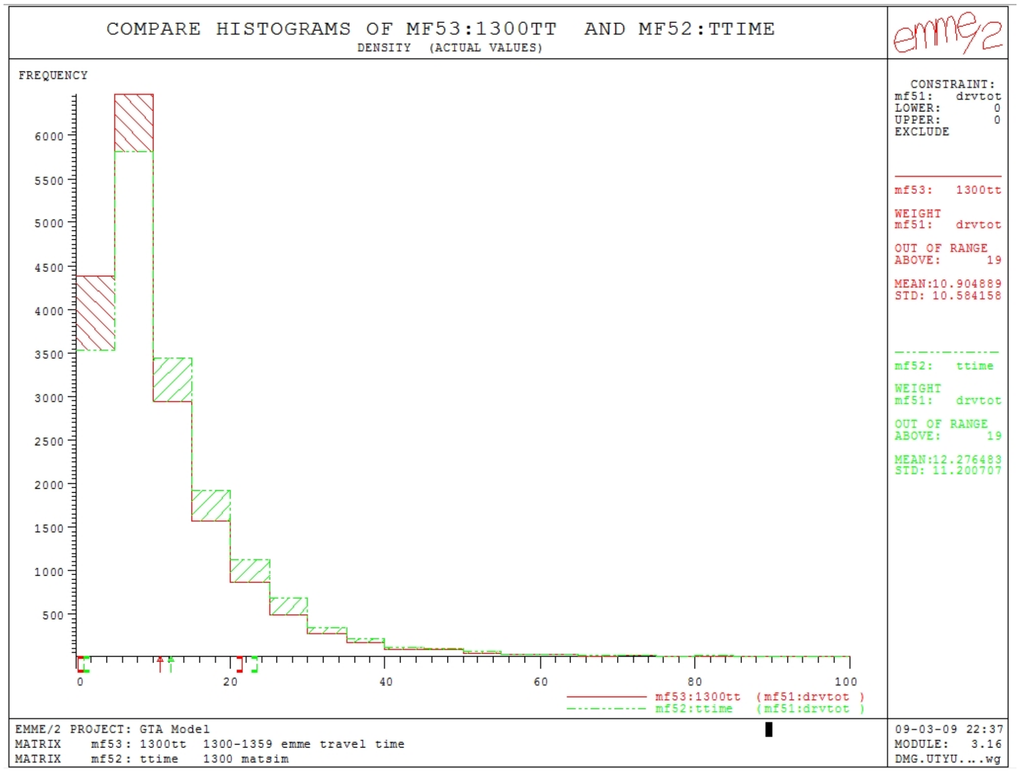
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE

mf53: 1200tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 12
MEAN:10.315919
STD: 10.147294

mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 15
MEAN:11.778634
STD: 11.025294

EMME/2 PROJECT: GTA Model
MATRIX mf53: 1200tt 1200-1259 emme travel time
MATRIX mf52: ttime 1200 matsim

09-03-09 22:34
MODULE: 3.16
DMG.UTYU....wg



COMPARE HISTOGRAMS OF MF53:1300TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)

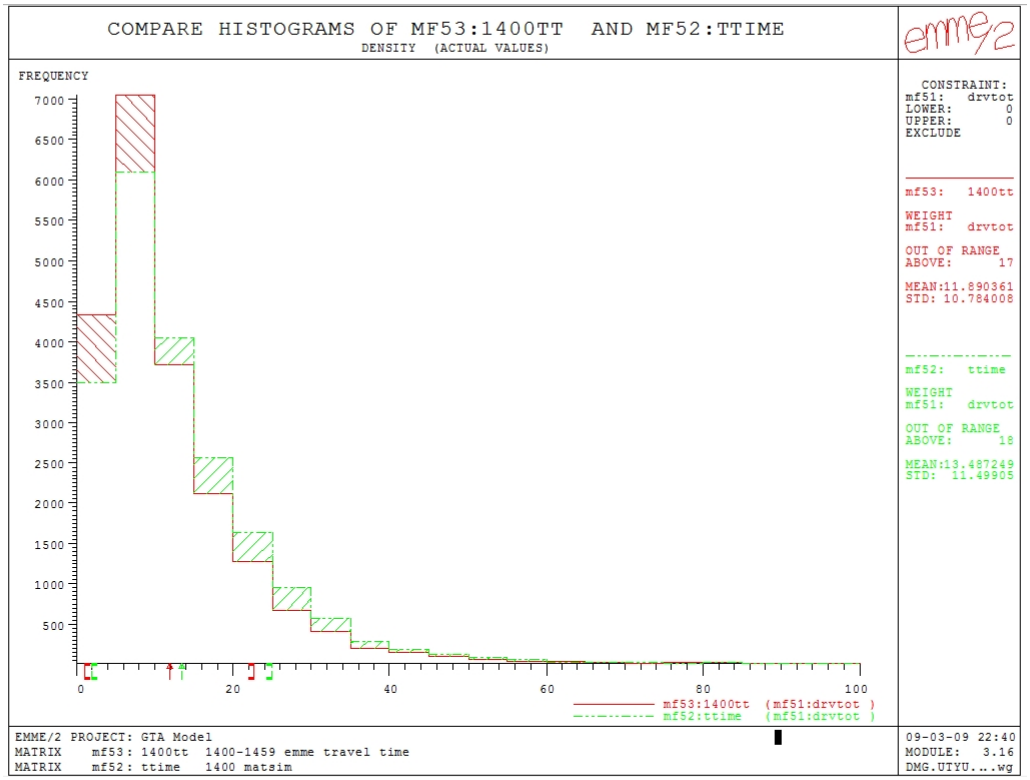
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE

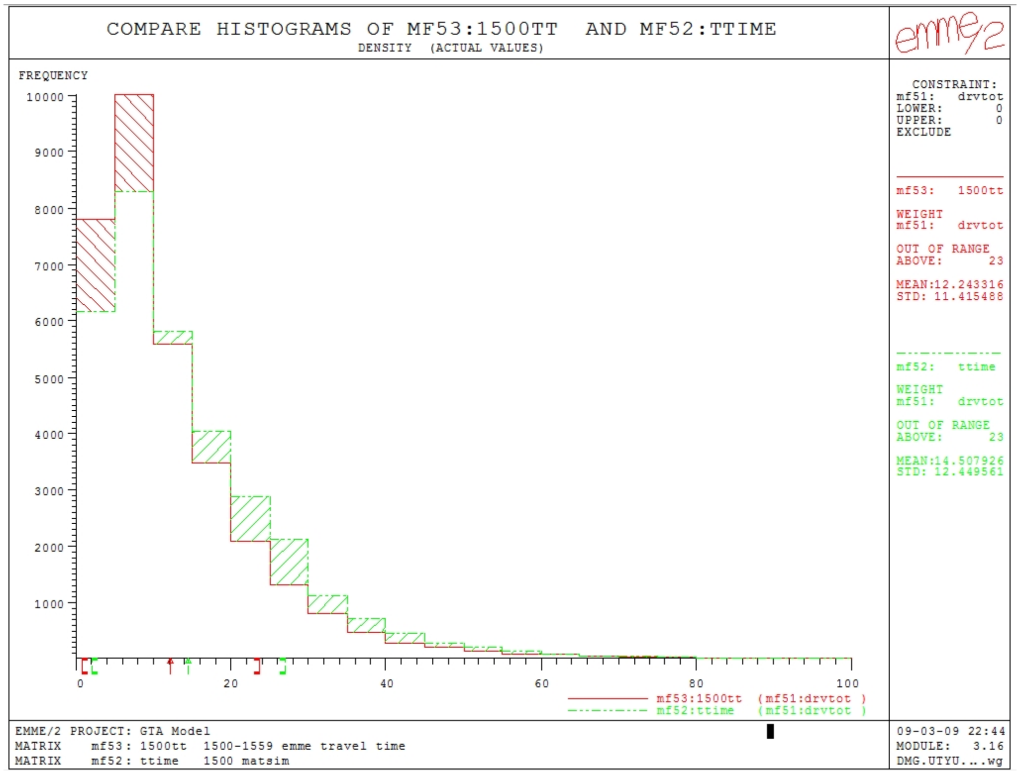
mf53: 1300tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 19
MEAN:10.904889
STD: 10.584158

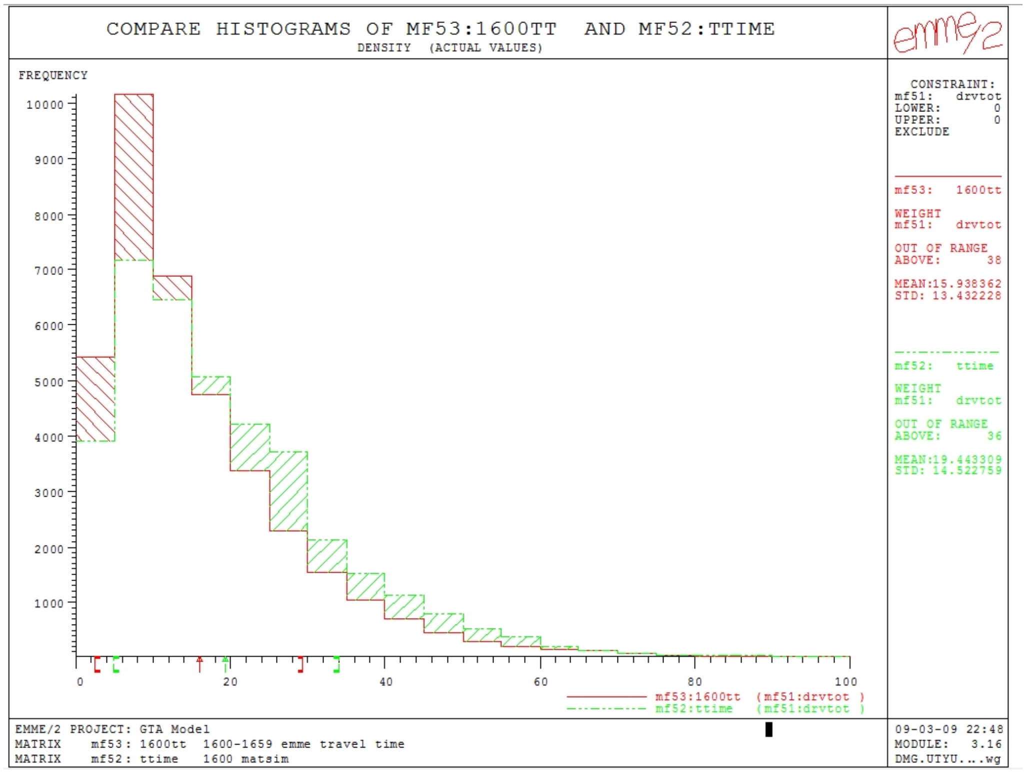
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 19
MEAN:12.276483
STD: 11.200707

EMME/2 PROJECT: GTA Model
MATRIX mf53: 1300tt 1300-1359 emme travel time
MATRIX mf52: ttime 1300 matsim

09-03-09 22:37
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:1400TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
20
40
60
80
100
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 1400tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 17
MEAN:11.890361
STD: 10.784008
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 18
MEAN:13.487249
STD: 11.49905
mf53:1400tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
EMME/2 PROJECT: GTA Model
MATRIX mf53: 1400tt 1400-1459 emme travel time
MATRIX mf52: ttime 1400 matsim
09-03-09 22:40
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:1500TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
20
40
60
80
100
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 1500tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 23
MEAN:12.243316
STD: 11.415488
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 23
MEAN:14.507926
STD: 12.449561
mf53:1500tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
EMME/2 PROJECT: GTA Model
MATRIX mf53: 1500tt 1500-1559 emme travel time
MATRIX mf52: ttime 1500 matsim
09-03-09 22:44
MODULE: 3.16
DMG.UTYU....wg



```
COMPARE HISTOGRAMS OF MF53:1600TT  AND MF52:TTIME
                DENSITY  (ACTUAL VALUES)

 CONSTRAINT:
mf51:   drvtot
LOWER:       0
UPPER:       0
EXCLUDE

mf53:   1600tt

WEIGHT
mf51:   drvtot

OUT OF RANGE
ABOVE:      38

MEAN:15.938362
STD: 13.432228

mf52:   ttime

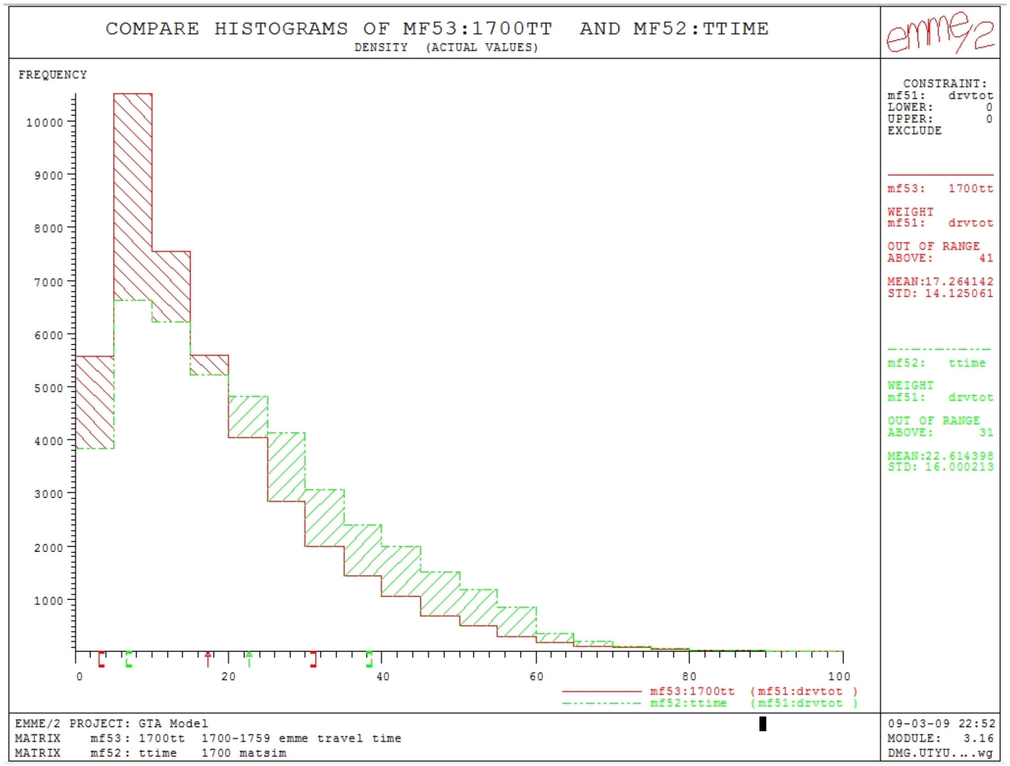
WEIGHT
mf51:   drvtot

OUT OF RANGE
ABOVE:      36

MEAN:19.443309
STD: 14.522759

EMME/2 PROJECT: GTA Model
MATRIX    mf53: 1600tt   1600-1659 emme travel time
MATRIX    mf52: ttime    1600 matsim

09-03-09 22:48
MODULE:   3.16
DMG.UTYU....wg
```



```
COMPARE HISTOGRAMS OF MF53:1700TT  AND MF52:TTIME
                DENSITY  (ACTUAL VALUES)

 CONSTRAINT:
mf51:   drvtot
LOWER:       0
UPPER:       0
EXCLUDE

mf53:   1700tt

WEIGHT
mf51:   drvtot

OUT OF RANGE
ABOVE:      41

MEAN:17.264142
STD: 14.125061

mf52:   ttime

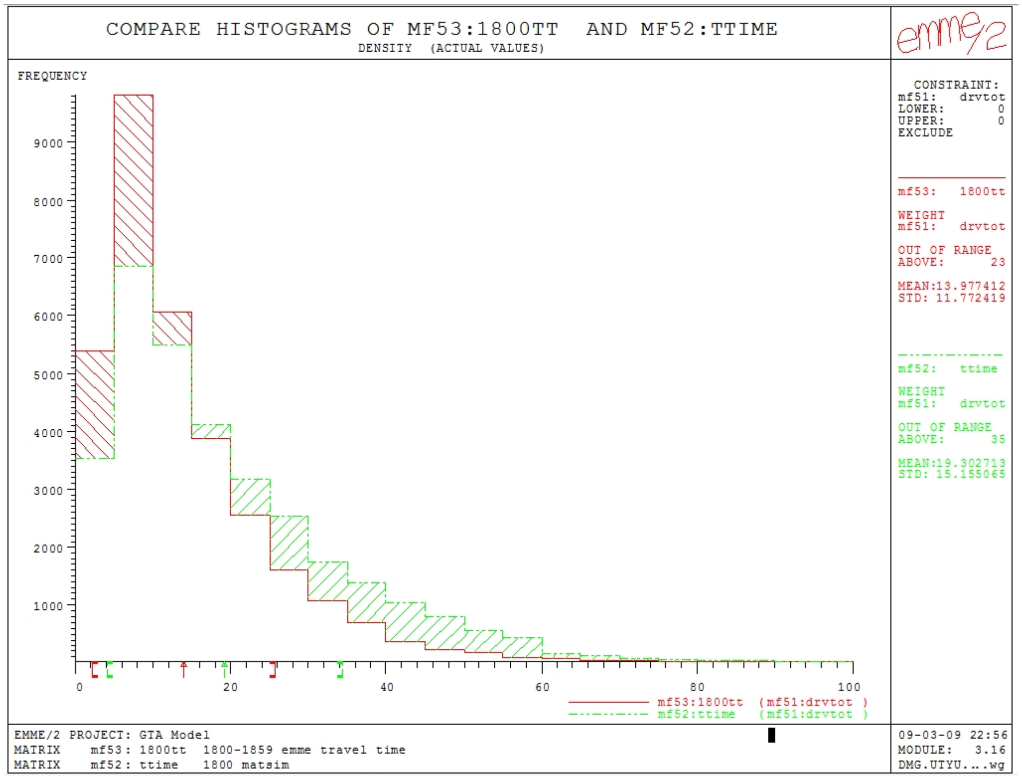
WEIGHT
mf51:   drvtot

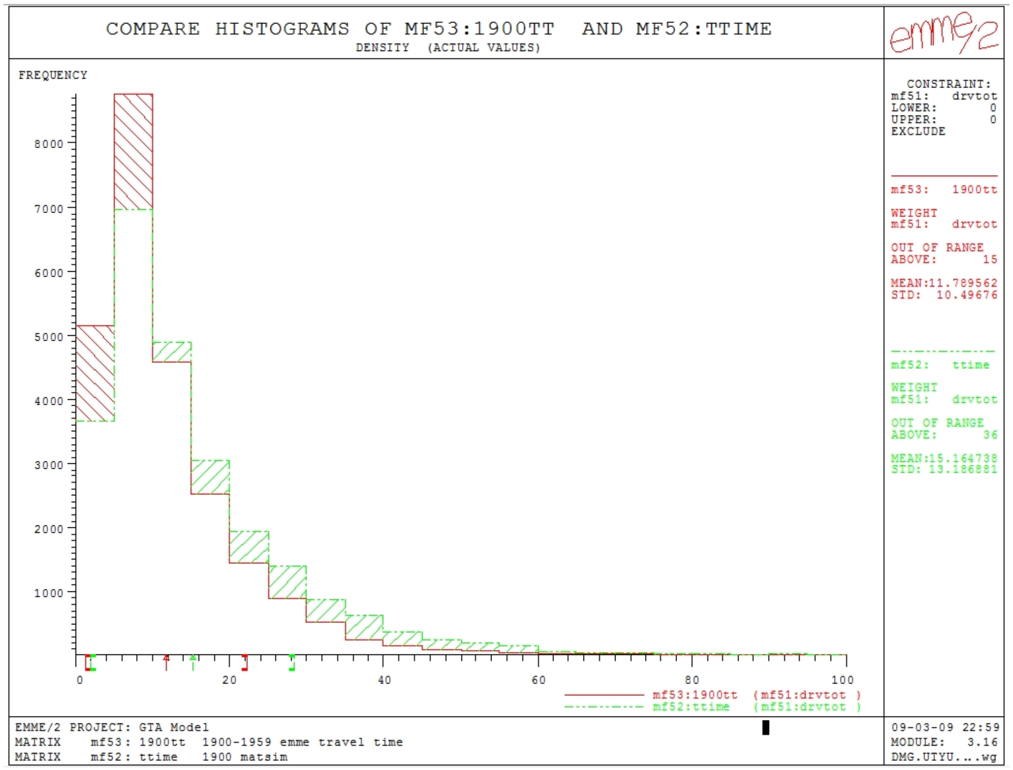
OUT OF RANGE
ABOVE:      31

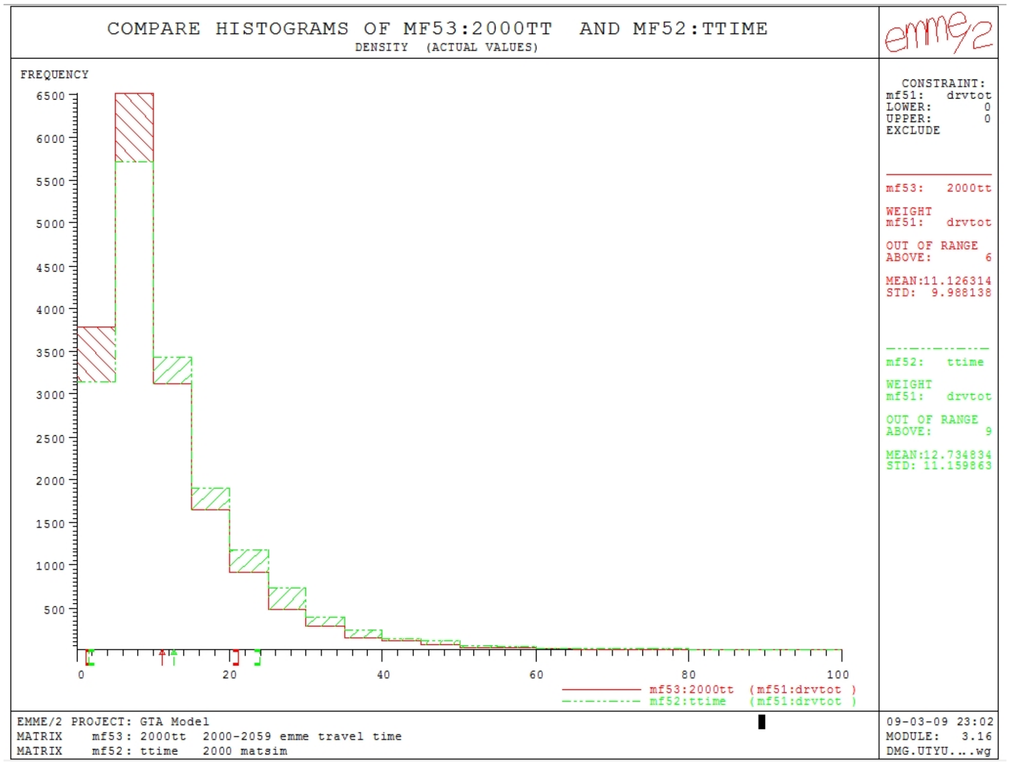
MEAN:22.614398
STD: 16.000213

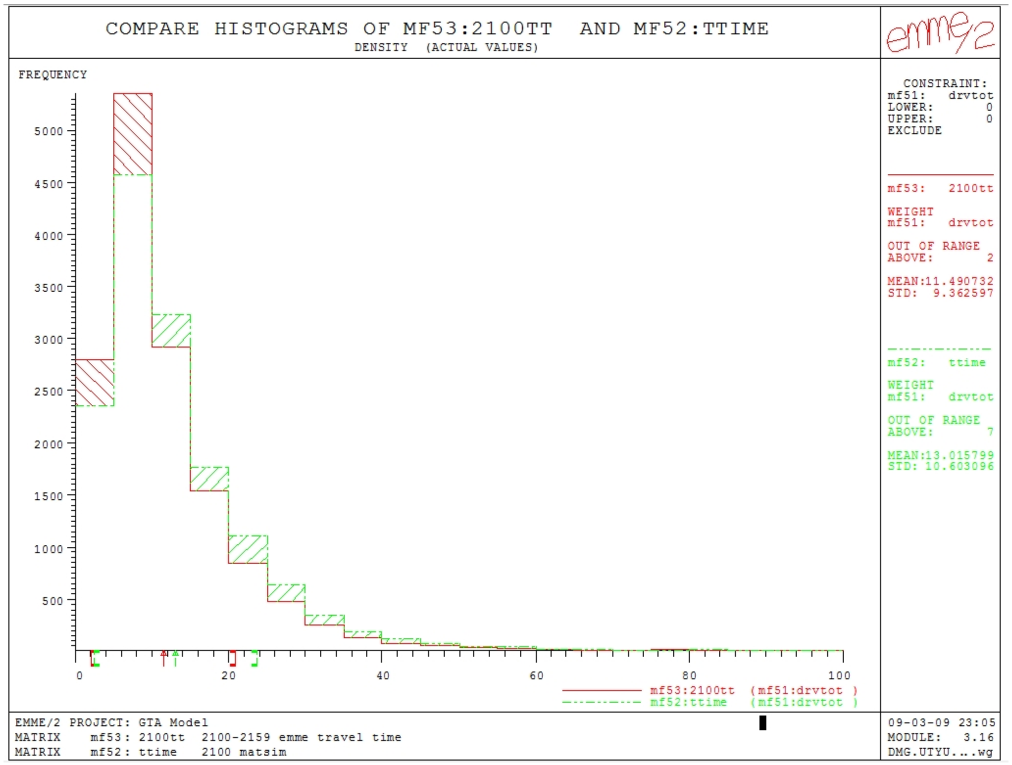
EMME/2 PROJECT: GTA Model
MATRIX    mf53: 1700tt   1700-1759 emme travel time
MATRIX    mf52: ttime    1700 matsim

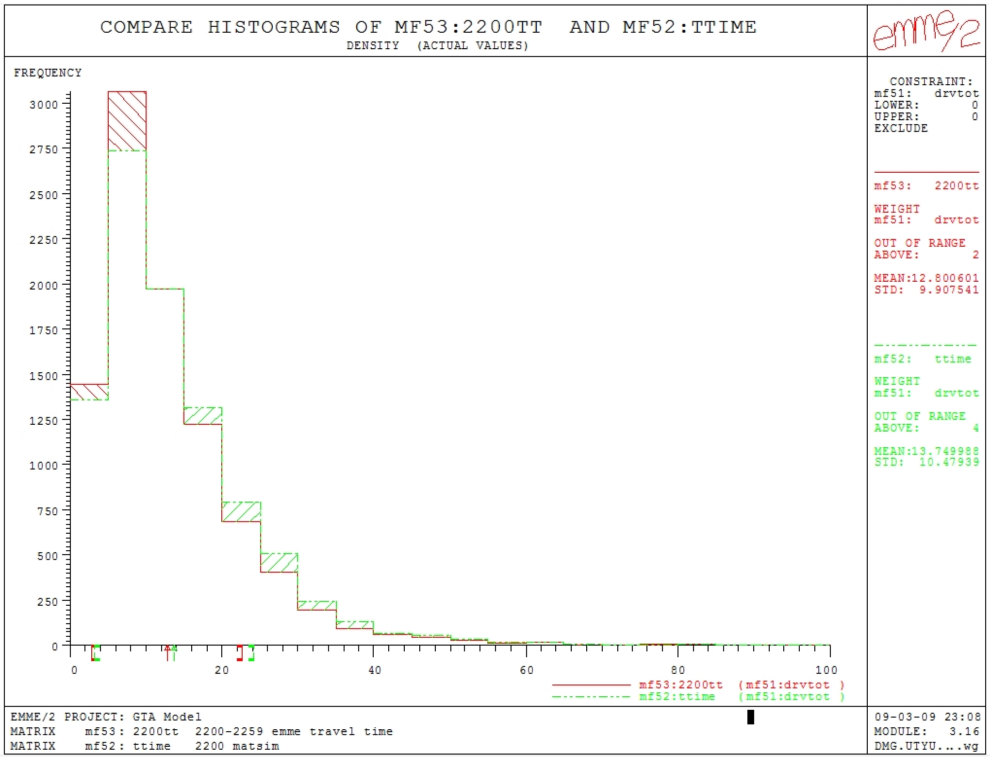
09-03-09 22:52
MODULE:   3.16
DMG.UTYU....wg
```

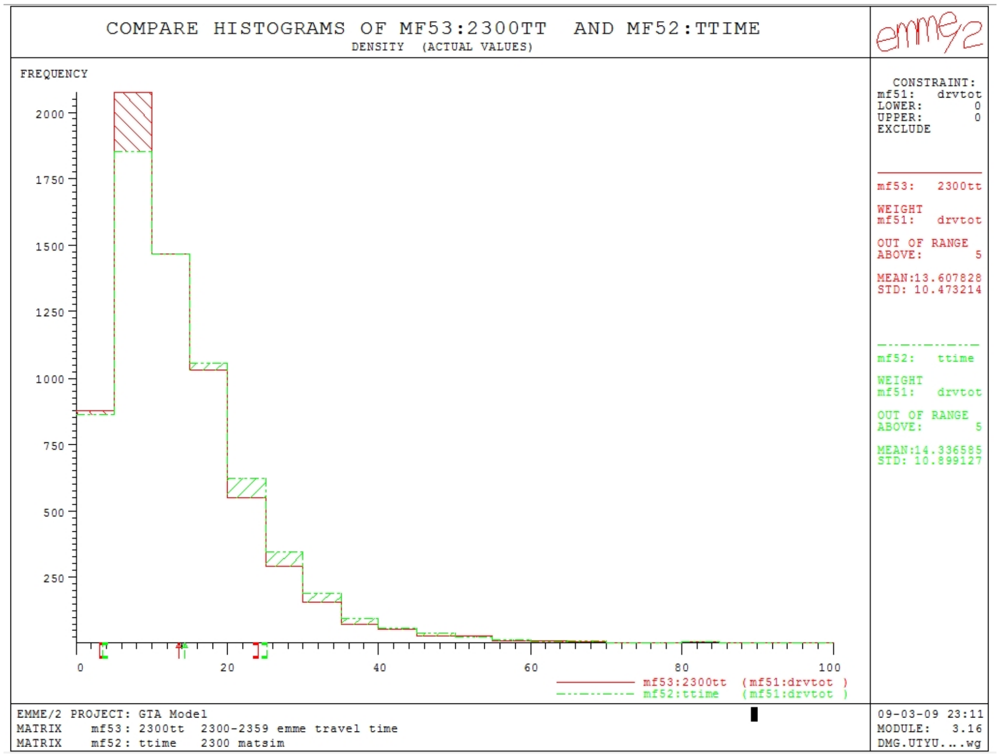

COMPARE HISTOGRAMS OF MF53:1800TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
20
40
60
80
100
mf53:1800tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 1800tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 23
MEAN:13.977412
STD: 11.772419
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 35
MEAN:19.302713
STD: 15.155065
EMME/2 PROJECT: GTA Model
MATRIX mf53: 1800tt 1800-1859 emme travel time
MATRIX mf52: ttime 1800 matsim
09-03-09 22:56
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:1900TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
8000
7000
6000
5000
4000
3000
2000
1000
0
20
40
60
80
100
mf53:1900tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 1900tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 15
MEAN:11.789562
STD: 10.49676
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 36
MEAN:15.164738
STD: 13.186881
EMME/2 PROJECT: GTA Model
MATRIX mf53: 1900tt 1900-1959 emme travel time
MATRIX mf52: ttime 1900 matsim
09-03-09 22:59
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:2000TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
20
40
60
80
100
mf53:2000tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 2000tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 6
MEAN:11.126314
STD: 9.988138
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 9
MEAN:12.734834
STD: 11.159863
EMME/2 PROJECT: GTA Model
MATRIX mf53: 2000tt 2000-2059 emme travel time
MATRIX mf52: ttime 2000 matsim
09-03-09 23:02
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:2100TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
20
40
60
80
100
mf53:2100tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 2100tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 2
MEAN:11.490732
STD: 9.362597
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 7
MEAN:13.015799
STD: 10.603096
EMME/2 PROJECT: GTA Model
MATRIX mf53: 2100tt 2100-2159 emme travel time
MATRIX mf52: ttime 2100 matsim
09-03-09 23:05
MODULE: 3.16
DMG.UTYU....wg


COMPARE HISTOGRAMS OF MF53:2200TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
0
20
40
60
80
100
mf53:2200tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 2200tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 2
MEAN:12.800601
STD: 9.907541
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 4
MEAN:13.749988
STD: 10.47939
EMME/2 PROJECT: GTA Model
MATRIX mf53: 2200tt 2200-2259 emme travel time
MATRIX mf52: ttime 2200 matsim
09-03-09 23:08
MODULE: 3.16
DMG.UTYU....wg

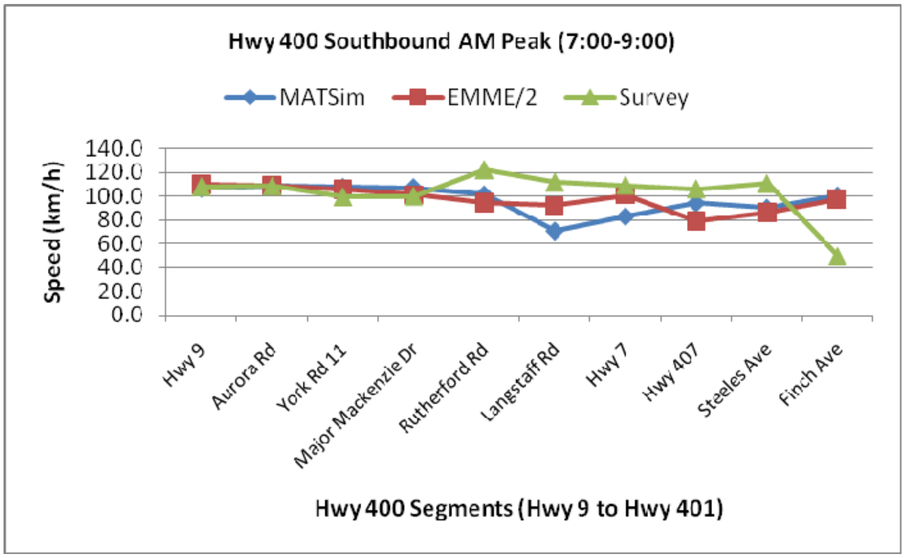

COMPARE HISTOGRAMS OF MF53:2300TT AND MF52:TTIME
DENSITY (ACTUAL VALUES)
emme/2
FREQUENCY
2000
1750
1500
1250
1000
750
500
250
0
20
40
60
80
100
mf53:2300tt (mf51:drvtot)
mf52:ttime (mf51:drvtot)
CONSTRAINT:
mf51: drvtot
LOWER: 0
UPPER: 0
EXCLUDE
mf53: 2300tt
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 5
MEAN:13.607828
STD: 10.473214
mf52: ttime
WEIGHT
mf51: drvtot
OUT OF RANGE
ABOVE: 5
MEAN:14.336585
STD: 10.899127
EMME/2 PROJECT: GTA Model
MATRIX mf53: 2300tt 2300-2359 emme travel time
MATRIX mf52: ttime 2300 matsim
09-03-09 23:11
MODULE: 3.16
DMG.UTYU....wg

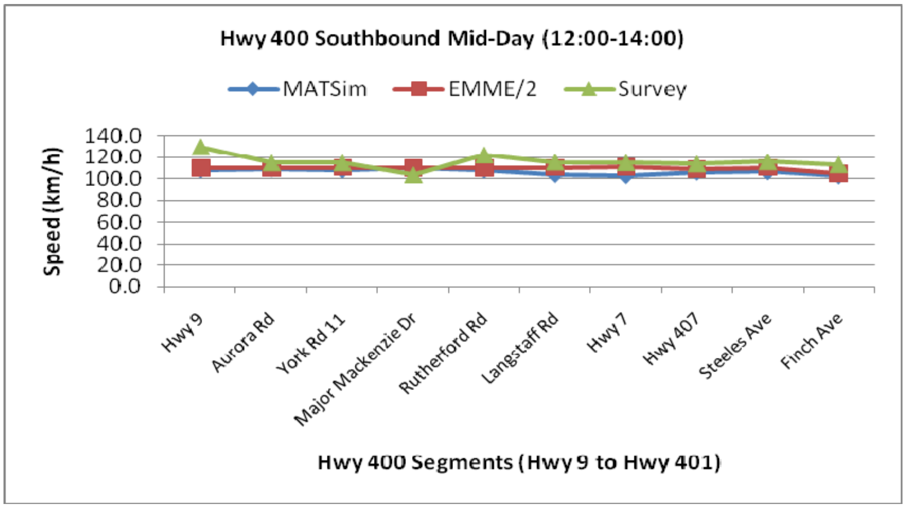
Appendix C The Percentage Differences of Link Volumes Comparison at Screenlines

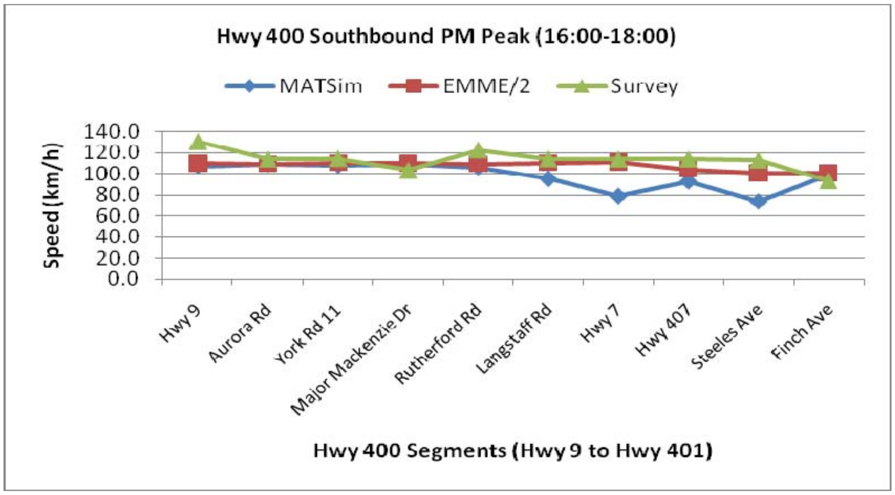
Screenline		Direction		No. of Stations	MATSim vs. Survey		EMME2 vs. Survey		MATSim vs. EMME/2	
					AM	PM	AM	PM	AM	PM
1	Halton West Boundary	Hamilton --> Halton	E	6	-49%	-32%	-54%	-33%	9%	2%
		Halton --> Hamilton	W	6	-26%	-46%	-24%	-46%	-2%	1%
2	Halton-Peel Boundary	Halton --> Peel	E	17	-23%	-12%	-26%	-19%	4%	9%
		Peel --> Halton	W	17	-2%	-34%	-8%	-27%	6%	-10%
3	Peel-York Boundary	Peel --> York	E	12	-8%	-11%	-16%	-22%	9%	15%
		York --> Peel	W	12	-25%	-24%	-29%	-23%	5%	-1%
4	Peel-Toronto Boundary	Peel --> Toronto	E	18	-20%	-18%	-12%	-18%	-10%	-1%
		Toronto --> Peel	W	18	-11%	-18%	-8%	-10%	-4%	-8%
5	Toronto-York Boundary	Toronto --> York	N	40	-12%	-21%	-12%	-17%	-1%	-5%
		York --> Toronto	S	40	-16%	-23%	-16%	-21%	0%	-2%
6	York-Durham Boundary	York --> Durham	E	35	-49%	-57%	-38%	-49%	-18%	-17%
		Durham --> York	W	35	-42%	-44%	-42%	-34%	1%	-15%
7	Toronto-Durham Boundary	Toronto --> Durham	E	5	-9%	-24%	-2%	-14%	-7%	-12%
		Durham --> Toronto	W	5	-19%	-15%	-17%	-13%	-3%	-2%
8	Durham East Boundary	Durham --> East	E	21	-23%	-81%	1%	-78%	-24%	-13%
		East --> Durham	W	21	-92%	-35%	-93%	-32%	6%	-4%
9	Toronto Metro Boundary	Inbound		63	-18%	-20%	-14%	-19%	-4%	-1%
		Outbound		63	-12%	-20%	-9%	-14%	-3%	-7%
10	Toronto Suburban	Inbound		36	-5%	-13%	-2%	-9%	-4%	-5%
		Outbound		37	-5%	-17%	0%	-10%	-5%	-8%
11	Toronto Central Area	Inbound		31	6%	-16%	23%	-16%	-14%	1%
		Outbound		31	-7%	-1%	-8%	6%	1%	-7%
12	Toronto Downtown Core	Inbound		16	17%	-31%	21%	-46%	-3%	29%
		Outbound		17	-18%	3%	-30%	12%	16%	-8%

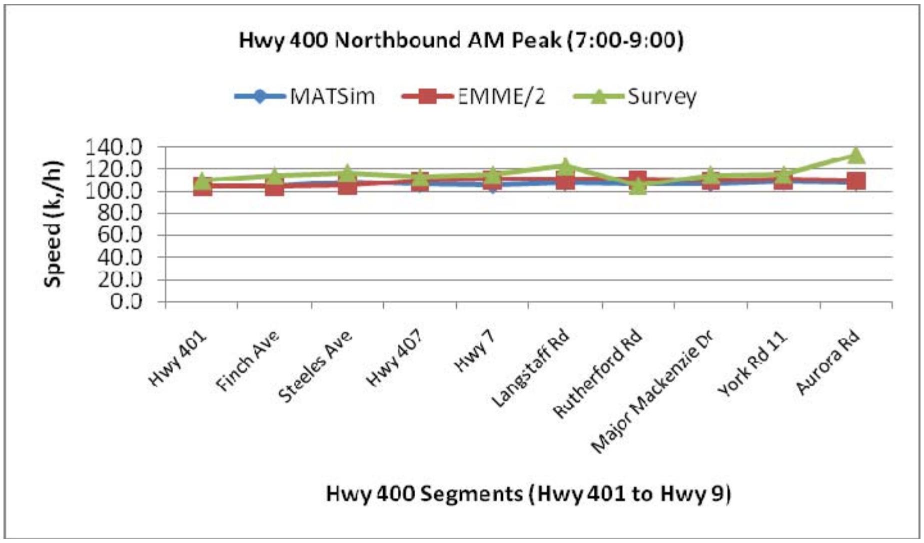
Note: E - Eastbound; W - Westbound; N - Northbound; S - Southbound

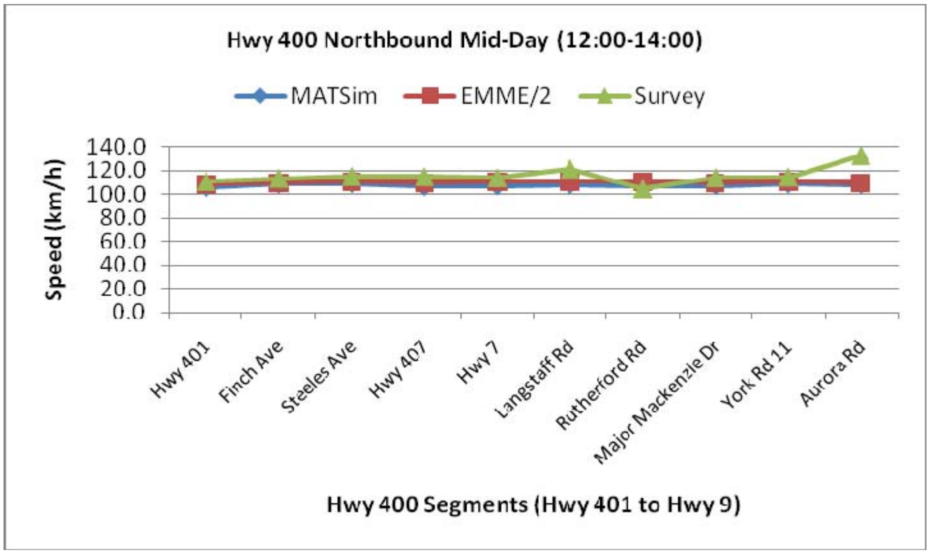
Appendix D Hwy 400 between Hwy 9 and Hwy 401 Auto Speed at AM Peak, Mid-Day and PM Peak respectively

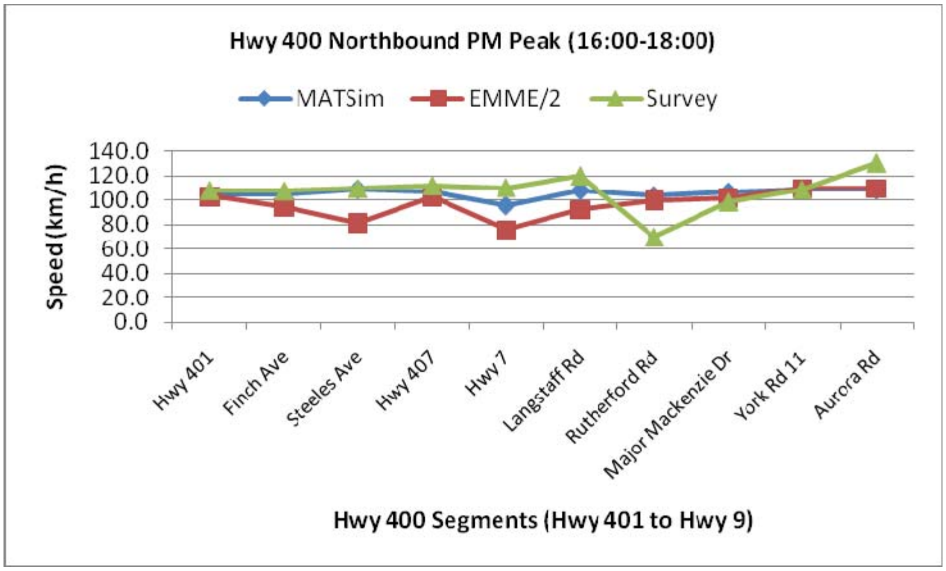







Hwy 400 Northbound AM Peak (7:00-9:00)
MATSim
EMME/2
Survey
Speed (k,/h)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Hwy 401
Finch Ave
Steeles Ave
Hwy 407
Hwy 7
Langstaff Rd
Rutherford Rd
Major Mackenzie Dr
York Rd 11
Aurora Rd
Hwy 400 Segments (Hwy 401 to Hwy 9)


Hwy 400 Northbound Mid-Day (12:00-14:00)
MATSim
EMME/2
Survey
Speed (km/h)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Hwy 401
Finch Ave
Steeles Ave
Hwy 407
Hwy 7
Langstaff Rd
Rutherford Rd
Major Mackenzie Dr
York Rd 11
Aurora Rd
Hwy 400 Segments (Hwy 401 to Hwy 9)


Hwy 400 Northbound PM Peak (16:00-18:00)
MATSim
EMME/2
Survey
Speed (km/h)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Hwy 401
Finch Ave
Steeles Ave
Hwy 407
Hwy 7
Langstaff Rd
Rutherford Rd
Major Mackenzie Dr
York Rd 11
Aurora Rd
Hwy 400 Segments (Hwy 401 to Hwy 9)