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Arun Chatterjee

Arun Chatterjee, Major Professor

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COMPARISON OF TRAFFIC SIMULATION MODELS:

A CASE STUDY - NETSIM, NETFLO1 AND NETFLO2

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Sunil Taori

August 1994

DEDICATION

This thesis is dedicated to
my parents
who have continually supported me
even through their own hardships
and
my sister
whose support has always been
the source of my motivation to succeed.

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ABSTRACT

This research was an attempt to compare the outputs from TRAF-NETSIM, NETFLO1 and NETFLO2 traffic simulation models. The three models adopt different approaches to simulate traffic on an urban street network. Four different scenarios of traffic network with varying network layout and intersection geometries were simulated by the three models at three different volume levels. The average networkwide speed and delay outputs from the three models were compared for each scenario. Analysis of Variance techniques were used for statistical analyses. The execution speed of the models were also compared. The major finding of this study was that the outputs from the three models were significantly different at each level of comparison. The speed values generated by NETSIM were found to be the lowest whereas NETFLO2 values were highest. NETFLO1 values were always in the middle. In most cases, NETFLO1 values were more closer to NETFLO2 than to NETSIM values. Identical results were found from the analysis of delay values. NETFLO2 was found to be the fastest of the three models whereas NETSIM was the slowest. The execution speed of NETFLO2 was found to be drastically higher than NETSIM. Even NETFLO1 was found to be much faster than NETSIM. There was a significant trade-off between the statistics generated by these models and their execution speeds.

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CHAPTER 1

INTRODUCTION

Role of Computer Simulation in Transportation

Although the United States has one of the best surface transportation systems in the world, continued growth in travel is severely straining the system. Congestion on Nation's highways continues to increase, particularly in urban areas and along heavily traveled inter-city corridors. Urban congestion has become a national problem in the US. Each year billions of hours are wasted in traffic congestion, which causes monetary losses and environmental problems. The annual cost of congestion to the Nation in lost productivity alone is about $100 billion, exclusive of costs of wasted fuel and environmental damage(1). Traffic engineers have been trying to alleviate the negative impacts of urban congestion by implementing travel demand management strategies as well as by increasing the operational efficiency of traffic control systems, i.e., transportation systems management (TSM) strategies. Computer simulation models are now being used as decision support tools for evaluating or assessing various strategies more frequently than before. There are obvious advantages of using computer simulations over actual field testing of various strategies. Simulation eliminates the need for costly, time-consuming, risky and sometimes infeasible field experiments and evaluations before real-life implementation of a new or alternative system management or control strategy.

Computer simulation is likely to play a major role in the analysis and assessment of the Intelligent Vehicle Highway Systems (IVHS) technologies. Traffic simulation models will be used in the design, analysis, and evaluation of IVHS concepts ranging from demand-responsive traffic signals to fully automated roadways(2). The models are intended to be used off-line as design and evaluation tools and on-line as decision-support systems. The off-line applications demand versatility and flexibility of the modeling system, i.e., models should be able to represent a variety of traffic environment and allow the user to experiment with alternative traffic management strategies. The on-line usage of the models would require sufficient quickness (near real-time) of execution and the ability to exchange information with other systems.

Level of Simulation Details

There are different types of simulation programs available. Broadly, the simulation models could be classified into two categories, microscopic and macroscopic. The question often arises how to select one of these for a particular problem to be analyzed. There has been an ongoing debate since the early days of computer models regarding the use of macroscopic models versus the microscopic models. This question has become more critical considering wider acceptance and application of simulation models as a decision support tool in the field of traffic engineering. In traffic simulation, the microscopic models involve more detailed levels of simulation (i.e., vehicle by vehicle) than macroscopic models, and hence are considered as being closer to reality. On one hand, the more details a model includes explicitly, the better, we think, the model resembles reality. On the other hand, more details generally make the solution of problems more difficult. Because of the increased number of functions that a more detailed model must perform, a concomitant increase in the program running time on the computer, and hence cost, is expected[(3)]. In general, microscopic models need substantially more time for the execution of simulation runs than macroscopic models. Unfortunately, there appears to be a trade-off between the execution time of the models and the realism or accuracy of the results obtained from them. There could also be a mesoscopic approach to simulation. Mesoscopic models are less detailed than microscopic models but more detailed than macroscopic models. The major question is which approach fulfills the analysis or evaluation requirements better than the other for a given case. Do the microscopic, mesoscopic and macroscopic models produce compatible results under different traffic conditions?

TRAF Family of Simulation Models

For simulating urban street networks, there are three different models available in the TRAF family of models developed by Federal Highway Administration (FHWA). These are NETSIM, NETFLO1 and NETFLO2. Of these, NETSIM is the most detailed (microscopic) model. NETFLO1 (Also called LEVEL I) is less detailed than NETSIM while

NETFLO2 (also called LEVEL II) is the least detailed (macroscopic) model. It was decided to compare the result of these three models when simulating identical traffic conditions. The TRAF system was chosen for this study because it seems to be the single most integrated source of traffic simulation models. These models are sophisticated and widely used for traffic simulation. Perhaps, TRAF-NETSIM is perhaps one of the most widely used traffic simulation models in the field of transportation today. TRAF consists of an integrated set of simulation models to represent a variety of traffic environments. These models are available under the Traffic Software Integrated System (TSIS) package sponsored by FHWA. TSIS is a utility program that provides a user-friendly, menu-driven environment for accessing many of the commonly used traffic engineering programs(4). The TSIS software provides access to TRAF-NETSIM directly, while the two NETFLO models, namely LEVEL I and LEVEL II along with another model called FREEFLO (a macroscopic simulation model for Freeways), are incorporated under a common executable command CORFLO. Executing CORFLO from the TSIS menu automatically runs one of the models that has been specified in the input file.

NETSIM applies interval based simulation to describe traffic operations(5). This means that every vehicle is defined as a distinct object which is moved through the network every second and all variable control devices (traffic signals), and events are updated every second. Each time a vehicle is moved, both -- its position (lateral as well as longitudinal) on the link and its relationship with other vehicles nearby, are calculated. Vehicles are moved according to car following logic, response to traffic control devices and response to other drivers. Turn movements, free flow speed, queue discharge headways and other behavioral attributes are assigned stocastically.

NETFLO1 is an event based simulation of traffic operations(5). The traffic stream is modeled explicitly; each vehicle on the network is treated as an identifiable entity. Each time a vehicle is moved by the program logic, its position (both lateral and longitudinal) on a link as well its relationship with other vehicles nearby is determined. Here again the turn movements, free flow speed, queue discharge headways and other attributes are assigned stocastically. This treatment appears to be comparable to that of the NETSIM simulation. The NETFLO1 model, however, differs in detail from NETSIM in many ways. The most important difference lies is the level of detail of individual vehicle movements. NETFLO1 moves each vehicle intermittently, whenever an "event" or a change in its status occurs, and moves the vehicle as far downstream as possible in a single "jump". Thus a vehicle may move a substantial distance before its status is changed. Hence, NETFLO1 does not generate detailed vehicle trajectories as NETSIM does.

NETFLO2 was adapted from TRANSYT flow model(5). Inputs were simplified and the ability to handle time varying traffic flow rates and multiple cycle lengths for a traffic signal were added. It is platoon dispersion model, which is macroscopic in nature. The traffic stream is described in terms of a set of link-specific statistical histograms representing traffic flow characteristics. These histograms describe the platoon structure of the traffic stream on each network. The NETFLO2 logic identifies five types of histograms. These are Entry, Input, Service, Queue and Output histograms. These histograms are generated to represent the flow of traffic on each link for each time interval. The items of its output are similar to NETFLO1 and NETSIM.

Objective and Scope of the Study

The purpose of this research was to perform a comparative analysis of the three simulation models available under TRAF system for simulating traffic on urban street networks. The objective was to find out if the results of simulating a given traffic network differ significantly with different models. The comparisons were made to see the compatibility of results obtained from different models with each other. The comparisons included the results generated by the models when simulating identical traffic conditions and their execution speeds in terms of computer time used. Execution speed of the models was of particular interest to see if the difference in the execution times of these models was significant. Any differences in the output were tested for statistical significance. This study also provided an opportunity to identify if any trends or patterns existed between outputs from these models. The results of this study will help the analysts in the selection of models based on the intended applications and the perceived realism of the outputs. The results of this study would be very helpful, especially in IVHS studies, where very fast execution speeds of simulation would be of great significance for near real-time responses. Also this study may offer opportunities for further research to look into the simulation logic and approaches adopted by various models to see which are more useful than others.

The relative comparison of these models is the basic objective of this study. Validation of these models for the accuracy of their outputs as compared to the actual field data is beyond the scope of this study. This study is not an exhaustive evaluation of the models being studied. The findings of this study may not apply to all types of traffic scenarios.

Thesis Outline

This report is divided into different chapters. Chapter 2 following this introduction chapter discusses the literature researched and identifies those found useful for this study. Chapter 3 presents the Study Design. This section describes in detail the variables chosen for the study and the assumptions associated with various variables for the formulation of study networks. The inputs to the models are discussed here. The approach used for the statistical analysis of the outputs is explained in Chapter 4. Results of analysis are presented in two parts in Chapters 5 and 6 for Single Intersection and Arterial Section scenarios respectively. The statistical analysis performed on the outputs obtained from various simulation runs and their interpretations are described here. Conclusions and recommendations are presented in Chapter 7.

CHAPTER 2

LITERATURE REVIEW

A literature search was done to find if any study had been done earlier on the comparison of the NETSIM model with the NETFLO1 and/or NETFLO2. It was found that there has been no such study involving the comparison of these three models. NETSIM appeared to be one of the most used network models in the field of transportation. However, there was not much literature available for the two NETFLO models. The major source of information on NETFLO models was the "TRAF User Reference Guide"(5). There have been several studies that involved the use of NETSIM model.

TRAF Family of Traffic Simulation Models

"TRAF User Reference Guide"(5) was the main source of information on NETFLO models. It provides detailed information on the input data and concepts needed to effectively utilize the traffic simulation models available under TRAF family. The way the simulation models are named in TRAF is explained in the guide as follows :

> *" The naming convention for these models is based on a combination of prefix and suffix. The prefix indicates what kind of network is being simulated. The prefixes NET, FRE and ROAD are for surface street network, freeway network and two lane road network, respectively.*

The suffixes SIM and FLO are for microscopic simulation and macroscopic simulation, respectively."

Hence, according to the "Guide", NETSIM is a microscopic simulation model for surface street networks while NETFLO1 and NETFLO2 are both macroscopic models for the same.

There are no detailed guidelines provided in the Guide regarding the selection of model for simulating any particular type of road network. Some general guidelines are however provided, as stated below :

" The network representing the traffic environment may be subdivided into smaller components, called sub networks, which interface with one another. This feature permits the user to assign each sub network to a particular simulation model, depending on the user's need for detail and on the type of roadways included in the sub network. The user has complete freedom in partitioning the analysis network into its component sub networks. The choice of sub network configuration (and assigned simulation models) depends upon many considerations, including the following :

- *Level of detail desired for the study.*
- *Computer, financial and time resources available.*
- *Network topology.*
- *Anticipated level of traffic congestion.*
- *Extent of mass transit operations.*
- *Detail of input.*

For urban networks, in which a high level of detailed analysis is required and available input data is detailed, or available resources for data collection are ample, the user can select the most detailed urban model, NETSIM. Where some of the above conditions are absent, ***the user can conserve resources by specifying NETFLO1 and NETFLO2, appropriately, and yet obtain results of satisfactory accuracy."***

Hence, the "TRAF User Reference Guide" states that NETFLO1 and NETFLO2 can be used instead of NETSIM without having to compromise on the accuracy of results. But it fails to provide any guideline regarding how much compromise has to be made and under what traffic conditions this could be done. It seems from the above statement that it has been assumed that NETSIM model, being a more detailed model, is more accurate.

The major features which can be simulated by the NETSIM, NETFLO1 and NETFLO2 models are summarized in Table 2.1. Apart from these features there are other built-in distributions of various traffic parameters that are used during simulation. NETSIM has the ability to let the users define their own distributions by overwriting the default distributions. Some such parameters include turn calibration data, acceptable gap in near side and far side, amber phase response data, left turn gap, free flow percentages, queue discharge headway distributions, etc. All these features are not available with NETFLO models. A few parameters such as bus dwell time distribution can be modified when using NETFLO models. Then

TABLE 2.1 : Major Features of TRAF models : NETSIM, NETFLO1 and NETFLO2.

CHARACTERISTIC	NETSIM	NETFLO1	NETFLO2
Fleet Components	Buses, Carpools, Cars, Trucks	Buses, Carpools, Cars, Trucks	Buses, Cars, Trucks
Load Factors (# of Passengers/vehicle)	√	√	√
Turn Movement	√	√	√
Bus Operations			
Paths	√	√	√
Flow Volumes	√	√	√
Stations, routes & dwell times	√	√	√
Trucks	√	√	√
Carpools	√	√	NO
HOV Lanes (Buses, Carpools, or both)	√	√	Buses Only
Queue Discharge Distribution	√	√	N/A
Detailed Approach Geometry	√	√	√
Stop & Yield Signs	√	√	√
Pretimed Signal Control	√	√	√
Single Ring Actuated Control	√	√	NO
Dual Ring Actuated Control	√	NO	NO
Number of lanes per approach	7	6	6
Incidents and Temporary Events	√	Blockage Factor	Blockage Factor

there are some capabilities of NETSIM such as simulating long term and short term events and parking activities, providing conditional turn movements at intersections and using user specified vehicle type specifications that cannot be modeled using the NETFLO models.

NETSIM is capable of providing more detailed outputs than the two NETFLO models. NETSIM outputs include details about queue lengths and phase failures for each link in the network whereas the NETFLO models are not capable of providing these statistics. However, the important features that describe the characteristics of traffic as expressed in terms of measures of effectiveness (MOE) that are available as outputs from all the three models include average vehicle speed, vehicle stops, average delays (stopped as well as total), vehicle-hours of travel, and vehicle-miles of travel.

Studies involving NETSIM

Applications of NETSIM have been numerous and diverse, ranging from the simulation of very complex conditions [Rathi & Lieberman, 1989](6) to that of simple strategies at single intersections [Davis & Ryan, 1981](7). Venigalla(8) used NETSIM for the comparison of the operational effects of two-way-left-turn lanes with the raised median. Then there have been studies involving the evaluation of NETSIM itself. Wong [1990](9) compared field observations to the capacity and level of service estimates from Highway Capacity Software (HCS) and NETSIM. NETSIM's estimates of stopped delay and delays in the presence of heavy pedestrian flows and lane blockage were found to be more realistic. Davis and Ryan

[1981][7] used NETSIM to estimate delay and queue length at an isolated intersection and compared the results to those of HCS as well as to field observations. NETSIM results were found to agree with field observations, and to predict higher delays than HCS at near capacity conditions. Nemeth and Mekemson [10] compared the results of NETSIM with SOAP for pretimed and actuated signal control at a single intersection. They found fairly uniform differences between the excess fuel consumption estimates from SOAP and the total fuel consumption estimates from NETSIM. The delay predictions of SOAP and NETSIM were found to be fully compatible, but only after taking into account the differences in delay definitions, SOAP's more conservative left-turn saturation-flow-rate relationships, and NETSIM's delay sensitivity to unit extensions for actuated signal controllers.

In most of these studies, the issue of variability of NETSIM outputs came up but for the most part the users did not address it. Most of them used replication method (multiple runs) to reduce variability. There have been a number of other studies which dealt solely with the problem of variability in NETSIM's output due to its stochastic nature and several variance reduction techniques were applied to TRAF-NETSIM to assess their effectiveness. Several methods for handling the output from stochastic models as NETSIM, were provided in the Statistical Guideline for Simulation Experiments[11].

Recent acceptance and wide-spread use of NETSIM, along with the improved features of the program gave rise to new efforts aimed at reducing and/or dealing with such variability. Chang & Kanaan [1991](12) applied NETSIM to a congested isolated intersection and used the results to provide an assessment of the variability of the output. They also evaluated the replication and batch means statistical approaches to parameter estimation and concluded that the replication approach provides more precise estimates of confidence intervals, although it involves more computational costs. Rathi & Santiago [1990](13) suggested the use of common random number seed for the different runs to reduce such variability. This method was found to be very effective. The reduction in variability is achieved through the positive correlation created between the same parameters in different runs. Rathi & Venigalla [1992](14) applied another variance reduction technique called the antithetic variates and compared its effectiveness with common random numbers strategy. With antithetic variates, variance is reduced by creating a negative correlation between the estimates of the same parameters in paired replications. In applications of the variance reduction techniques to NETSIM it was assumed that the desired correlations are attainable with the way NETSIM generates random variables.

It was found that the replication method or the multiple run method is the most widely used variance reduction tool applied in the analysis of outputs from traffic simulation models. But none of these studies provided any guidelines for the length of each simulation run. Most commonly, these runs were 10 to 15 minutes long. It should be noted that longer the simulation run, smaller is the variation in the output statistics to be expected in stochastic models.

CHAPTER 3

STUDY DESIGN

Sample urban street networks were created with varying traffic flow conditions and roadway geometry. Traffic operation through urban streets is itself a very complex phenomenon, and numerous combinations of various factors that affect the traffic flow are feasible. A wide range of traffic characteristic parameters can be represented in the three simulation models under study. The inputs to these models are extensive, and it is possible to study the effects of various combinations of these parameters. However, for this study, it was not possible to evaluate all possible variations of these parameters due to constraints of resources. Hence it was assumed appropriate to hold some input variables at constant levels, while changing some of the vital parameters of interest. Identical conditions were simulated by the three models. In this chapter, the input values of parameters used in the study and the strategy for statistical analysis are discussed.

Representing the Traffic Environment

The traffic environment must be specified by the user to exercise the TRAF models. The basic traffic environment was same for all the three models. TRAF uses the concept of links and nodes. Nodes are (usually) the intersection of streets for surface street networks. Links are one directional segments of streets. Typically the traffic environment representation for TRAF models needs the following input data :

- Topology of the roadway system (in the form of link-node diagram).
- Geometry of each roadway component (link lengths, number of lanes, turn pockets, grades etc.).
- Channelization of traffic (left, through, right).
- Traffic control devices (stop, yield, signal phasing and timing etc.).
- Traffic volumes entering the roadway system.
- Turning movement data.
- Operational characteristics (free flow speed, mean queue discharge headway etc.).

Simulated Scenarios

An infinite range of travel environments are possible in terms of geometric design, capacity, traffic volumes, traffic control devices, and other factors that affect travel characteristics. In order to create different traffic scenarios that are typically found in urban street networks, a combination of the roadway parameters, as discussed below, were used for this study.

Network type

Since urban street networks typically include signalized intersections, stand alone as well as in a combination designed for traffic progression, the following two types of networks were considered :

1. A Single Intersection with four legs.
2. An Arterial Street with five intersections.

A layout of these two network configurations are shown in Figures 3.1 and 3.2 respectively.

Geometry type

Typically left-turning vehicles make traffic operation more complex and they require special treatments. They are provided a separate turning pocket, if possible, at places where the left-turning volumes are high, and they generally share the lane with through traffic at other places. So the following two types of lane geometry were included in the study :

1. Simple, without left turn pockets.
2. Complex, with left turn pockets.

A typical layout of these two types of geometric configurations are shown in Figures 3.3 and 3.4 respectively.

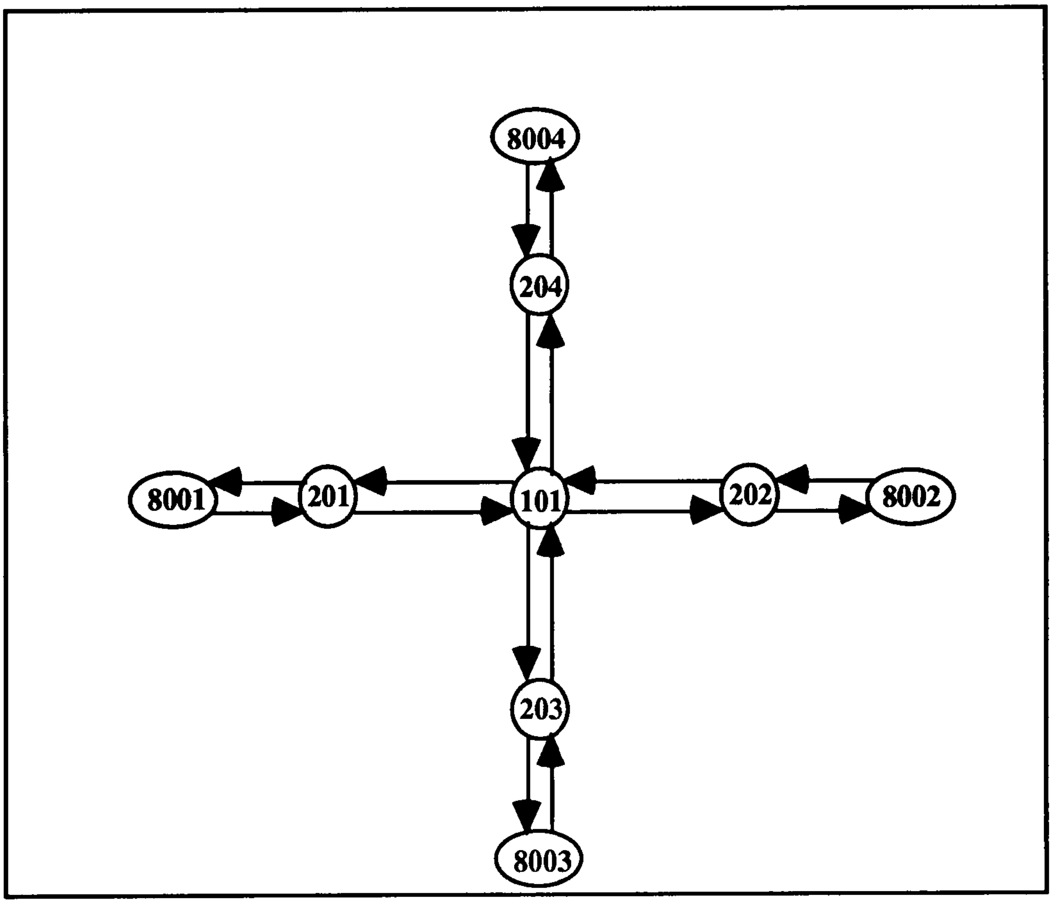

FIGURE 3.1 : Single Intersection Case : Link-Node Diagram'

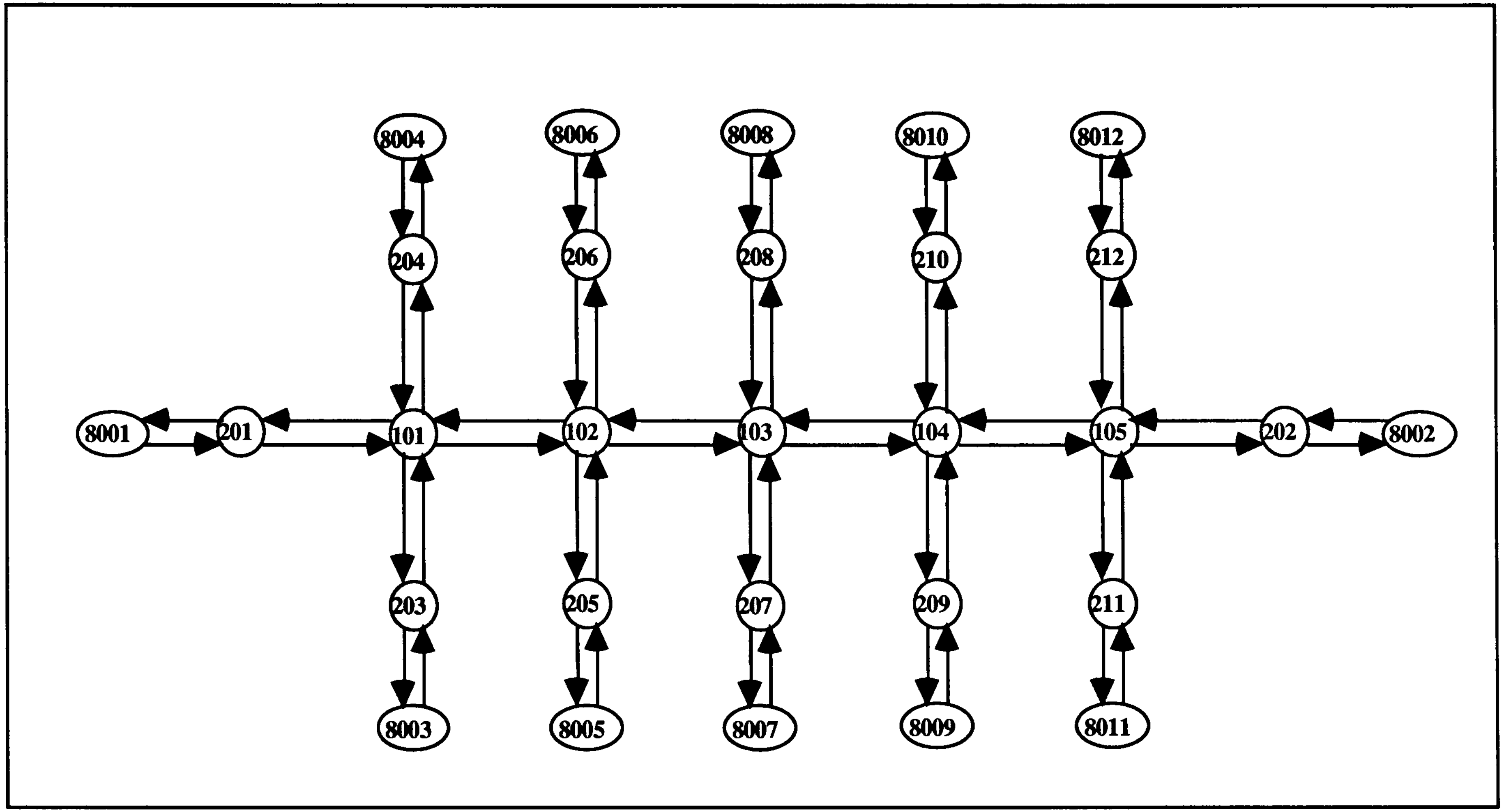

FIGURE 3.2 : Arterial Section Case : Link-Node Diagram.

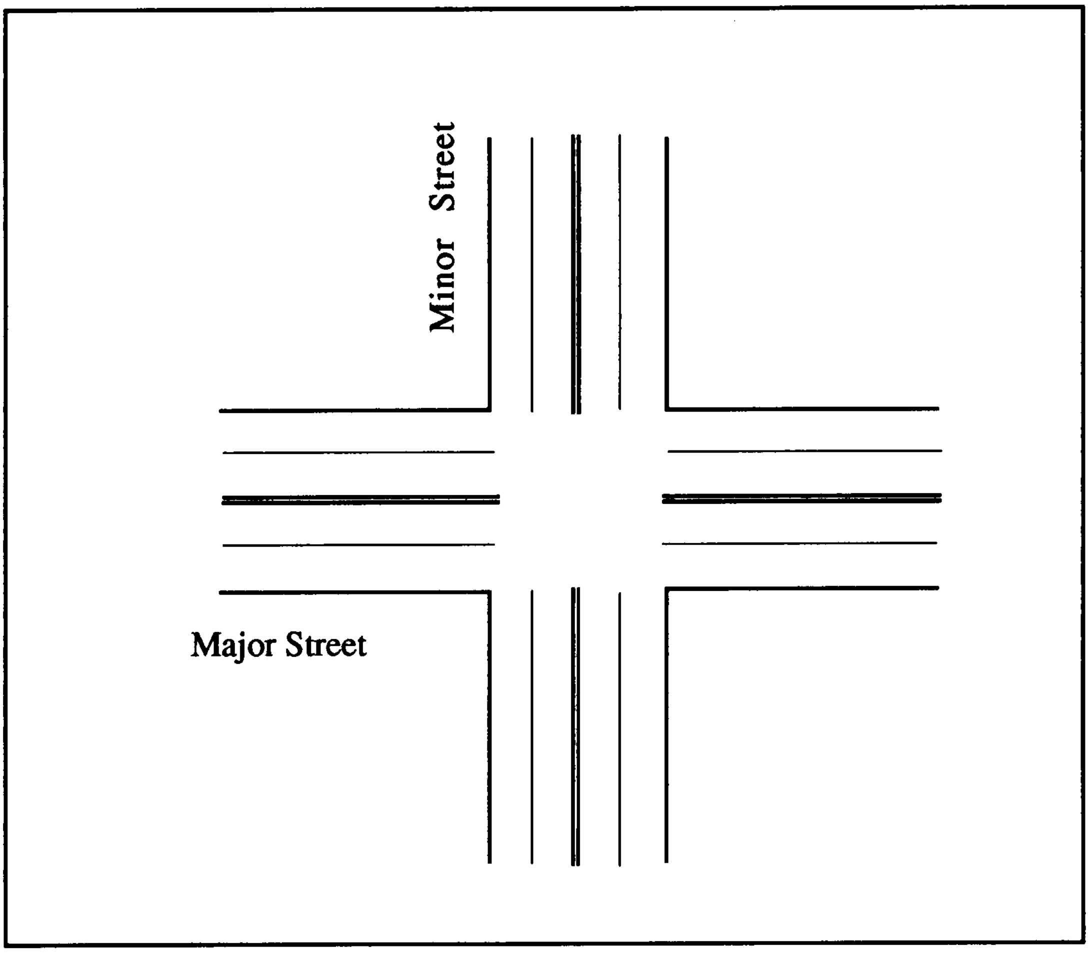

FIGURE 3.3 : Simple Geometry Case : Intersection Details.

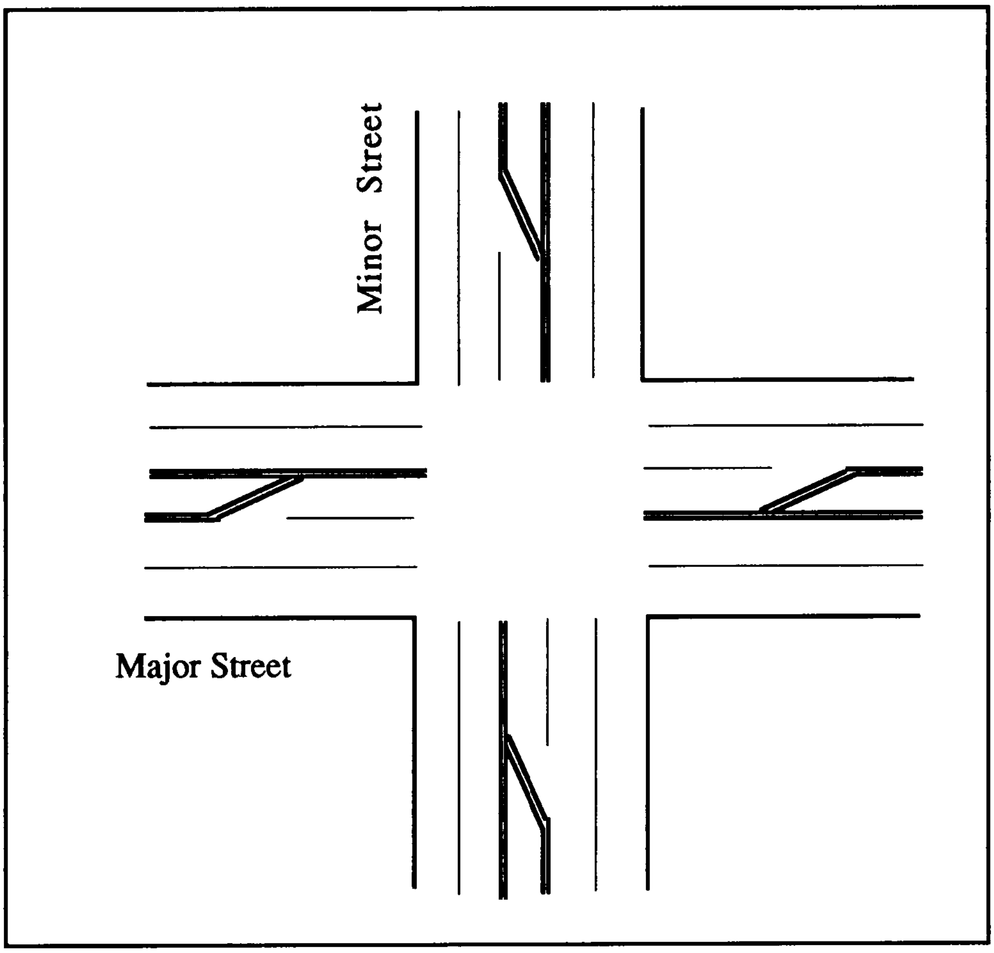

FIGURE 3.4 : Complex Geometry Case : Intersection Details.

With the combination of these parameters four different scenarios were created. Each of these scenarios then was loaded with varying levels of traffic volumes and simulated by the three models - NETSIM, NETFLO1, and NETFLO2, respectively. The values for other input parameters used to describe these networks are discussed in the following section.

Input Values of Parameters

Length of Links

The length of links is an essential input to all the models under study. For the single intersection scenarios, the length of entry links for each approach was chosen long enough so that the intersection can be treated as an isolated intersection. A length of 1500 ft. was deemed sufficient for this purpose. For the arterial scenarios, the length of each of the external links were selected as 1500 ft., while the length of each internal link was set at 700 ft. so that signal timings at these intersections can be designed for progression.

Number of lanes

Since most arterial roads in urban areas have a minimum of four lanes, a minimum of two lanes were provided on each link (where a link represents only one direction of travel) for simple as well as complex geometry cases of the single intersection and arterial scenarios. For the complex geometry scenario, an additional left turn pocket of 150 ft. length was provided at the intersections in addition to the two lanes which stretched across the full length of the link.

Traffic Volume Levels

Traffic volumes on urban streets usually fluctuate with the time of day, day of week, special events and various other factors. Travel characteristics such as speed and delay, on a particular roadway, are affected largely by traffic volumes and flow rates that exist at the time of travel, which represent different levels of congestion. Three levels of traffic flow rates at the entry links were considered for this study :

1. Low volume, 600 vph per approach of the major road.
2. Medium volume, 1000 vph per approach of the major road.
3. High volume, 1400 vph per approach of the major road.

Traffic volumes on the cross streets (for arterial) and the minor street (for single intersection) were assumed to be approximately two thirds of the traffic on the arterial road.

Turn Volumes

In the real world, there is a considerable variation in turning traffic volumes at intersections. Turning volumes depend on many factors such as land use, direction of flow, through volume etc. However, in this study, the turning volumes were assigned as percentages of total approach volume to represent commonly found traffic situations.

For the complex geometry cases, left turn percentages were assumed to be higher than for simple geometry cases and separate left turn lanes were provided to accommodate higher left turning volumes. Right turns, in general, do not create as much complications in traffic operations as left turns do. The right turns from the arterial road were not changed for different geometries.

For all the scenarios, the right turns made from the arterial road into the minor road at all intersections were kept constant at 10% of the total approach volume. For single intersection cases, the right turns from the minor roads were also chosen as 10% of the approach volume. However, for the arterial cases, the right turns from the cross roads were assumed to be 15%. No separate right turn lanes were provided for these vehicles.

For the single intersection scenario, for simple geometry case, the left turn percentage was assumed to be 10% of the approach volume from both, the major road and the minor road. While in the case of complex geometry scenario, the left turns from the major road were assumed to be 20% of the approach volume, with a separate left turn lane and a separate left turn signal for left turn movements, and for the minor road, the left turn percentage was set at 15% of the approach volume with a separate left turn lane.

For arterial scenario, for simple geometry case, the left turn percentage at each intersection was chosen as 5% of the approach volume from the arterial. While from all the cross streets, the left turns were assumed to be 10% of the approach volumes. For the complex geometry case, the left turns from the arterials were assumed to be 10% of the approach volume at each intersection with the provision of separate left-turn signal phase and a separate left-turn pocket. The left turns from the cross streets were set at 15% with a separate left turn pocket.

Other Input Data

The Progression Analysis and Signal System Evaluation Routine (PASSER II-87)[15] were used to determine signal timings that were used as the basis for the signal timing inputs. The PASSER II-87 runs also gave the Level of Service (LOS) in addition to signal progression times. It was observed that the LOS for low volume levels was A or B, for medium volumes it was C or D and for high volumes it was E or F. Hence, the volume levels chosen reflect different levels of congestion. The free flow speeds on all the links in all cases were assumed to be 30 mph. For the other parameters such as mean queue discharge headway and the start-up lost time for the first vehicle, default values of the simulation models were used. All the approaches were assumed to be level, that is the grade for all links was assumed to be zero.

Network Coding and Simulation Runs

Network coding for the TRAF models is a time consuming and laborious process. TRAFEDIT, the editor to create input files for TRAF models, was used to input the data for simulation runs. Also the beta version of INET program (which is a graphical input editor for creating traffic networks for TRAF-NETSIM) was used to create the basic traffic networks for traffic. However, the network files created using INET were opened using TRAFEDIT to ensure the correctness of input stream. TRAF models are designed to do extensive error checking before executing the simulation runs. Error messages generated by these models help the user to identify mistakes in coding of the input data. However, error-free simulation runs do not necessarily guarantee the correctness of the input data. In order to ensure accuracy of the data entry, first a single intersection and an arterial network were coded for the low volume - simple geometry case for the NETSIM model. Diagnostic runs were made for checking and correcting coding errors. Then the input files were thoroughly checked for any data entry mistakes. Each of these networks were used as "basic" networks and were simply modified by changing only the parameters required to represent the different scenarios.

Pilot or Test Runs

Initially some test or "pilot" runs were made with NETSIM model for a sample network with varying volume levels, in order to estimate the simulation run time and the number of replications required to obtain stable statistics, i.e., statistics with small variability. Four independent runs with different random number seeds were made. Each run was 15 minutes long. Then a long run for 2 hours was made. Assuming that the statistics from the long run were true estimates of the output parameters, it was found that the average speed and delay values were within the 95% confidence interval predicted by the multiple runs. This was true for all the volume levels tested. This indicated that four runs, with 15 minutes run time, were enough to obtain reliable statistics. Anyway, to allow for any undetected variations, it was decided to make 5 runs for each scenario, each being a 30 minute run. This assured a better estimate, i.e., with very small variations, of the selected MOE's.

To generate one complete set of observations for a particular scenario, nine (9) simulation runs were made, using the models being studied at three different volume levels. To generate multiple replications, the random number seeds, which control the sequence of random numbers generated by the models, were changed in the run control cards of these input files. Since it was decided to make five replications of each set to perform analysis of variance, therefore five different sets of random number seeds, generated randomly, were used. For a particular set of observation, the random number seed was kept same for all the models .

Factorial Experiment

It was decided to perform the statistical analysis on each scenario separately, where a scenario being a unique combination of the network type and geometry type. This study involves the comparison of selected Measures of Effectiveness (MOE) generated by the three models for different scenarios. Model type is hence one of the independent variables or a "factor". Here the type of model is essentially a categorical variable. The other independent variable that was used for analyzing the selected MOE was the traffic volume level, which again, was a categorical variable (low, medium and high being the three levels). Hence it was decided to use a factorial analysis for this study. From the format of the variables, category model seems to be almost natural candidates for factorial analysis. Category models are developed with a cross-classification analysis that creates a multidimensional matrix, each dimension representing an independent variable[16]. The independent variables themselves are stratified into several levels. The values are allocated to the appropriate cells of the matrix, and the average response for each defined category is determined. Before the discussion of setup of the factorial analysis for this study, it is appropriate to mention some of the important definitions associated with the factorial experiments.

Definitions

A Factorial Experiment is an experiment on which the response variable Y is observed at all factor-level combinations of the independent variables[17]. These experiments are useful for examining the effects of two or more factors (or independent variables) on the response variable, either individually or interactively.

A factor is an independent variable characterized by different levels at which measurements are obtained. A response variable is the dependent variable on which the effect of different factors is being measured.

The term main effect refers to the influence of a factor on the response variable(s) individually. The main effect of a factor is said to be significant if that factor by itself has a significant influence on the response variable. Two factors are said to interact if the difference in the mean response for any two levels of one factor is not constant across the different levels of the second factor.

The Experiment

Simulation experiments with multiple replications of identical traffic streams were performed to obtain the response variables. The two factors (categorical variables) for this experiment, each with three levels are :

Factor 1 : Model Type (NETSIM, NETFLO1 and NETFLO2), and
Factor 2 : Traffic Volume (Low, Medium and High).

The experimental design is shown in Figure 3.5. The selection of response variables is discussed in next chapter. It may be noted that the experimental design created 9 cells of a matrix, each cell representing a unique combination of the two factor levels. Each cell would have five observations for every response variable obtained from five replications of simulation runs.

Traffic Volume Level	Simulation Model Type NETSIM	NETFLO1	NETFLO2
LOW	y_i	y_i	y_i
MEDIUM	y_i	y_i	y_i
HIGH	y_i	y_i	y_i

Note : y_i refers to the i^{th} measured value of the response variable at a given factor level, where $i = 1$ to n (n = sample size)

FIGURE 3.5 : Factorial Experiment Design.

CHAPTER 4

ANALYSIS APPROACH

The differences in the performance of the simulation models as measured by selected response variables were analyzed using the Analysis of Variance (ANOVA) technique. The Statistical Analysis System (SAS) installed on the VAX cluster at the University of Tennessee was used to perform ANOVA for this study. This chapter presents a discussion on the approach used for the statistical analysis of the outputs obtained from the three simulation models for various scenarios.

Selection of Response Variables

The outputs from the three models are extensive. These include various parameters that depict the quality of traffic, such as vehicle-miles traveled, stop time, delay and speed for every link and the entire network. These parameters are available for each link in the network as well as the aggregate values for the entire network. Most of these variables are interrelated, and hence it may not be appropriate to use all these variables for analysis.

Two important MOE's that characterize the quality of traffic operations are average speed and delay. Network-wide average speed and network-wide average delay were chosen as response variables for this analysis.

Analysis Focus

The values of networkwide (including all the links in the study network) delay and speed were extracted from the outputs of the simulation runs for each replication of each scenario. For each scenario, the mean values of five replications for average speed and delay respectively were plotted against the volume levels to visualize if any obvious trends existed. Then each of the response variables was subject to statistical tests as explained below.

Design of Factorial Analysis

The analysis will be performed separately for the four different scenarios. These are :

1. Single Intersection with Simple Geometry.
2. Single Intersection with Complex Geometry.
3. Arterial section with Simple Geometry.
4. Arterial section with Complex Geometry.

As discussed earlier in Chapter 3, it was decided to use factorial experiment for the analysis of this study. Here it would be a two factor factorial experiment as two factors (categorical variables) will be involved. The two factors of the experiment are :

Factor 1 : Model type (three levels : 1=NETSIM, 2=NETFLO1 and 3=NETFLO2)

Factor 2 : Traffic Volume (three levels : 1=Low, 2=Medium and 3=High)

The experimental design was discussed in chapter 3. The response variables are networkwide speed and delay to all vehicles. It may be noted that the experimental design created 9 cells of a matrix, each cell representing a unique combination of different levels of the two factors. As mentioned earlier, each cell will have five observations from five replications of the simulation runs.

Analysis of Variance and Test of Significance

The purpose of this analysis was to verify whether or not the simulation model type affects the response variables under different levels of volumes. To study the effect of traffic volume alone on these response variables is not the purpose of this study; so it will not be emphasized. The General Linear Model procedure (PROC GLM) of SAS was used to perform the desired analysis of variance. All hypotheses were tested at 95% confidence level. The null hypotheses (H_0) and alternate hypotheses (H_1) that were tested for the effects of model, volume and their interaction are listed below :

1. H_0 : Model type has no significant effect on the response variable.
   H_1 : Model type does have significant effect on the response variable.

2. H_0 : Volume level has no significant effect on the response variable.
   H_1 : Volume level does affect the response variable significantly.

3. H_0 : There is no significant interaction between model type and volume level.

H_1 : There is a significant interaction between the two factors.

Also, to see if the three models differ significantly from each other on an overall basis, Contrasts were written in the ANOVA model to test the following three hypotheses :

1. H_0 : Model 1 (NETSIM) does not differ from Model 2 (NETFLO1) significantly.
   H_1 : There is a significant difference between the two models.

2. H_0 : Model 2 (NETFLO1) does not differ from Model 3 (NETFLO2) significantly.
   H_1 : There is a significant difference between the two models.

3. H_0 : Model 1 (NETSIM) does not differ from Model 3 (NETFLO2) significantly.
   H_1 : There is a significant difference between the two models.

To see the results of these contrasts more clearly, pairwise t-tests were performed, which group together the variables (here, model type) that do not differ significantly from each other and hence differentiates them from others. Acceptance or rejection of the null hypotheses was based on the p-values from the statistical tables obtained from SAS analysis.

Cell Address Approach for Contrasts

In the ANOVA, the three models can be contrasted to see if the three models differ significantly from each other on an overall basis. Tests of significance for the differences in the performance of the three simulation models at different levels of traffic volumes which will indicate the specific levels at which the models are significantly different from each other was not possible with the analysis approach used earlier. This was done through contrast analysis using "cell address" model. In this approach, every individual combination of factor levels at which observations are recorded are assigned a unique identification called "cell address" as shown in Figure 4.1. Each digit shown in the figure is the cell address for that combination of the factor levels. For example, cell address 22 refers to the observed response variable for NETFLO1 model at medium level of traffic volume. Using these cell addresses, the differences in the performance of the three models were contrasted for each of the three levels of traffic volumes.

Traffic Volume Level	Simulation Model Type (1) NETSIM	(2) NETFLO1	(3) NETFLO2
(1) LOW	11	21	31
(2) MEDIUM	12	22	32
(3) HIGH	13	23	33

FIGURE 4.1 Cell Address for Contrast Analysis.

Hypotheses Testing for Cell Address Analysis

For each scenario, these tests were performed separately for the two response variables, networkwide average speed and delay.

For each volume level, each model was contrasted against each of the other two models. A set of null hypotheses (H_0) and alternate hypotheses (H_1) that were tested to determine if there were significant differences in the response variables from the three models at low volume levels are shown below :

1. H_0 : For low volume level, Model 1 (NETSIM) and Model 2 (NETFLO1) produce response variables that are not significantly different.
   H_1 : The two models do produce significantly different response variables, for low traffic volume level.

2. H_0 : For low volume level, Model 2(NETFLO1) and Model 3(NETFLO2) produce response variables that are not significantly different.
   H_1 : The two models do produce significantly different response variables, for low traffic volume level.

3. H_0 : For low volume level, Model 3 (NETFLO2) and Model 1 (NETSIM) produce response variables that are not significantly different.
   H_1 : The two models do produce significantly different response variables, for low traffic volume level.

Similar sets of hypotheses were tested for Medium and High levels of traffic volumes. Hence, in all, nine sets of contrasts were tested for this analysis. If significant difference was found between any two models, then more contrasts were tested to see if this difference was significantly different from the difference between each of these models and the third model.

CHAPTER 5

RESULTS OF ANALYSIS-I: SINGLE INTERSECTION

The statistical analysis was performed on the outputs obtained from the three simulation models as explained in the earlier chapters. The results of these analyses are being presented in two parts. Results of the analysis for the single intersection scenarios for both, the simple geometry and the complex geometry cases are presented in this chapter while the results for the arterial section will be discussed in the next chapter.

Single Intersection with Simple Geometry

Networkwide Average Speed

For the single intersection scenario without left-turn lanes, the average networkwide speed for different volume levels, as observed by the three models in five replications are shown in TABLE 5.1. The mean values of five replicated observations and their standard deviations are shown in TABLE 5.2. These mean values were plotted against the three traffic volume levels and are shown in FIGURE 5.1. It can be seen from this plot that, for all the three models, the average speed decreases consistently with the increase in volume. But it should be noted that for NETSIM, the drop in speed from

TABLE 5.1 : Networkwide Average Speed (mph) for a Single Intersection with Simple Geometry.

VOLUME	REPLICATION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	22.5	23.7	24.4
	2	22.3	23.6	24.4
	3	22.4	23.5	24.4
	4	22.4	23.7	24.4
	5	22.4	23.4	24.4
MEDIUM	1	21.0	22.3	23.7
	2	20.9	22.2	23.7
	3	21.0	22.3	23.7
	4	21.2	22.3	23.7
	5	20.9	22.2	23.7
HIGH	1	18.2	20.5	21.9
	2	18.1	20.4	21.9
	3	17.7	20.4	21.9
	4	18.4	20.7	21.9
	5	18.3	20.5	21.9

TABLE 5.2 : Mean Networkwide Average Speed (mph) for a Single Intersection with Simple Geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	22.40 (0.07)*	23.58 (0.13)	24.40 (0.00)
MEDIUM	21.00 (0.12)	22.26 (0.05)	23.70 (0.00)
HIGH	18.14 (0.27)	20.50 (0.12)	21.90 (0.00)

* Values in parentheses are Standard Deviations.

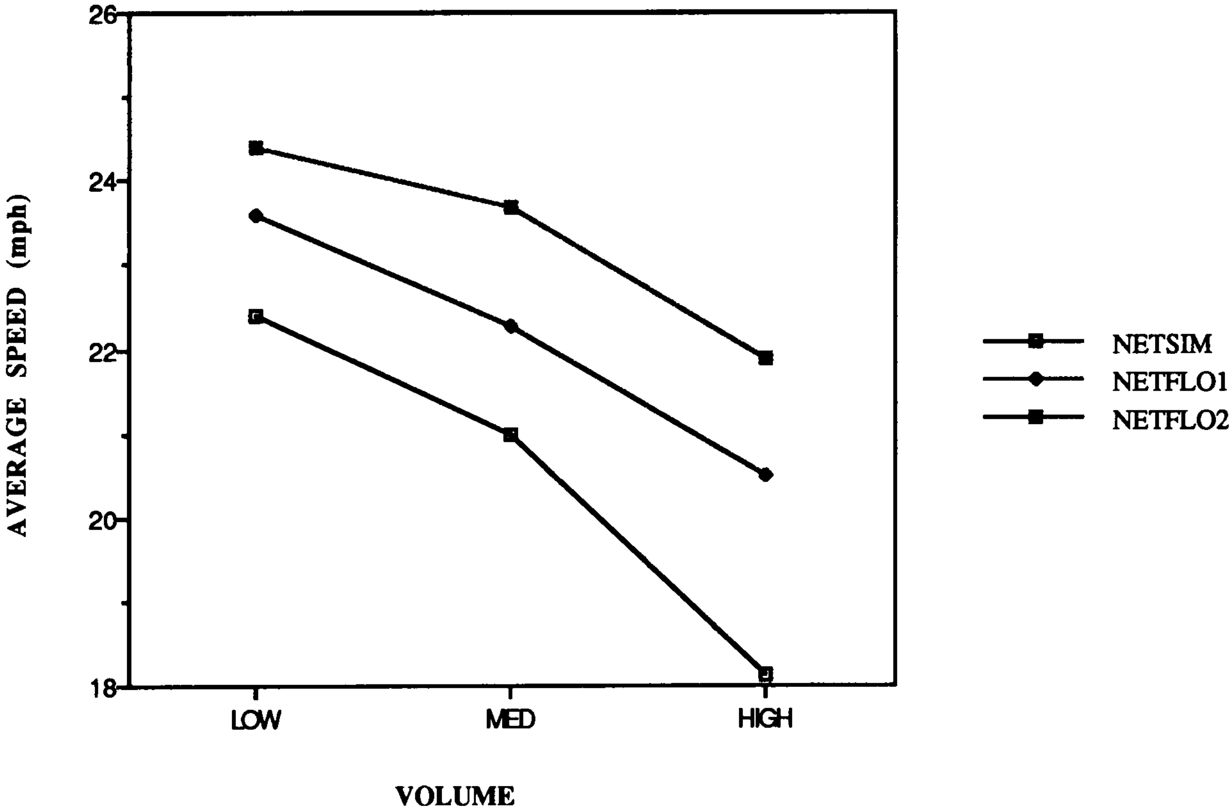

FIGURE 5.1 : Variation of Networkwide Average Speed with Volume for a Single Intersection with Simple Geometry.

medium volume to high volume is sharper than the other two models. However, the important point to be noted from FIGURE 5.2 is that NETFLO2 consistently gives higher average speeds than NETFLO1 and NETSIM, while NETFLO1 speeds are consistently higher than those estimated by NETSIM. For low and high volumes, the NETFLO1 values appear to differ from NETSIM values more than they differ from NETFLO2 values. The difference however is evidently larger at high volume as compared to the low volume. Whereas, for medium volume the NETFLO1 values are closer to NETSIM values.

The ANOVA output from SAS is shown in FIGURE 5.2. The analysis clearly shows that p-values are too small to support the null hypotheses for all the terms in the model. It means that the Model type, Volume level and the interaction between Model and Volume all have significant effects on the networkwide average speed. Also the contrast analysis shows that each of the three models are significantly different from each other as far as estimating the average speed is concerned. This is very clearly understood from the pairwise t-test result. It puts Model 1 (NETSIM), Model 2 (NETFLO1) and Model 3 (NETFLO2) in different groups that are significantly different from each other. This test is redundant here as it gives the same message as that given by the contrast analysis, but is included here only for this scenario to show how significantly different Models are grouped.

The cell address analysis is shown in FIGURE 5.3. It can be seen that the p-values for all the contrasts are too small to accept the null hypotheses stated in the previous section. It means that, at each of

SINGLE INTERSECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	147.66000	18.45750	1297.79	0.0001
Error	36	0.51200	0.01422		
Corrected Total	44	148.17200			

R-Square	C.V.	Root MSE	SPEED Mean
0.996545	0.542406	0.1193	21.987

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	60.004000	30.002000	2109.52	0.0001
VOLUME	2	83.188000	41.594000	2924.58	0.0001
MODEL*VOLUME	4	4.468000	1.117000	78.54	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	60.004000	30.002000	2109.52	0.0001
VOLUME	2	83.188000	41.594000	2924.58	0.0001
MODEL*VOLUME	4	4.468000	1.117000	78.54	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	19.200000	19.200000	1350.00	0.0001
2vs3	1	11.163000	11.163000	784.90	0.0001
3vs1	1	59.643000	59.643000	4193.65	0.0001

FIGURE 5.2 : ANOVA Table for Networkwide Speed for Single Intersection- Simple Geometry.

SINGLE INTERSECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

T tests (LSD) for variable: SPEED

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 36 MSE= 0.014222
Critical Value of T= 2.03
Least Significant Difference= 0.0883

Means with the same letter are not significantly different.

T Grouping	Mean	N	MODEL
A	23.33333	15	3
B	22.11333	15	2
C	20.51333	15	1

FIGURE 5.2 (contd.) : ANOVA Table for Networkwide Speed for Single Intersection- Simple Geometry.

SINGLE INTERSECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	147.66000	18.45750	1297.79	0.0001
Error	36	0.51200	0.01422		
Corrected Total	44	148.17200			

R-Square	C.V.	Root MSE	SPEED Mean
0.996545	0.542406	0.1193	21.987

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	147.66000	18.45750	1297.79	0.0001

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	147.66000	18.45750	1297.79	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	3.481000	3.481000	244.76	0.0001
LOW 2vs3	1	1.681000	1.681000	118.20	0.0001
LOW 3vs1	1	10.000000	10.000000	703.13	0.0001
MED 1vs2	1	3.969000	3.969000	279.07	0.0001
MED 2vs3	1	5.184000	5.184000	364.50	0.0001
MED 1vs3	1	18.225000	18.225000	1281.45	0.0001
HIGH 1vs2	1	13.924000	13.924000	979.03	0.0001
HIGH 2vs3	1	4.900000	4.900000	344.53	0.0001
HIGH 1vs3	1	35.344000	35.344000	2485.13	0.0001
LOW 1v2 Vs 2v3	1	0.108000	0.108000	7.59	0.0091
MED 1v2 Vs 2v3	1	0.027000	0.027000	1.90	0.1768
HIGH 1v2 Vs 2v3	1	0.768000	0.768000	54.00	0.0001

FIGURE 5.3 : Single Intersection - Simple Geometry : Contrast Analysis for Networkwide Speed using Cell Address Model.

the three volume levels, each model is significantly different from the other two models, meaning that the three models generate significantly different speed statistics when simulating identical conditions. To further investigate if these differences follow any pattern, difference between NETSIM and NETFLO1 was contrasted against the difference between NETFLO1 and NETFLO2 for each volume level. It was found that these differences were significantly different for low volume and high volume levels. For both cases, the difference between NETSIM and NETFLO1 values is greater than that between NETFLO1 and NETFLO2. But for medium volume level, it was found that the difference between NETSIM and NETFLO1 is not significantly different from that between NETFLO1 and NETFLO2 models. Hence, there does not seem to be any pattern in which these differences vary with volume level.

Networkwide Average Delay

For the single intersection scenario without left-turn lanes, the average networkwide delay for different volume levels, as estimated by the three models in five replications are shown in TABLE 5.3. TABLE 5.4 shows the mean values of five observations and their standard deviations. These mean values were plotted against the three traffic volume levels and are shown in FIGURE 5.4. The ANOVA output from SAS is shown in FIGURE 5.5. The cell address analysis is shown in FIGURE 5.6.

Results of this analysis were in full agreement with those obtained for average speed. It was found that the three models were

TABLE 5.3 : Networkwide Average Delay (min./veh-trip) for a Single Intersection with Simple Geometry.

VOLUME	REPLICATION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	0.38	0.30	0.26
	2	0.39	0.31	0.26
	3	0.39	0.31	0.26
	4	0.38	0.30	0.26
	5	0.39	0.32	0.26
MEDIUM	1	0.49	0.39	0.30
	2	0.49	0.40	0.30
	3	0.48	0.39	0.30
	4	0.47	0.39	0.30
	5	0.49	0.40	0.30
HIGH	1	0.73	0.52	0.42
	2	0.74	0.54	0.42
	3	0.80	0.53	0.42
	4	0.71	0.51	0.42
	5	0.73	0.53	0.42

TABLE 5.4 : Mean Networkwide Average Delay (min./veh-trip) for a Single Intersection With Simple Geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	0.386 (0.005)*	0.308 (0.008)	0.260 (0.00)
MEDIUM	0.484 (.009)	0.394 (0.005)	0.300 (0.00)
HIGH	0.742 (0.034)	0.526 (0.011)	0.420 (0.00)

* Values in parentheses are Standard Deviations.

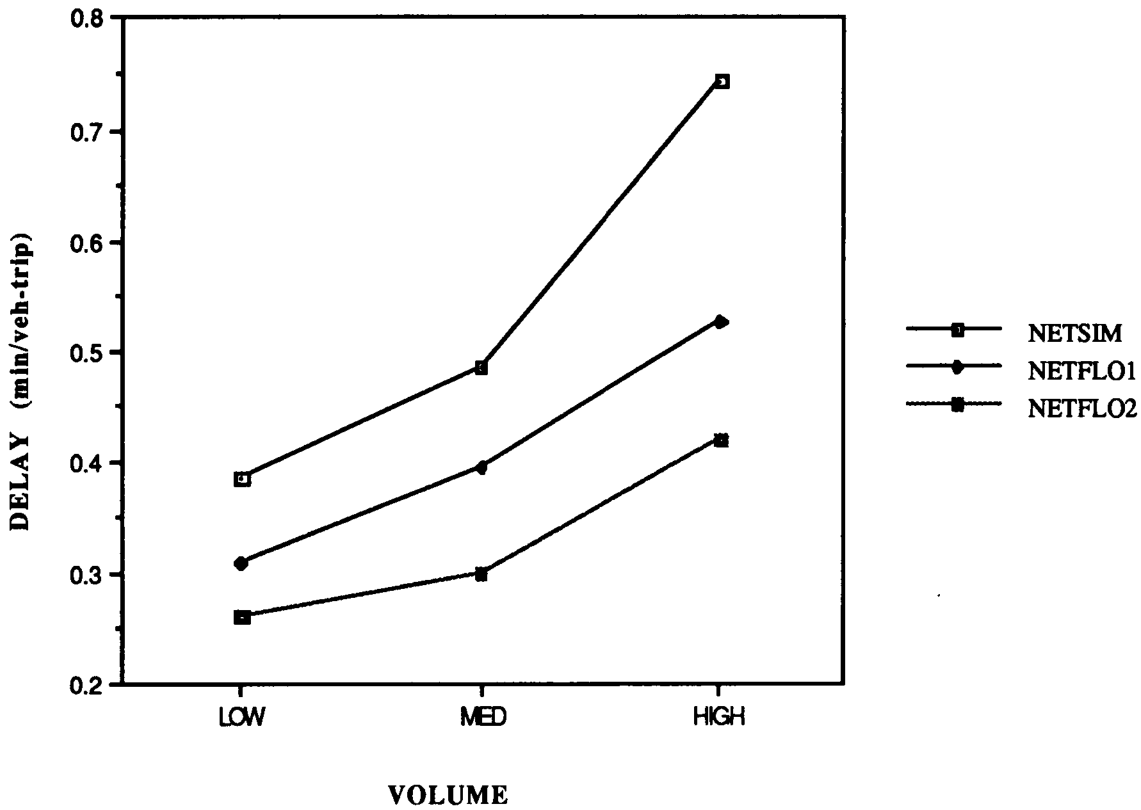

FIGURE 5.4 : Variation of Networkwide Average Delay with Volume for a Single Intersection with Simple Geometry.

SINGLE INTERSECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.8660711	0.1082589	645.25	0.0001
Error	36	0.0060400	0.0001678		
Corrected Total	44	0.8721111			

R-Square	C.V.	Root MSE	DELAY Mean
0.993074	3.051732	0.0130	0.4244

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	0.3379911	0.1689956	1007.26	0.0001
VOLUME	2	0.4716844	0.2358422	1405.68	0.0001
MODEL*VOLUME	4	0.0563956	0.0140989	84.03	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	0.3379911	0.1689956	1007.26	0.0001
VOLUME	2	0.4716844	0.2358422	1405.68	0.0001
MODEL*VOLUME	4	0.0563956	0.0140989	84.03	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	0.1228800	0.1228800	732.40	0.0001
2vs3	1	0.0512533	0.0512533	305.48	0.0001
3vs1	1	0.3328533	0.3328533	1983.89	0.0001

FIGURE 5.5 : ANOVA Table for Networkwide Speed for a Single Intersection- Complex Geometry.

SINGLE INTERSECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.8660711	0.1082589	645.25	0.0001
Error	36	0.0060400	0.0001678		
Corrected Total	44	0.8721111			

R-Square	C.V.	Root MSE	DELAY Mean
0.993074	3.051732	0.0130	0.4244

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	0.8660711	0.1082589	645.25	0.0001

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	0.8660711	0.1082589	645.25	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	0.0152100	0.0152100	90.66	0.0001
LOW 2vs3	1	0.0057600	0.0057600	34.33	0.0001
LOW 3vs1	1	0.0396900	0.0396900	236.56	0.0001
MED 1vs2	1	0.0202500	0.0202500	120.70	0.0001
MED 2vs3	1	0.0220900	0.0220900	131.66	0.0001
MED 1vs3	1	0.0846400	0.0846400	504.48	0.0001
HIGH 1vs2	1	0.1166400	0.1166400	695.21	0.0001
HIGH 2vs3	1	0.0280900	0.0280900	167.42	0.0001
HIGH 1vs3	1	0.2592100	0.2592100	1544.96	0.0001
LOW 1v2 Vs 2v3	1	0.0007500	0.0007500	4.47	0.0415
MED 1v2 Vs 2v3	1	0.0000133	0.0000133	0.08	0.7796
HIGH 1v2 Vs 2v3	1	0.0100833	0.0100833	60.10	0.0001

FIGURE 5.6 : Single Intersection - Simple Geometry : Contrast Analysis for Networkwide Delay using Cell Address Model.

significantly different from each other. NETSIM consistently gave highest delay values while NETFLO2 gave lowest values. Also, for the medium volume level, the difference between NETSIM and NETFLO1 was not significantly different from that between NETFLO1 and NETFLO2 values.

An interesting observation to be noted here is that for both speed and delay observations, there is absolutely no variation in the outputs from NETFLO2 model. This suggests that the NETFLO2 outputs were not affected by the random number seed.

Single Intersection with Complex Geometry

Networkwide Average Speed

For the single intersection scenario with left-turn lanes, the average networkwide speed for different volume levels, as observed by the three models in five replications are shown in TABLE 5.5. TABLE 5.6 shows the mean values of five replicated observations and their standard deviations. A plot of these mean values against volume levels is shown in FIGURE 5.7. It can be seen that the average speed decreases consistently with the increase in volume for all the three models. But the drop in speed from medium volume to high volume appears to be sharper than the drop from low to medium volume for NETSIM and NETFLO2 models. While this difference in drop in speed does not appear to be very significant for NETFLO1. However, the important point to be noted from FIGURE 5.7 is that NETFLO2 consistently gives higher average speeds than NETFLO1 and

TABLE 5.5 : Networkwide Average Speed (mph) for a Single Intersection with Complex Geometry.

VOLUME	REPLICATION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	21.7	23.0	23.5
	2	21.6	22.7	23.5
	3	21.6	22.6	23.5
	4	21.6	22.9	23.5
	5	21.6	22.7	23.5
MEDIUM	1	20.3	21.6	23.1
	2	20.3	21.3	23.1
	3	20.3	21.5	23.1
	4	20.5	21.6	23.1
	5	20.3	21.4	23.1
HIGH	1	17.2	19.4	21.6
	2	17.7	19.5	21.6
	3	17.8	19.8	21.6
	4	17.7	19.7	21.6
	5	17.2	19.8	21.6

TABLE 5.6 : Mean Networkwide Average Speed (mph) for a Single Intersection with Complex Geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	21.62 (0.045)*	22.78 (0.164)	23.5 (0.00)
MEDIUM	20.34 (0.089)	21.48 (0.130)	23.1 (0.00)
HIGH	17.52 (0.295)	19.64 (0.182)	21.6 (0.00)

* Values in parentheses are Standard Deviations.

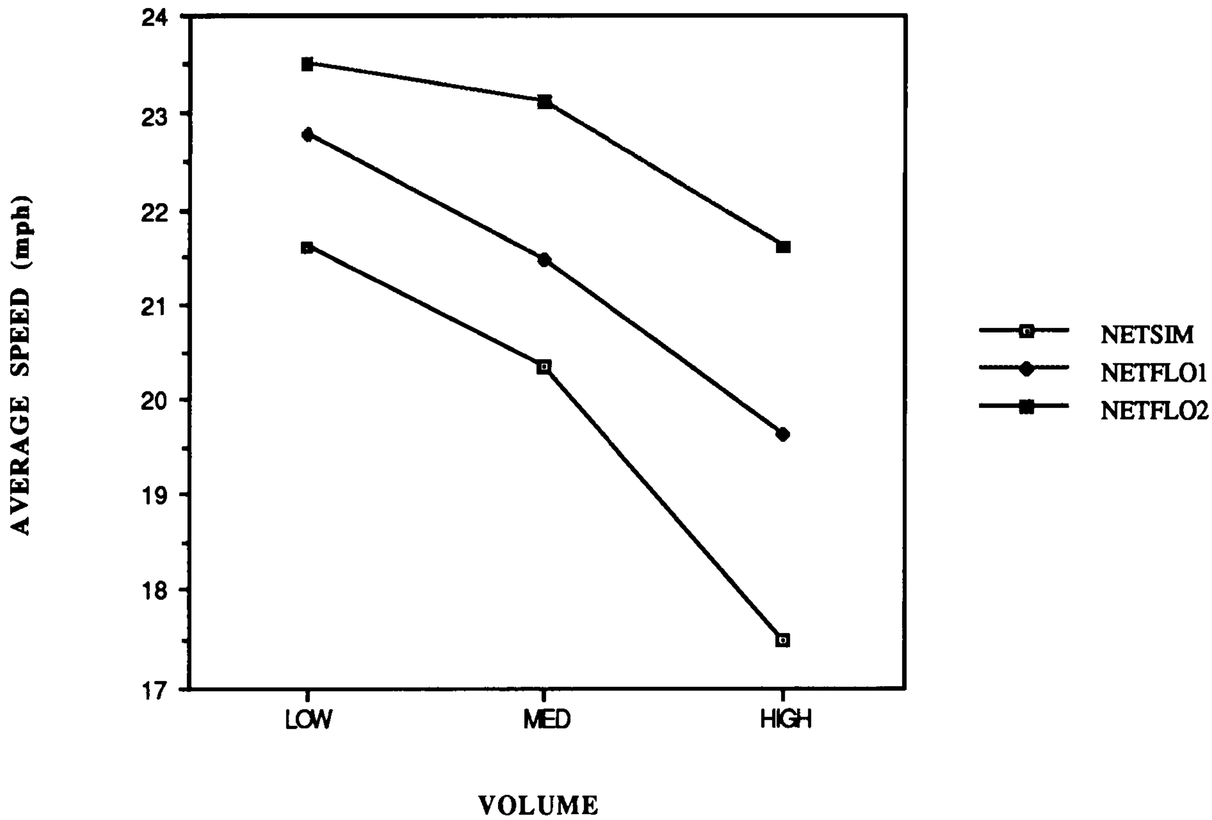

FIGURE 5.7 : Variation of Networkwide Average Speed with Volume for a Single Intersection with Complex Geometry.

NETSIM, while NETFLO1 speeds are consistently higher than those estimated by NETSIM. Though the difference in values for NETFLO1 from NETFLO2 does not appear to be large at low volume, but they seem to be quite different at medium and high volumes. While NETSIM and NETFLO1 values appear to differ at all levels of volume, this difference is much more pronounced for high volume. Here there does not appear any pattern in which these models differ from each other. NETFLO1 values appear to differ from NETSIM values more than NETFLO2 values for low volume but vice-versa for medium volume. While for high volume, NETFLO1 appears to have nearly same difference from NETSIM and NETFLO2.

The ANOVA output from SAS is shown in FIGURE 5.9. The analysis clearly shows that p-values are not significant at all to support the null hypotheses for each of the terms in the model. It means that the Model type, Volume level and the interaction of Model and Volume all have significant effects on the network-wide average speed. Also the contrast analysis shows that each of the three models are significantly different from each other. Hence, it can be said that the three models estimate the average speed that are statistically different.

The cell address analysis is shown in FIGURE 5.9. It can be seen that the p-values for all pairwise contrasts are too small to accept the null hypotheses. It means that, at each of the three volume levels, each model is significantly different from the other two models. This implies that while simulating the same traffic

SINGLE INTERSECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	142.29600	17.78700	920.02	0.0001
Error	36	0.69600	0.01933		
Corrected Total	44	142.99200			

R-Square	C.V.	Root MSE	SPEED Mean
0.995133	0.653199	0.1390	21.287

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	63.369333	31.684667	1638.86	0.0001
VOLUME	2	72.425333	36.212667	1873.07	0.0001
MODEL*VOLUME	4	6.501333	1.625333	84.07	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	63.369333	31.684667	1638.86	0.0001
VOLUME	2	72.425333	36.212667	1873.07	0.0001
MODEL*VOLUME	4	6.501333	1.625333	84.07	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	16.280333	16.280333	842.09	0.0001
2vs3	1	15.408333	15.408333	796.98	0.0001
3vs1	1	63.365333	63.365333	3277.52	0.0001

FIGURE 5.8 : ANOVA Table for Networkwide Speed for Single Intersection- Complex Geometry.

SINGLE INTERSECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	142.29600	17.78700	920.02	0.0001
Error	36	0.69600	0.01933		
Corrected Total	44	142.99200			

R-Square	C.V.	Root MSE	SPEED Mean
0.995133	0.653199	0.1390	21.287

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	142.29600	17.78700	920.02	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
C	8	142.29600	17.78700	920.02	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	3.364000	3.364000	174.00	0.0001
LOW 2vs3	1	1.296000	1.296000	67.03	0.0001
LOW 3vs1	1	8.836000	8.836000	457.03	0.0001
MED 1vs2	1	3.249000	3.249000	168.05	0.0001
MED 2vs3	1	6.561000	6.561000	339.36	0.0001
MED 1vs3	1	19.044000	19.044000	985.03	0.0001
HIGH 1vs2	1	11.236000	11.236000	581.17	0.0001
HIGH 2vs3	1	9.604000	9.604000	496.76	0.0001
HIGH 1vs3	1	41.616000	41.616000	2152.55	0.0001
LOW 1v2 Vs 2v3	1	0.161333	0.161333	8.34	0.0065
MED 1v2 Vs 2v3	1	0.192000	0.192000	9.93	0.0033
HIGH 1v2 Vs 2v3	1	0.021333	0.021333	1.10	0.3005

FIGURE 5.9 : Single Intersection - Complex Geometry : Contrast Analysis for Networkwide Speed using Cell Address Model.

conditions, the three models produce average speed statistics that are significantly different from each other.

Further, for each volume level, on contrasting the differences between NETSIM and NETFLO1 versus the differences between NETFLO1 and NETFLO2, it was found that only for high volume level these differences are not significantly different from each other. It means that while simulating high volume conditions the NETSIM model differs from NETFLO1 as much as NETFLO1 differs from NETFLO2 model. While for low and medium volume conditions, these differences are statistically significant. For low volume conditions, the difference between NETSIM and NETFLO1 is larger than that between NETFLO1 and NETFLO2, while for medium volume, the opposite is true. Hence, there does not seem to be any pattern for these differences.

Networkwide Average Delay

For the single intersection scenario with left-turn lanes, the average networkwide delay for different volume levels, as estimated by the three models in five replications are shown in TABLE 5.7. TABLE 5.8 shows the mean values of five observations and their standard deviations. These mean values were plotted against the three traffic volume levels and are shown in FIGURE 5.10. The ANOVA outputs from SAS are shown in the FIGURE 5.11. The cell address analysis is shown in FIGURE 5.12.

It was found that the three models estimate the average delay which are significantly different from each other. NETSIM model

TABLE 5.7 : Networkwide average delay (min./veh-trip) for single intersection with Complex Geometry.

VOLUME	REPLICATION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	0.43	0.34	0.32
	2	0.44	0.37	0.32
	3	0.44	0.37	0.32
	4	0.44	0.36	0.32
	5	0.44	0.36	0.32
MEDIUM	1	0.54	0.44	0.34
	2	0.54	0.46	0.34
	3	0.54	0.45	0.34
	4	0.53	0.45	0.34
	5	0.54	0.46	0.34
HIGH	1	0.85	0.62	0.44
	2	0.79	0.61	0.44
	3	0.78	0.59	0.44
	4	0.79	0.59	0.44
	5	0.85	0.58	0.44

TABLE 5.8 : Mean networkwide average delay (min./veh-trip) for single intersection with complex geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	0.438 (0.004)*	0.360 (0.012)	0.320 (0.00)
MEDIUM	0.538 (0.004)	0.452 (0.008)	0.340 (0.00)
HIGH	0.812 (0.035)	0.598 (0.016)	0.440 (0.00)

* Values in parentheses are Standard Deviations.

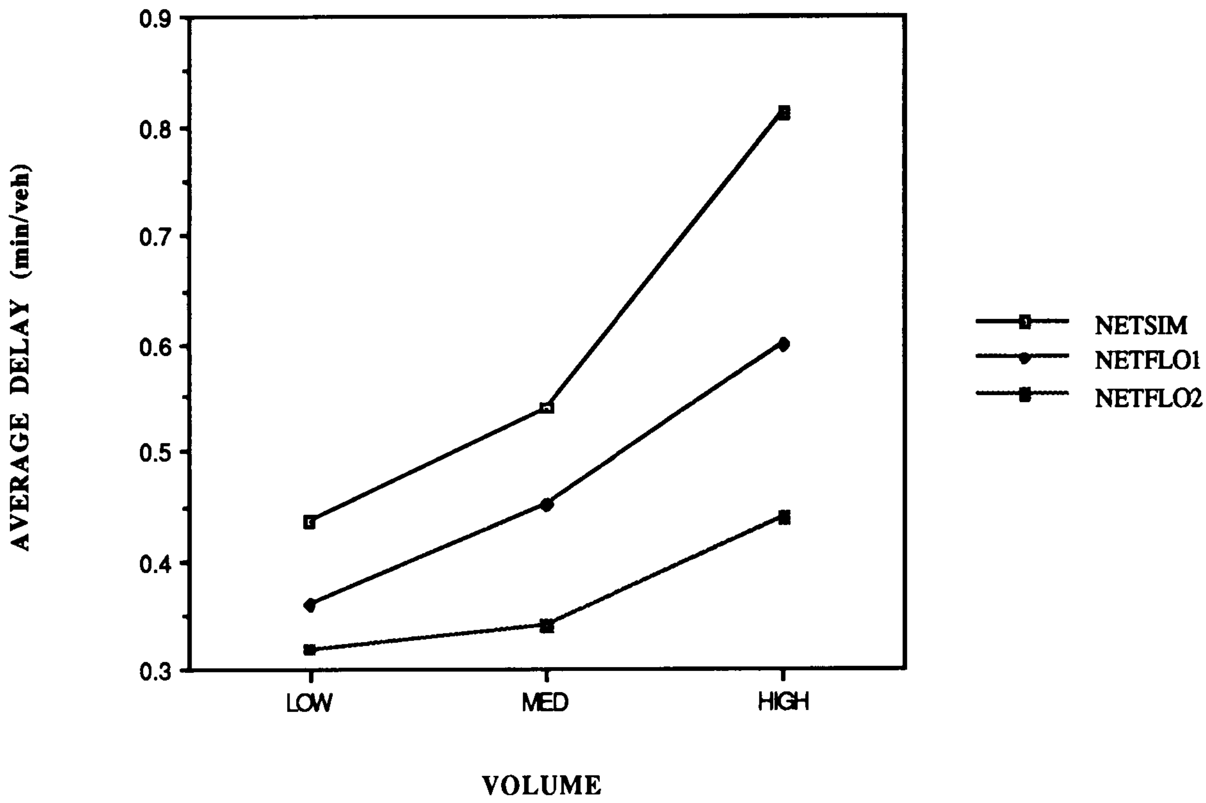

FIGURE 5.10 : Variation of networkwide average delay with volume for single intersection with complex geometry.

SINGLE INTERSECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.9560311	0.1195039	614.59	0.0001
Error	36	0.0070000	0.0001944		
Corrected Total	44	0.9630311			

R-Square	C.V.	Root MSE	DELAY Mean
0.992731	2.919940	0.0139	0.4776

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	0.3957378	0.1978689	1017.61	0.0001
VOLUME	2	0.4728711	0.2364356	1215.95	0.0001
MODEL*VOLUME	4	0.0874222	0.0218556	112.40	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	0.3957378	0.1978689	1017.61	0.0001
VOLUME	2	0.4728711	0.2364356	1215.95	0.0001
MODEL*VOLUME	4	0.0874222	0.0218556	112.40	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	0.1190700	0.1190700	612.36	0.0001
2vs3	1	0.0800833	0.0800833	411.86	0.0001
3vs1	1	0.3944533	0.3944533	2028.62	0.0001

FIGURE 5.11 : ANOVA Table for Networkwide Delay for a Single Intersection- Complex Geometry.

SINGLE INTERSECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.9560311	0.1195039	614.59	0.0001
Error	36	0.0070000	0.0001944		
Corrected Total	44	0.9630311			

R-Square	C.V.	Root MSE	DELAY Mean
0.992731	2.919940	0.0139	0.4776

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	0.9560311	0.1195039	614.59	0.0001

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	0.9560311	0.1195039	614.59	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	0.0152100	0.0152100	78.22	0.0001
LOW 2vs3	1	0.0040000	0.0040000	20.57	0.0001
LOW 3vs1	1	0.0348100	0.0348100	179.02	0.0001
MED 1vs2	1	0.0184900	0.0184900	95.09	0.0001
MED 2vs3	1	0.0313600	0.0313600	161.28	0.0001
MED 1vs3	1	0.0980100	0.0980100	504.05	0.0001
HIGH 1vs2	1	0.1144900	0.1144900	588.81	0.0001
HIGH 2vs3	1	0.0624100	0.0624100	320.97	0.0001
HIGH 1vs3	1	0.3459600	0.3459600	1779.22	0.0001
LOW 1v2 Vs 2v3	1	0.0012033	0.0012033	6.19	0.0176
MED 1v2 Vs 2v3	1	0.0005633	0.0005633	2.90	0.0974
HIGH 1v2 Vs 2v3	1	0.0026133	0.0026133	13.44	0.0008

FIGURE 5.12 : Single Intersection - Complex Geometry : Contrast Analysis for Networkwide Delay using Cell Address Model.

consistently produced highest delays and NETFLO2 produced the lowest values. But the difference between delay values at different volume levels does not follow the same pattern as in the speed values. Here the difference between NETSIM and NETFLO1 values is significantly different than that between NETFLO1 and NETFLO2 at low volume and high volume levels (in both cases, former being greater than latter) but is not significant for medium volume level.

Again, as was seen in the simple geometry case, for both speed and delay observations, there is absolutely no variation in the outputs from NETFLO2 model. This suggests that the NETFLO2 outputs are not affected by the random number seed.

Simulation Execution Time (CPU Time)

Simulation runs for this study were performed on an IBM 486 computer with 25 MHz speed and a math coprocessor. As mentioned already, simulation run for each scenario was performed for a 30-minute period. The CPU time, or the computer time, taken by the three models to complete these 30-minute simulations for single intersection scenarios with and without turn lanes are shown in Tables 5.17 and 5.18 respectively. It can be seen that the execution speed for NETFLO2 does not change with the volume level. While for NETSIM and NETFLO1 models, the program execution times increase as the volume increases. The increase in execution time is much higher for NETSIM than NETFLO1. However, NETFLO1 execution times are much lower than those for NETSIM model for all single intersection scenarios. This is suggestive of the fact that NETSIM is a

TABLE 5.9 : CPU Time (in seconds) for Single Intersection - Simple Geometry Scenario.

VOLUME	REPLICA-TION #	NETSIM	NETFLO1	NETFLO2
LOW	1	51.08	5.06	2.85
	2	51.59	5.22	2.85
	3	51.14	5.05	2.91
	4	51.13	5.17	2.80
	5	51.19	5.22	2.85
MEDIUM	1	67.12	8.24	2.92
	2	67.18	8.29	2.91
	3	67.01	8.19	2.91
	4	66.9	8.23	2.91
	5	67.28	8.23	2.92
HIGH	1	87.72	13.24	2.91
	2	88.27	13.24	2.91
	3	89.09	13.4	2.91
	4	87.33	12.96	2.91
	5	87.88	13.30	2.91

TABLE 5.10 : CPU Time (in seconds) for Single Intersection - Complex Geometry Scenario'

VOLUME	REPLICATION #	NETSIM	NETFLO1	NETFLO2
LOW	1	54.15	5.39	2.91
	2	50.86	5.27	2.86
	3	52.45	5.33	2.86
	4	52.57	5.27	2.85
	5	52.68	5.16	2.85
MEDIUM	1	69.42	8.45	2.91
	2	69.04	8.46	2.96
	3	69.20	8.40	2.91
	4	68.88	8.46	2.96
	5	69.15	8.41	2.91
HIGH	1	92.44	13.56	2.96
	2	90.69	13.40	2.91
	3	90.52	13.13	2.91
	4	90.68	13.07	2.91
	5	92.22	13.07	2.97

microscopic stocastic model while NETFLO2 is a macroscopic model. Also the NETFLO1 execution times suggest that it is not entirely a macroscopic model as suggested in the TRAF User's Manual. At the same time it does not appear to be simulating at the same level of detail as NETSIM does, since it is much faster than NETSIM. Hence NETFLO1 model can be, at best, termed as a mesoscopic model.

CHAPTER 6

RESULTS OF ANALYSIS-II: ARTERIAL SECTION

In this section, the results of analysis for the arterial section for both, simple geometry and complex geometry cases are presented.

Arterial Section with Simple Geometry

Networkwide Average Speed

For the arterial section scenario without left-turn lanes at intersections, the average networkwide speed for different volume levels, as observed by the three models in five replications are shown in TABLE 6.1. TABLE 6.2 shows the mean values of five replicated observations and their standard deviations for each volume level. These mean values were plotted against the three traffic volume levels and are shown in FIGURE 6.1. It can be seen from this plot that, for all the three models, the average speed decreases consistently with the increase in volume. But it should be noted that for NETSIM, the drop in speed from medium volume to high volume is much more sharper than the other two models. However, the important point that should be noted from FIGURE 6.1 is that NETFLO2 consistently gives higher average speeds than NETFLO1 and NETSIM, while NETFLO1 speeds are consistently higher than those estimated by NETSIM. The difference between values for

TABLE 6.1 : Networkwide Average Speed (mph) for Arterial Section with Simple Geometry.

VOLUME	REPLICATION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	20.3	21.8	23.0
	2	20.3	21.8	23.0
	3	20.3	21.8	23.0
	4	20.3	21.9	23.0
	5	20.3	21.9	23.0
MEDIUM	1	18.1	20.8	22.5
	2	18.3	20.8	22.5
	3	18.3	21.0	22.5
	4	18.2	21.0	22.5
	5	18.4	20.9	22.5
HIGH	1	11.7	18.0	19.3
	2	11.7	17.9	19.3
	3	12.0	18.0	19.3
	4	11.8	18.2	19.3
	5	11.5	18.1	19.3

TABLE 6.2 : Mean Networkwide Speed (mph) for Arterial Section with Simple Geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	20.30 (0.000)*	21.84 (0.055)	23.00 (0.000)
MEDIUM	18.26 (0.114)	20.90 (0.100)	22.50 (0.000)
HIGH	11.74 (0.182)	18.04 (0.114)	19.30 (0.000)

* Values in parentheses are Standard Deviations.

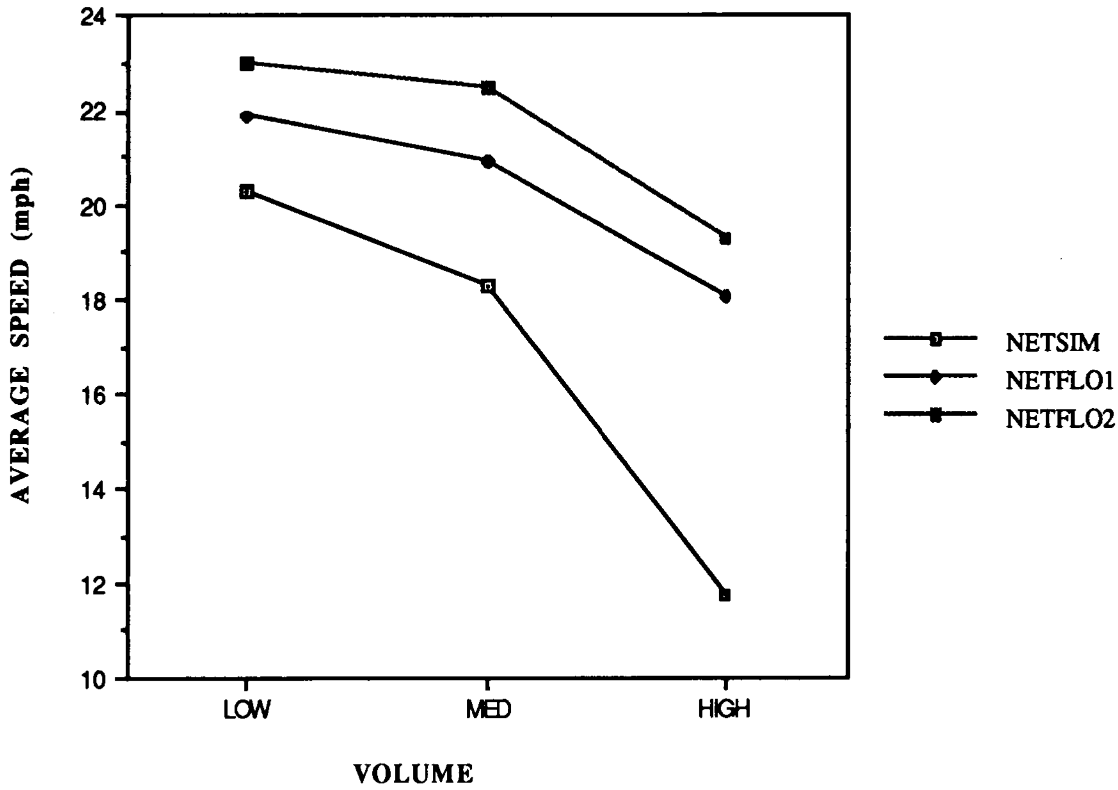

FIGURE 6.1 : Variation of networkwide average speed with volume for arterial section with simple geometry.

NETFLO1 and NETFLO2 does not appear to vary much for different levels of volume. These differences for medium and high volumes do not appear to be as large as the difference between NETSIM and NETFLO1 values. While at low volume conditions, the NETFLO1 values appear to differ from NETSIM values about the same as they differ from NETFLO2 values, the difference between NETFLO1 and NETSIM however becomes much larger at high volume as compared to the low and medium volumes.

The ANOVA output from SAS is shown in FIGURE 6.2. The analysis clearly shows that p-values are too small to support the null hypotheses for all the terms in the model. It means that the Model type, Volume level and the interaction between Model and Volume all have significant effects on the network-wide average speed. The contrast analysis shows that each of the three models are significantly different from the other two models in the way they generate network-wide average speed statistics. Hence, on an overall basis, it can be said that the three models estimate the average speed that are statistically different.

The cell address analysis is shown in FIGURE 6.3. It can be seen that the p-values for all the pairwise contrasts for each volume level are too small to accept the null hypotheses. It means that, at each of the three volume levels, each model is significantly different from the other two models. This implies that while simulating the same traffic conditions, the three models produce average speed statistics that are significantly different from each other.

ARTERIAL SECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	466.18178	58.27272	7284.09	0.0001
Error	36	0.28800	0.00800		
Corrected Total	44	466.46978			

R-Square	C.V.	Root MSE	SPEED Mean
0.999383	0.457690	0.0894	19.542

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	186.80044	93.40022	11675.03	0.0001
VOLUME	2	237.93911	118.96956	14871.19	0.0001
MODEL*VOLUME	4	41.44222	10.36056	1295.07	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	186.80044	93.40022	11675.03	0.0001
VOLUME	2	237.93911	118.96956	14871.19	0.0001
MODEL*VOLUME	4	41.44222	10.36056	1295.07	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	91.52533	91.52533	11440.67	0.0001
2vs3	1	13.46700	13.46700	1683.37	0.0001
3vs1	1	175.20833	75.20833	21901.04	0.0001

FIGURE 6.2 : ANOVA Table for Networkwide Speed for Arterial Section- Simple Geometry.

ARTERIAL SECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	466.18178	58.27272	7284.09	0.0001
Error	36	0.28800	0.00800		
Corrected Total	44	466.46978			

R-Square	C.V.	Root MSE	SPEED Mean
0.999383	0.457690	0.0894	19.542

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	466.18178	58.27272	7284.09	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
C	8	466.18178	58.27272	7284.09	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	5.92900	5.92900	741.12	0.0001
LOW 2vs3	1	3.36400	3.36400	420.50	0.0001
LOW 3vs1	1	18.22500	18.22500	2278.12	0.0001
MED 1vs2	1	17.42400	17.42400	2178.00	0.0001
MED 2vs3	1	6.40000	6.40000	800.00	0.0001
MED 1vs3	1	44.94400	44.94400	5618.00	0.0001
HIGH 1vs2	1	99.22500	99.22500	12403.12	0.0001
HIGH 2vs3	1	3.96900	3.96900	496.12	0.0001
HIGH 1vs3	1	142.88400	142.88400	17860.50	0.0001
LOW 1v2 Vs 2v3	1	0.12033	0.12033	15.04	0.0004
MED 1v2 Vs 2v3	1	0.90133	0.90133	112.67	0.0001
HIGH 1v2 Vs 2v3	1	21.16800	21.16800	2646.00	0.0001

FIGURE 6.3 : Arterial Section - Simple Geometry : Contrast Analysis for Networkwide Speed using Cell Address Model.

Further, for each volume level, on contrasting the differences between NETSIM and NETFLO1 versus the differences between NETFLO1 and NETFLO2, it was found that at all volume levels these differences are significantly different from each other. It means that the amount by which NETFLO1 speed values are higher from NETSIM values is significantly different than the amount by which those values are lower than NETFLO2 values. The difference between NETSIM and NETFLO1 is greater than that between NETFLO1 and NETFLO2 for all volume levels. This difference increases with the increase in volume.

Networkwide Average Delay

For the arterial section scenario without left-turn lanes at intersections, the networkwide average delay for different volume levels, as observed by the three models in five replications of the simulation runs are shown in TABLE 6.3. TABLE 6.4 shows the mean values of the five replicated observations and their standard deviations. These mean values were plotted against the three traffic volume levels and are shown in FIGURE 6.4. The ANOVA output from SAS is shown in FIGURE 6.5. The cell address analysis is shown in FIGURE 6.6.

This analysis yielded the same results as the analysis for speed values. All the three models were found to give significantly different networkwide average delay values. NETSIM consistently gave the highest delay values while NETFLO2 gave the lowest values. There appeared some evidence in the cell address analysis for low volume case that the difference between NETSIM and NETFLO1

TABLE 6.3 : Networkwide Average Delay (min./veh-trip) for Arterial Section with Simple Geometry.

VOLUME	REPLICA-TION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	0.67	0.52	0.42
	2	0.66	0.52	0.42
	3	0.66	0.53	0.42
	4	0.67	0.52	0.42
	5	0.67	0.51	0.42
MEDIUM	1	0.91	0.62	0.47
	2	0.89	0.62	0.47
	3	0.88	0.60	0.47
	4	0.90	0.60	0.47
	5	0.87	0.60	0.47
HIGH	1	2.14	0.92	0.77
	2	2.15	0.93	0.77
	3	2.05	0.92	0.77
	4	2.14	0.89	0.77
	5	2.20	0.91	0.77

TABLE 6.4 : Mean Networkwide Average Delay (min./veh-trip) for Arterial Section with Simple Geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	0.666 (0.005)*	0.520 (0.007)	0.420 (0.000)
MEDIUM	0.890 (0.016)	0.608 (0.011)	0.470 (0.000)
HIGH	2.136 (0.054)	0.914 (0.015)	0.770 (0.000)

* Values in parentheses are Standard Deviations.

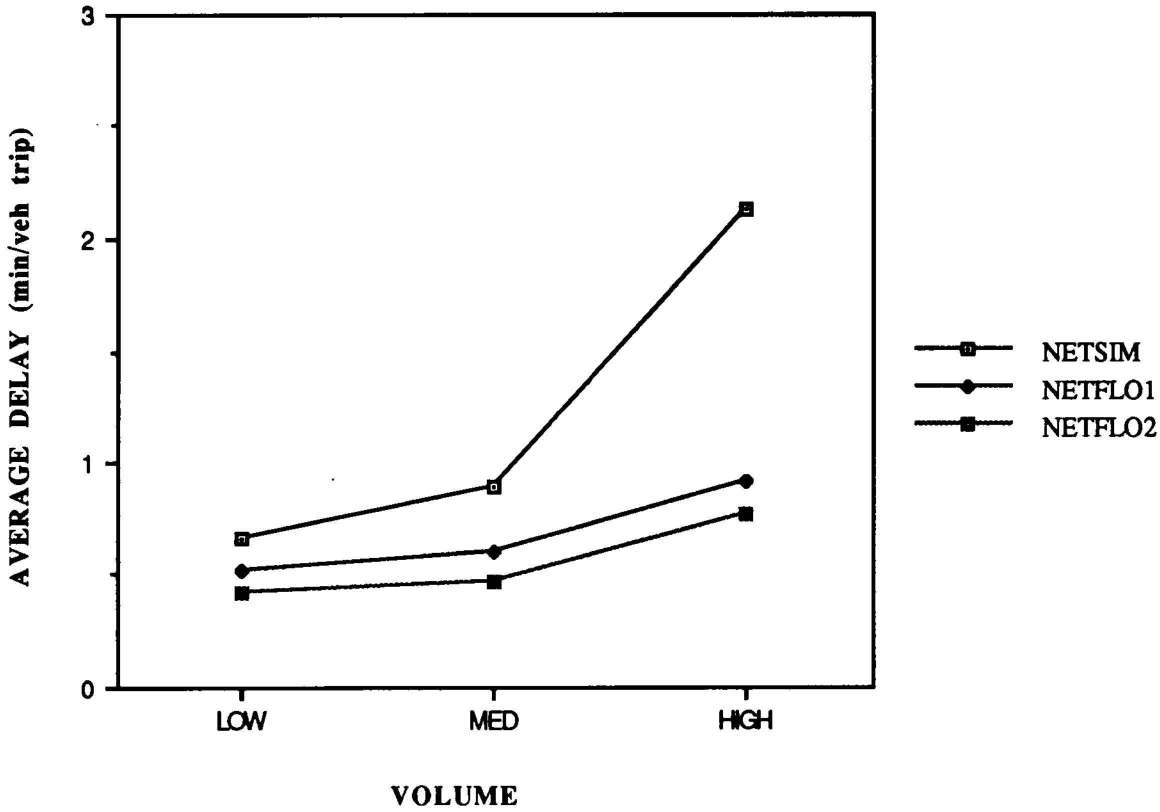

FIGURE 6.4 : Variation of Networkwide Average Delay with Volume for Arterial Section with Simple Geometry.

ARTERIAL SECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	10.946151	1.368269	3411.20	0.0001
Error	36	0.014440	0.000401		
Corrected Total	44	10.960591			

R-Square	C.V.	Root MSE	DELAY Mean
0.998683	2.437785	0.0200	0.8216

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	3.8874711	1.9437356	4845.88	0.0001
VOLUME	2	4.7015244	2.3507622	5860.63	0.0001
MODEL*VOLUME	4	2.3571556	0.5892889	1469.14	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	3.8874711	1.9437356	4845.88	0.0001
VOLUME	2	4.7015244	2.3507622	5860.63	0.0001
MODEL*VOLUME	4	2.3571556	0.5892889	1469.14	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	2.2687500	2.2687500	5656.16	0.0001
2vs3	1	0.1216033	0.1216033	303.17	0.0001
3vs1	1	3.4408533	3.4408533	8578.30	0.0001

FIGURE 6.5 : ANOVA Table for Networkwide Delay for Arterial Section- Simple Geometry.

ARTERIAL SECTION - SIMPLE GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	10.946151	1.368269	3411.20	0.0001
Error	36	0.014440	0.000401		
Corrected Total	44	10.960591			

R-Square	C.V.	Root MSE	DELAY Mean
0.998683	2.437785	0.0200	0.8216

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	10.946151	1.368269	3411.20	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
C	8	10.946151	1.368269	3411.20	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	0.0532900	0.0532900	132.86	0.0001
LOW 2vs3	1	0.0250000	0.0250000	62.33	0.0001
LOW 3vs1	1	0.1512900	0.1512900	377.18	0.0001
MED 1vs2	1	0.1988100	0.1988100	495.65	0.0001
MED 2vs3	1	0.0476100	0.0476100	118.70	0.0001
MED 1vs3	1	0.4410000	0.4410000	1099.45	0.0001
HIGH 1vs2	1	3.7332100	3.7332100	9307.17	0.0001
HIGH 2vs3	1	0.0518400	0.0518400	129.24	0.0001
HIGH 1vs3	1	4.6648900	4.6648900	11629.92	0.0001
LOW 1v2 Vs 2v3	1	0.0017633	0.0017633	4.40	0.0431
MED 1v2 Vs 2v3	1	0.0172800	0.0172800	43.08	0.0001
HIGH 1v2 Vs 2v3	1	0.9684033	0.9684033	2414.30	0.0001

FIGURE 6.6 : Arterial Section - Simple Geometry : Contrast Analysis for Networkwide Delay using Cell Address Model.

values are not different than that between NETFLO1 and NETFLO2, but this is not significant at 95% confidence level.

Interestingly, as was observed in both cases of single intersection, for both speed and delay observations, there is absolutely no variation in the outputs from NETFLO2 model. This suggests that the NETFLO2 outputs are not affected by the random number seed.

Arterial Section with Complex Geometry

Networkwide Average Speed

For the arterial section scenario with left-turn lanes at intersections and left-turn signal phases for the arterial road, the average networkwide speed for different volume levels, as observed by the three models in five replications are shown in TABLE 6.5. TABLE 6.6 shows the mean values of five replicated observations and their standard deviations for each volume level. These mean values were plotted against the three traffic volume levels and are shown in FIGURE 6.7. It can be seen from this plot that, for all the three models, the average speed decreases consistently with the increase in volume. But it should be noted that for NETSIM, the drop in speed is much more sharper than the other two models. However, the important point that should be noted from FIGURE 6.7 is that NETFLO2 consistently gives higher average speeds than NETFLO1 and NETSIM, while NETFLO1 speeds are consistently higher than those estimated by NETSIM. The difference between values for NETFLO1

TABLE 6.5 : Networkwide Average Speed (mph) for Arterial Section with Complex Geometry.

VOLUME	REPLICATION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	19.7	21.5	22.5
	2	19.8	21.4	22.5
	3	19.8	21.4	22.5
	4	19.7	21.4	22.5
	5	19.7	21.5	22.5
MEDIUM	1	15.8	19.6	21.8
	2	16.3	19.4	21.8
	3	16.5	19.5	21.8
	4	15.8	19.5	21.8
	5	15.7	19.6	21.8
HIGH	1	12.0	17.5	19.3
	2	11.8	17.6	19.3
	3	11.8	17.5	19.3
	4	11.4	17.8	19.3
	5	11.8	17.7	19.3

TABLE 6.6 : Mean Networkwide Average Speed (mph) for Arterial Section with Complex Geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	19.74 (0.055)*	21.44 (0.055)	22.50 (0.000)
MEDIUM	16.02 (0.356)	19.52 (0.084)	21.80 (0.000)
HIGH	11.76 (0.219)	17.62 (0.130)	19.30 (0.000)

* Values in parentheses are Standard Deviations.

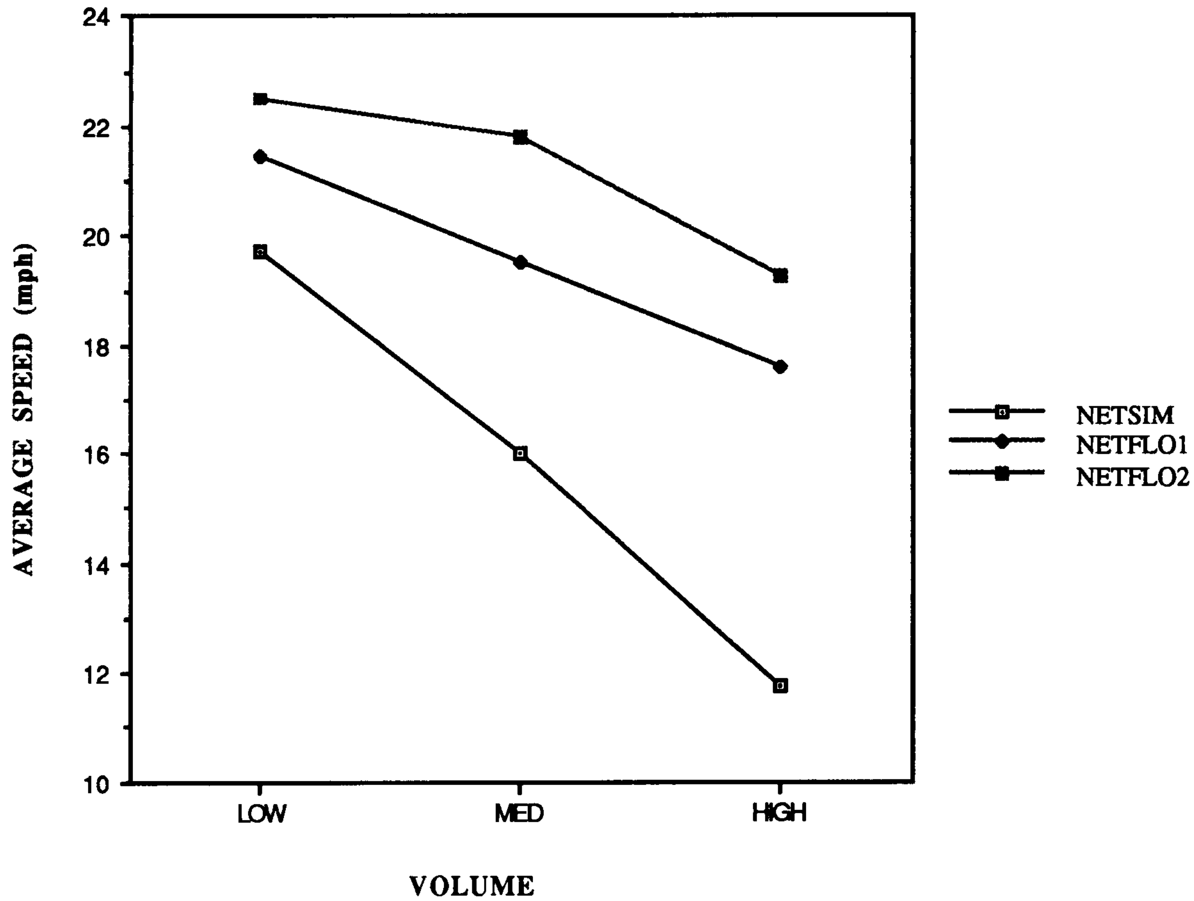

FIGURE 6.7 : Variation of Networkwide Average Speed with Volume for Arterial Section with Complex Geometry.

and NETFLO2 does not appear to vary much for different levels of volume, though they appear to be more different at medium volume level than low and high volumes. The difference between NETSIM and NETFLO1 speeds appear to be higher than that between NETFLO1 and NETFLO2 values for all volume levels; this difference consistently increases with the increase in volume.

The ANOVA output from SAS is shown in FIGURE 6.8. The analysis clearly shows that p-values are too small to support the null hypotheses for all the terms in the model. It means that the Model type, Volume level and the interaction between Model and Volume all have significant effects on the network-wide average speed. The contrast analysis shows that each of the three models are significantly different from the other two models in the way they generate network-wide average speed statistics. This can be clearly visualized from the pairwise t-test result. Model 1 (NETSIM), Model 2 (NETFLO1) and Model 3 (NETFLO2) are placed into different groups that are significantly different from each other. Hence, on an overall basis, it can be said that the three models estimate the average speed that are statistically different.

The cell address analysis is shown in FIGURE 6.9. It can be seen that the p-values for all the pairwise contrasts for each volume level are too small to accept the null hypotheses. It means that, at each of the three volume levels, each model is significantly different from the other two models. This implies that while simulating the same traffic conditions, the three models produce average speed statistics that are significantly different from each other.

ARTERIAL SECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	449.83111	56.22889	2468.59	0.0001
Error	36	0.82000	0.02278		
Corrected Total	44	450.65111			

R-Square	C.V.	Root MSE	SPEED Mean
0.998180	0.800417	0.1509	18.856

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	225.60578	112.80289	4952.32	0.0001
VOLUME	2	188.99511	94.49756	4148.67	0.0001
MODEL*VOLUME	4	35.23022	8.80756	386.67	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	225.60578	112.80289	4952.32	0.0001
VOLUME	2	188.99511	94.49756	4148.67	0.0001
MODEL*VOLUME	4	35.23022	8.80756	386.67	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	101.93633	101.93633	4475.25	0.0001
2vs3	1	21.00033	21.00033	921.97	0.0001
3vs1	1	215.47200	215.47200	9459.75	0.0001

FIGURE 6.8 : ANOVA Table for Networkwide Speed for Arterial Section- Complex Geometry.

ARTERIAL SECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	449.83111	56.22889	2468.59	0.0001
Error	36	0.82000	0.02278		
Corrected Total	44	450.65111			

R-Square	C.V.	Root MSE	SPEED Mean
0.998180	0.800417	0.1509	18.856

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	449.83111	56.22889	2468.59	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
C	8	449.83111	56.22889	2468.59	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	7.22500	7.22500	317.20	0.0001
LOW 2vs3	1	2.80900	2.80900	23.32	0.0001
LOW 3vs1	1	19.04400	19.04400	836.08	0.0001
MED 1vs2	1	30.62500	30.62500	1344.51	0.0001
MED 2vs3	1	12.99600	12.99600	570.56	0.0001
MED 1vs3	1	83.52100	83.52100	3666.78	0.0001
HIGH 1vs2	1	85.84900	85.84900	3768.98	0.0001
HIGH 2vs3	1	7.05600	7.05600	309.78	0.0001
HIGH 1vs3	1	142.12900	142.12900	6239.81	0.0001
LOW 1v2 Vs 2v3	1	0.34133	0.34133	14.99	0.0004
MED 1v2 Vs 2v3	1	1.24033	1.24033	54.45	0.0001
HIGH 1v2 Vs 2v3	1	14.56033	14.56033	639.23	0.0001

FIGURE 6.9 : Arterial Section - Complex Geometry: Contrast Analysis for Networkwide Speed using Cell Address Model.

Further, for each volume level, on contrasting the differences between NETSIM and NETFLO1 versus the differences between NETFLO1 and NETFLO2, it was found that at all volume levels these differences are significantly different from each other. It means that the amount by which NETFLO1 speed values are higher from NETSIM values is significantly different than the amount by which those values are lower than NETFLO2 values.

Networkwide Average Delay

For the arterial section scenario with left-turn lanes at intersections and protected left-turn phases for the arterial road, the networkwide average delay for different volume levels, as observed by the three models in five replications of the simulation runs are shown in TABLE 6.7. TABLE 6.8 shows the mean values of five replicated observations and their standard deviations. These mean values were plotted against the three traffic volume levels and are shown in FIGURE 6.10. The ANOVA output from SAS is shown in FIGURE 6.11. The cell address analysis is shown in FIGURE 12.

It was found that the three models differ significantly from each other at all volume levels. This is consistent with the results of analysis for speed values. In the detailed contrast analysis however it was found that at low volume level there is no significant difference between the difference between NETSIM and NETFLO1 models versus that between NETFLO1 and NETFLO2, which is in contrast with the speed analysis where this difference was found to be significant.

TABLE 6.7 : Networkwide Average Delay (min./veh-trip) for Arterial Section with Complex Geometry.

VOLUME	REPLICATION NO.	NETSIM	NETFLO1	NETFLO2
LOW	1	0.72	0.55	0.46
	2	0.71	0.56	0.46
	3	0.71	0.56	0.46
	4	0.72	0.56	0.46
	5	0.73	0.55	0.46
MEDIUM	1	1.24	0.73	0.52
	2	1.16	0.75	0.52
	3	1.13	0.74	0.52
	4	1.24	0.74	0.52
	5	1.25	0.73	0.52
HIGH	1	2.04	0.96	0.76
	2	2.10	0.96	0.76
	3	2.11	0.95	0.76
	4	2.23	0.93	0.76
	5	2.11	0.94	0.76

TABLE 6.8 : Mean Networkwide Average Delay (min./veh-trip) for Arterial Section with Complex Geometry.

VOLUME	NETSIM	NETFLO1	NETFLO2
LOW	0.718 (0.008)*	0.556 (0.005)	0.460 (0.00)
MEDIUM	1.204 (0.055)	0.738 (0.008)	0.520 (0.00)
HIGH	2.118 (0.069)	0.948 (0.013)	0.760 (0.00)

* Values in parentheses are Standard Deviations.

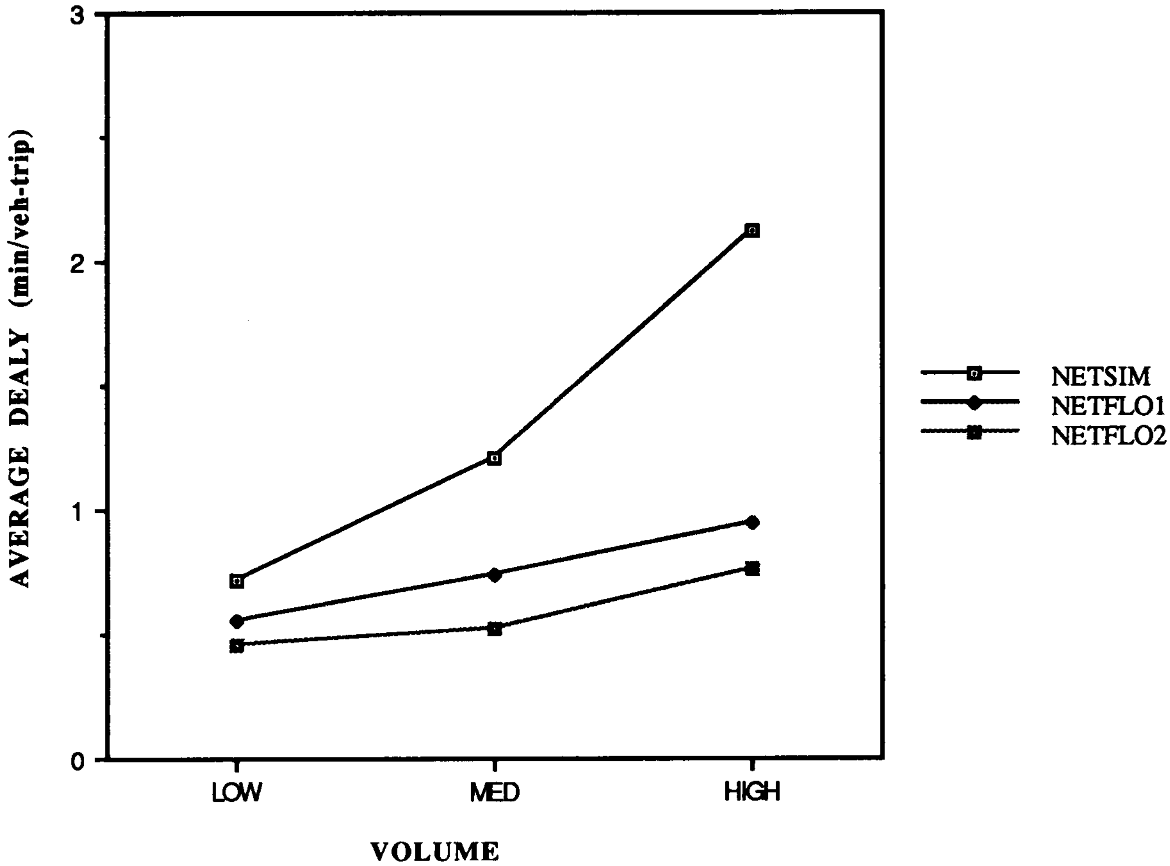

FIGURE 6.10 : Variation of Networkwide Average Delay with Volume for Arterial Section with Complex Geometry.

ARTERIAL SECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	10.564360	1.320545	1460.06	0.0001
Error	36	0.032560	0.000904		
Corrected Total	44	10.596920			

R-Square	C.V.	Root MSE	DELAY Mean
0.996927	3.374044	0.0301	0.8913

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	4.8748933	2.4374467	2694.97	0.0001
VOLUME	2	3.7594133	1.8797067	2078.30	0.0001
MODEL*VOLUME	4	1.9300533	0.4825133	533.49	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
MODEL	2	4.8748933	2.4374467	2694.97	0.0001
VOLUME	2	3.7594133	1.8797067	2078.30	0.0001
MODEL*VOLUME	4	1.9300533	0.4825133	533.49	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	2.6940033	2.6940033	2978.63	0.0001
2vs3	1	0.2100033	0.2100033	232.19	0.0001
3vs1	1	4.4083333	4.4083333	4874.08	0.0001

FIGURE 6.11 : ANOVA Table for Networkwide Delay for Arterial Section- Complex Geometry.

ARTERIAL SECTION - COMPLEX GEOMETRY SCENARIO

General Linear Models Procedure

Dependent Variable: DELAY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	10.564360	1.320545	1460.06	0.0001
Error	36	0.032560	0.000904		
Corrected Total	44	10.596920			

R-Square	C.V.	Root MSE	DELAY Mean
0.996927	3.374044	0.0301	0.8913

Source	DF	Type I SS	Mean Square	F Value	Pr > F
C	8	10.564360	1.320545	1460.06	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
C	8	10.564360	1.320545	1460.06	0.0001

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LOW 1vs2	1	0.0656100	0.0656100	72.54	0.0001
LOW 2vs3	1	0.0230400	0.0230400	25.47	0.0001
LOW 3vs1	1	0.1664100	0.1664100	183.99	0.0001
MED 1vs2	1	0.5428900	0.5428900	600.25	0.0001
MED 2vs3	1	0.1188100	0.1188100	131.36	0.0001
MED 1vs3	1	1.1696400	1.1696400	1293.21	0.0001
HIGH 1vs2	1	3.4222500	3.4222500	3783.81	0.0001
HIGH 2vs3	1	0.0883600	0.0883600	97.70	0.0001
HIGH 1vs3	1	4.6104100	4.6104100	5097.50	0.0001
LOW 1v2 Vs 2v3	1	0.0036300	0.0036300	4.01	0.0527
MED 1v2 Vs 2v3	1	0.0512533	0.0512533	56.67	0.0001
HIGH 1v2 Vs 2v3	1	0.8036033	0.8036033	888.50	0.0001

FIGURE 6.12 : Arterial Section - Complex Geometry: Contrast Analysis for Networkwide Delay using Cell Address Model.

Again, as was observed in the simple geometry case and both cases of single intersection, for both speed and delay observations, there is absolutely no variation in the outputs from NETFLO2 model. This suggests that the NETFLO2 outputs are not affected by the random number seed.

Simulation Execution Time (CPU Time)

The simulation runs for this study were performed on an IBM 486 computer with 25 MHz speed and a math coprocessor. As mentioned already, simulation run for each scenario was performed for a 30-minute period. The CPU time, or the computer time, taken by the three models to complete these 30-minute simulations for the arterial section scenarios for simple and complex geometric conditions are shown in Tables 6.9 and 6.10 respectively. It can be seen that for NETSIM and NETFLO1 models the computer time taken to simulate traffic networks increases as the volume level increases but NETFLO2 execution speed does not depend upon the traffic volume. However, the NETSIM execution time is much higher than NETFLO1 which itself takes longer time than NETFLO2 model to execute simulation . This is suggestive of the fact that NETSIM is a microscopic stocastic model while NETFLO2 is a macroscopic model. Also the NETFLO1 execution times suggest that it is not entirely a macroscopic model as suggested in the TRAF User's Manual. At the same time it does not appear to be simulating at the same level of detail as NETSIM does, since it is much faster than NETSIM. Hence NETFLO1 model can be, at best, termed as a mesoscopic model.

TABLE 6.9 : CPU Time (in seconds) for Arterial Section - Simple Geometry Scenario.

VOLUME	REPLICATION #	NETSIM	NETFLO1	NETFLO2
LOW	1	176.48	16.48	8.68
	2	175.66	16.37	8.73
	3	175.71	16.97	8.73
	4	176.47	16.25	8.68
	5	176.36	16.26	8.68
MEDIUM	1	242.17	34.83	8.67
	2	240.85	34.77	8.68
	3	248.81	34.82	8.68
	4	241.95	34.39	8.68
	5	239.97	34.05	8.68
HIGH	1	398.43	81.02	8.62
	2	394.47	81.12	8.62
	3	390.30	80.52	8.62
	4	396.51	78.10	8.68
	5	413.48	79.97	8.57

TABLE 6.10 : CPU Time (in Seconds) for Arterial Section - Complex Geometry Scenario.

VOLUME	REPLICATION #	NETSIM	NETFLO1	NETFLO2
LOW	1	180.37	17.64	9.40
	2	179.06	17.19	9.45
	3	179.94	17.36	9.50
	4	180.48	17.25	9.39
	5	180.87	17.13	9.45
MEDIUM	1	260.34	37.30	9.34
	2	255.51	36.25	9.44
	3	254.63	36.25	9.50
	4	260.45	35.97	9.45
	5	269.47	35.65	9.61
HIGH	1	394.21	73.93	9.33
	2	393.81	72.83	9.23
	3	398.32	72.83	9.33
	4	420.02	73.16	9.28
	5	401.12	71.07	9.22

CHAPTER 7

CONCLUSIONS

This study was conducted to identify the differences in the performance of a microscopic traffic simulation model, NETSIM, from the two macroscopic models NETFLO1 (also called LEVEL I model) and NETFLO2 (also called LEVEL II model). More specifically, the goal was to determine how compatible the results from these models are. Identical traffic conditions were simulated using these models in order to reduce the number of external variables that may affect model results. Analysis of Variance was used as the major tool for the statistical analysis of the outputs obtained from these models.

Four different scenarios were created with varying road network and intersection geometry. Two different types of network layouts considered were : (a) Single Intersection, and (b) Arterial Network with five intersections. Within each network type, the following two intersection geometries were considered : (a) Simple, without left turn pockets, and (b) Complex, with left turn pockets on all approaches at intersections. Each scenario was loaded with three different levels of traffic volume and was simulated using the three models under consideration. Five replications were made with each model for each scenario. Average networkwide speed and delay were chosen as the measures of effectiveness for this study. Statistical analyses were performed first to see if there was any overall significant difference in the performance of the three models or not. When the differences were found to be significant, then further tests were performed to see if there were significant differences in the models at individual volume levels.

Summary of Results

TABLE 7.1 summarizes the results of the tests of significance for the factors affecting the selected MOE's -- networkwide delay and networkwide average speed. This table represents the results for all the four scenarios simulated, as similar results were obtained. It is quite obvious from this table that the model type does have an affect on the selected MOE's apart from the volume levels. Also the interaction between model type and volume level has significant effect on the MOE's, which means that the way the MOE's are affected by a model varies with the volume level. This result warranted further investigation to see specifically at which volume levels the models produced significantly different speed and delay values.

TABLE 7.2 summarizes the results of the tests of significance for differences in the networkwide average speed from one model to the other at different volume levels. TABLE 7.3 summarizes the same for networkwide average delay. Again, these tables are representative of all the four scenarios, as similar results were obtained. It can be seen that each model produced significantly different networkwide average delay and networkwide average speed from the other. However, the amount of these differences was not same for all scenarios.

TABLE 7.1 : Summary† of Results of Analysis for Main Effects and Interaction Effects on MOE's.

Independent Variable	Response Variable (MOE): Networkwide Average Speed	Networkwide Average Delay
Main Effects :		
Volume Level	*	*
Model Type	*	*
Interaction :		
Model x Volume	*	*

Note : '*' indicates that the effect is significant at $\alpha = 0.05$

† Represents all the four scenarios studied.

TABLE 7.2 : Summary† of Contrast of Model Types at different Volume Levels for Average Networkwide Speed.

MODELS COMPARED	VOLUME LEVEL		
	LOW	MEDIUM	HIGH
NETSIM Vs NETFLO1	*	*	*
NETFLO1 Vs NETFLO2	*	*	*
NETFLO2 Vs NETSIM	*	*	*

Note : '*' indicates that the difference is significant at $\alpha = 0.05$

† Represents all the four scenarios studied.

TABLE 7.3 : Summary† of Contrast of Model Types at different Volume Levels for Average Networkwide Delay.

	VOLUME LEVEL		
MODELS COMPARED	LOW	MEDIUM	HIGH
NETSIM Vs NETFLO1	*	*	*
NETFLO1 Vs NETFLO2	*	*	*
NETFLO2 Vs NETSIM	*	*	*

Note : '*' indicates that the difference is significant at $\alpha = 0.05$

† Represents all the four scenarios studied.

Conclusions

NETSIM, NETFLO1 and NETFLO2 models produced MOE statistics that were significantly different from each other. For all the scenarios, under all traffic volume conditions, the microscopic model, NETSIM, consistently generated speed values that were lower and delay values that were higher than those produced by NETFLO1 and NETFLO2 models. While the NETFLO2 model consistently generated higher speeds and lower delays than NETFLO1 and NETSIM. NETFLO1 values were always in the middle. However, it was observed that the amounts of differences between the NETFLO1 and NETFLO2 statistics were generally smaller in comparison to that between NETSIM and NETFLO1 model. Especially at high volume levels, the difference between NETSIM and NETFLO1 were significantly larger in almost all cases. This indicates that as the congestion level increases, the difference in outputs from these models, in general, increases.

For the single intersection cases, NETFLO1 values fluctuated between NETSIM and NETFLO2 values. Sometimes they were closer to NETSIM while at other times they were closer to NETFLO2 values. No clear pattern of its difference from the other two appears. However, for the arterial network cases, NETFLO1 values were consistently closer to NETFLO2 values than NETSIM values at all volume levels. Also the difference between NETFLO1 and NETFLO2 values did not appear to vary significantly for different volume levels. This provides an opportunity to further explore the relationship between NETFLO1 and NETFLO2 values and see if this difference could be quantified. NETSIM values however consistently drift away further from NETFLO1 values with the increase in volume level. This also provides an opportunity to explore the possibility of developing a mathematical relationship between the outputs of these models.

As far as the execution speeds of the three models are concerned, the two macroscopic models were found to be significantly faster than the microscopic model. It was found that the simulation execution time for NETSIM and NETFLO1 models consistently increased with the increase in volume levels, while NETFLO2 remained insensitive to the changes in volume levels. Also to be noted is that the arterial sections took longer to simulate than single intersection for all the three models. Hence, it can be said that as the size of the network increases, these models take longer to execute the simulation. In any case, the macroscopic models in general and NETFLO2 in particular, are definitely more attractive in terms of execution speed than the microscopic model.

The results for some of the scenarios did not appear to be very much different in terms of absolute value, although they were found to be statistically different. In any case, the biggest concern is the large differences in the outputs at higher volume levels, especially evident in delay values, from these models.

Comparison with Other Models

As stated earlier in Chapter 2, there have been several studies involving the use of NETSIM model. In some of them, the results from NETSIM were compared to those from other widely used models, such as, SOAP and Highway Capacity Software and were also compared to field data on a limited basis. Although the raw statistics from these models were not fully compatible, the results were found to agree when the differences in the definitions of MOE's were taken into consideration. It was also observed in those studies that the NETSIM model was capable of generating more realistic outputs. No such comparisons are available for the NETFLO models at this time.

Other Observations

The TRAF User Reference Guide states that NETFLO models could be used instead of NETSIM in the absence of adequate resources without sacrificing the realism of outputs, but this study shows otherwise. It is quite obvious from this study that although the NETFLO models are much more attractive execution-timewise, their outputs are significantly different from NETSIM outputs.

Engineering acumen should be used in making a decision whether the difference is large enough for practical applications of a specific model or not. This may require considerable experience in the field of traffic and transportation engineering. Also it depends on the intended application of the values obtained from traffic simulation. Some applications could be more sensitive than others where statistically different values may produce different results. However, one should be very cautious in selecting the type of model for any study involving high levels of congestion, and if possible, validate the models with existing field data and use the one that produces most satisfactory results. If NETFLO1 or NETFLO2 is used for some study in order to save resources, then it should be taken into consideration that these models produce outputs that are relatively less conservative as compared to the microscopic NETSIM model, although they are more attractive execution time-wise. On the other hand, NETSIM model offers more detailed traffic parameters that are not available with the other two models, but the NETSIM statistics are relatively more conservative than the other two models. The user should keep these points in mind before accepting the simulation outputs, as-is, from any of these models.

The program execution time of any computer program depends on the type of hardware installed on the computer. Using a faster computer, say 50 MHz, could reduce the execution time for these simulation models considerably. But even then, relatively speaking, a macroscopic model would remain attractive in saving the computational time.

This study provides the practicing engineers and professionals with an opportunity to examine the implications of using traffic simulation models as decision making tools. Especially in the light of emerging IVHS technologies where near real-time traffic information is proposed to be used, quick (less computational time) models would be more useful for on-line use in Traffic Management Centers (TMC). At the same time reliable results will also be required. With currently available models, it has been shown in this study that there is a major trade-off between execution speed and the compatibility of outputs from different models. Definitely there is a need to do more research in this area.

Scope for Future Research

Further studies are needed to find out more specific areas of difference between these models and to validate these models with real-life field data. There could be various reasons for the differences in the outputs from these models. Some of the probable reasons that could be looked into are listed here :

- There may be some programming errors (or bugs) in the source code of one or more of these models, and hence the models may not be doing exactly what they are supposed to do.
- Secondly, there could be some errors in the simulation logic of one or more of these models.
- Third, there are many default parameters that are used in these models. Especially NETSIM has more built-in traffic parameter distributions than the other two models, which are not obvious to the user. These default values may not be compatible with the simulation logic of the other models.

This study provides a reason for the researchers to revisit the simulation logic used by these traffic simulation models. This study also reiterates the need to thoroughly validate the models through extensive field data.

A follow-up to this study can be taken up to establish a relationship among the amount of differences of the outputs from these models. If a consistent pattern is found and a high correlation is established among the results, then the user might be able to simulate any network with NETFLO2 within fractions of a minute and predict the MOE's that would be estimated by the more detailed model -- NETSIM. This would be particularly of great help in the IVHS type scenarios where near real-time data are needed.

In general, more detailed guidelines need to be developed for specific uses of these traffic simulation models.

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VITA

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