12-2011

Development of a State of the Art Traffic Microsimulation Model for Nebraska

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NDOR
Nebraska Department of Roads

Report # UNL: SPR-1(06) P584

Final Report

WBS: 26-1118-0075-001

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"This report was funded in part through grant[s] from the Federal Highway Administration [and Federal Transit Administration], U.S. Department of Transportation. The views and opinions of the authors [or agency] expressed herein do not necessarily state or reflect those of the U. S. Department of Transportation."

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A Report on Research Sponsored by

Nebraska Department of Roads

Nebraska Transportation Center
University of Nebraska-Lincoln

December 2011

Technical Report Documentation Page

1. Report No. SPR-1(06) P584	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Development of a State of the Art Traffic Microsimulation Model for Nebraska		5. Report Date December 2011
		6. Performing Organization Code
7. Author(s) Justice Appiah, Bhaven Naik, Yifeng Chen, Seung-Jun Kim, Laurence R. Rilett		8. Performing Organization Report No. 26-1118-0075-001
9. Performing Organization Name and Address Nebraska Transportation Center 2200 Vine St. Lincoln, NE 68583		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Highway Administration 1200 New Jersey Ave., SE Washington, D.C. 20509		13. Type of Report and Period Covered Draft Report 07/05 – 12/11
		14. Sponsoring Agency Code MATC TRB RiP No. 10736
15. Supplementary Notes		

16. Abstract

The main objective of this research was to develop a state-of-the-art microsimulation model for the Nebraska State Highway System which can be used by Nebraska Department of Roads (NDOR) designers, planners and traffic engineers. Because accurately and efficiently modeling traffic flow characteristics, driver behavior, and traffic control operations is critical for obtaining realistic microsimulation results, the model was calibrated to Nebraska conditions. In addition, the model is designed so that a wide range of applications can be analyzed. The network consisted of 200 miles of roadway including 102 miles of Interstate 80 between York, NE and Omaha, NE; 49 miles of US Highway 6 between Lincoln, NE and Omaha; NE and 20 miles of State Highway 2 between Lincoln, NE and Palmyra, NE. All major highways and arterial roadways that crossed perpendicular to the network roads were included. These cross streets were modeled to a distance of approximately half a mile or to the first traffic signal. Supply data, including number of lanes, speed limit, lane width, traffic signal timings, etc. were obtained from various state and local agencies. Demand data was estimated from empirical traffic data. The microsimulation model VISSIM, version 5.2, was used in this project and the model was calibrated to empirical traffic data.

17. Key Words: Microsimulation, calibration, large scale model	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 70	22. Price

Disclaimer

This report was funded in part through grants from the Federal Highway Administration, U.S. Department of Transportation. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the U. S. Department of Transportation, the Nebraska Department of Roads, or the University of Nebraska-Lincoln. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names that appear in this report are cited only because they were relevant to this research. The appearances of trade or manufacturers' names do not constitute endorsements.

Acknowledgements

We would like to acknowledge the contributions of numerous individuals and organizations who made the successful completion of this project possible. We are especially grateful to:

- The members of the Technical Advisory Committee (TAC): Dan Waddle, Phil Tenhulzen and Matt Neeman of NDOR, Glenn Hansen of the City of Omaha, Matt Selinger of HDR, and Virendra Singh of the City of Lincoln. Their comments and suggestions were extremely helpful;
- Mr. Glenn Hansen of the City of Omaha Public Works Department for providing traffic signal timing data for Omaha;
- Ms. Erin Sokolik of the City of Lincoln Public Works Department for providing traffic signal timing data for Lincoln;
- Mr. Greg Youell of the Metropolitan Area Planning Agency (MAPA) for providing travel time data;
- Mr. Ron Guay of the Nebraska Department of Roads (NDOR) for providing speed data;
- Messrs. Kiel Ova and Jongsun Won of PTV America for providing technical support regarding VISSIM;

Executive Summary

The use of microscopic traffic simulation models in traffic operations, transportation design, and transportation planning has become widespread across the United States because of: i) the rapidly increasing computer power that is required for complex microsimulations; ii) the development of sophisticated traffic microsimulation tools; iii) the increase in comprehensive traffic data sets as the results of Intelligent Transportation System deployments; and iv) the need by transportation engineers to solve complex problems that do not lend themselves to traditional analysis techniques. Microscopic traffic simulation models mimic closely the stochastic and dynamic nature of both the vehicle-to-vehicle and vehicle-to-traffic interactions that occur within the transportation system. Thus, once developed, they provide a convenient environment for analyzing complex transportation systems and evaluating alternatives in a fast, inexpensive, and risk-free manner.

The main objective of this research was to develop a state-of-the-art microsimulation model for the Nebraska State Highway System which can be used by Nebraska Department of Roads (NDOR) designers, planners and traffic engineers. Because accurately and efficiently modeling traffic flow characteristics, driver behavior, and traffic control operations is critical for obtaining realistic microsimulation results, the model was calibrated to Nebraska conditions. In addition, the model is designed so that a wide range of applications can be analyzed. The network consisted of approximately 200 miles of Nebraska roadways including a 102 mile section of Interstate 80 between York and Omaha, a 49 mile section of US Highway 6 between Lincoln and Omaha and a 20 mile section of State Highway 2 between Lincoln and Palmyra. The

microsimulation model VISSIM, version 5.2, was used. However, both the input supply data (e.g., links, nodes, traffic signal timing plans, etc.) and the input demand data (e.g., Origin-Destination matrix, observed traffic volumes, etc.) are available for use in other microsimulation models.

The benefits of this research are threefold:

i. A general, Nebraska-based microsimulation model was developed that is independent of the end application. Therefore, any group within NDOR will have the potential to utilize it in their work. While the NDOR engineers and planners may have to configure and calibrate the model for a given application, this will involve considerably less work than if they had to develop the model from scratch.

ii. It is much more economical to have a single microsimulation model rather than an individual microsimulation model for specific operations. This study leverages the knowledge and data from various NDOR departments. While it is relatively straightforward to run a microsimulation model, it is considerably more difficult to calibrate and validate it. Consequently, because the calibration has been done, the marginal cost of all future applications involving this model will be considerably lower.

iii. The model can be used when explaining complex transportation projects to the general public. The graphics of VISSIM are fairly sophisticated and can be used readily to illustrate complex topics during public meetings.

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Chapter 1 Introduction

1.1 Background

1.1.1 Microscopic Traffic Simulation

The use of traffic simulation models has become widespread in traffic engineering. They are used for a number of applications including operations, planning, and research. They are especially useful for analyzing complex problems that do not lend themselves to traditional analyses techniques such as those described in the Highway Capacity Manual.

Three types of traffic simulation models are currently in use. These are macroscopic, mesoscopic, and microscopic models. They differ in the manner and level of complexity at which traffic flow is modeled. Traffic microsimulation models represent the interaction of the physical transportation system and the users of the transportation system at an individual unit level (e.g., vehicles, people). Macroscopic models describe the traffic stream in terms of aggregate flow (e.g., veh/h, tons/day, etc.) using continuum equations. Mesoscopic models are a hybrid of macroscopic and microscopic models. That is, they describe some aspects of traffic at high level of detail and some at a lower level of detail. For example, vehicles may be modeled as individuals at intersections using discrete queuing theory while their link travel time is modeled using macroscopic speed-density relationships (Kim 2006). Both macroscopic and mesoscopic models require less data input and computing power and are therefore suitable for modeling large networks.

With recent advances in computing power, there has been a proliferation of microscopic traffic simulation models built around the concept of realistic movement of individual vehicles.

A study in 1997 identified over 50 separate commercially available traffic microsimulation packages (Algers et al. 1997), and there is no doubt this list has grown substantially since then. Microscopic traffic simulation models consist of a number of components that interact to model the movement of individual vehicles, both in response to each other's motions and in response to the presence of geometric features on the highway and to the operation of the traffic control system. Each vehicle that enters the network is stochastically assigned a unique set of operational characteristics, which it maintains as it travels through the network (for example, vehicle type and corresponding vehicle characteristics and performance). The interactions among system entities—whether vehicle-vehicle, vehicle-roadway, and vehicle-control device—are modeled based on specific car-following and lane-changing models (Kim 2006). Dynamic behavior is modeled by scanning the network every second or microsecond and updating relevant information associated with each vehicle's movement, such as position and speed. Some of the more well-known microscopic traffic simulation models available for commercial and research purposes in the United States are CORSIM, VISSIM, PARAMICS, INTEGRATION, and SimTraffic. Each of these models incorporates a specific car-following law that describes how a follower vehicle reacts in response to the motion of its leader. In general, other things being equal, the acceleration or deceleration of a leader will be followed in time by acceleration or deceleration of the follower as it tries to maintain or satisfy some postulated operational objectives. The microscopic traffic simulation model VISSIM was selected for this project because of its ability to model multimodal systems and the flexibility provided by its programmable traffic control logic. However, it is important to note that the underlying data that were collected and the underlying input that was estimated are generic in nature. For example, the network or supply information (e.g., links, nodes, traffic signal timing plans) and the demand information (e.g., estimated OD matrix) can be output and used, with some modification, in any other microsimulation model. A brief review of VISSIM is provided in the next section.

1.1.2 VISSIM

VISSIM is a discrete, stochastic, time step based microscopic traffic simulation model with driver-vehicle units modeled as single entities. It was developed by Planung Transport Verkehr (PTV) in Germany (VISSIM Manual 2009). The model consists internally of two distinct components that communicate through an interface—first, a traffic simulator that simulates the movement of vehicles and generates the corresponding output and second, a signal state generator that determines and updates the signal status using detector information from the traffic simulator on a discrete time step basis. The input data required for VISSIM include network geometry, traffic demands, phase assignments, signal control timing plans, vehicle speed distributions, and the acceleration and deceleration characteristics of vehicles. VISSIM allows the user to model traffic signals with three different control types: pre-timed, National Electrical Manufacturers Association (NEMA) standard signal control emulator (which can operate in fully actuated, coordinated, or semi-actuated coordinated modes), and vehicle actuated programming (VAP). The model is also capable of producing measures of effectiveness commonly used in the traffic engineering profession, such as average delay, queue lengths, and fuel emissions (Ambadipudi et al. 2006).

VISSIM incorporates Wiedemann's psychophysical car-following models for longitudinal movement and a rule-based algorithm for lateral movements. The basic idea of a Wiedemann model is the assumption that a driver can be in one of four driving states as he or she travels along a highway section. These states are the free-driving, approaching, following, and braking states (VISSIM Manual 2009).

1.1.2.1 Free driving

In this state, the driver does not observe the influence of preceding vehicles. Instead, the driver seeks to reach and maintain a certain speed, the driver's individually desired speed. In reality, this speed cannot be kept constant, but oscillates around the desired speed.

1.1.2.2 Approaching

In this state, the driver adapts his own speed to the lower speed of a preceding vehicle. While approaching, the driver decelerates so that the difference in speed between the two vehicles is zero at the moment he reaches his desired safety distance.

1.1.2.3 Following

In the following state, a driver follows the preceding vehicle at a more or less constant safe distance without any conscious acceleration or deceleration. However, due to imperfect estimation or perception, the speed difference is not constant but oscillates around 0 mph.

1.1.2.4 Braking

Braking is the application of medium to high deceleration when the distance between two vehicles falls below the desired safety distance. This occurs if a vehicle immediately ahead of the observed vehicle decelerates or if a vehicle moves from an adjacent lane in front of the observed vehicle. The amount of braking is a function of a number of variables including the speed of the various vehicles and the relative distance between the vehicles.

The acceleration of an individual vehicle in a given state is described as a result of speed, speed difference, distance, and individual characteristics of the driver. The driver switches from one state to another as soon as she reaches a certain threshold, defined as a combination of speed difference and distance (Fritsche 1994).

In the VISSIM model, a rule-based algorithm is used to model lateral movements on multi-lane highways. A driver is motivated to change lanes if the preceding vehicle predictably hinders her movement, or it is necessary to stay within a predefined route, such as an upcoming exit with a deceleration lane. Before executing a lane change, the driver checks whether the intended change will improve the present conditions of speed and position. The driver considers the speeds and positions of the vehicle directly ahead of him of her as well as those of the leading and following vehicles in the intended destination lane to determine the potential benefit of the lane change (Kim 2006, VISSIM 2009).

1.1.3 Building and Calibrating a VISSIM Traffic Microsimulation Model

Major steps typically involved in building and calibrating a VISSIM microsimulation model include: i) coding network and signal control elements; ii) assigning traffic demand to the coded network; and ii) calibrating and validating the model. Specific details regarding how these steps were addressed in this project are provided in subsequent chapters. In addition, Appendix A provides a detailed description of the model and basic information for practical use.

1.2 Objective

The main objective of this research was to develop a state-of-the-art microsimulation model for the Nebraska State Highway System which can be used by NDOR designers, planners and traffic engineers. Because the ability to accurately and efficiently model traffic flow characteristics, driver behavior, and traffic control operations is critical for obtaining realistic microsimulation results, the model was calibrated to Nebraska conditions. In addition, it is designed so that a wide range of applications can be analyzed. The network consisted of approximately 200 miles of Nebraska roadways including 102 miles of Interstate 80 between York and Omaha, 49 miles of US Highway 6 between Lincoln and Omaha; and 20 miles of State Highway 2 between Lincoln and Palmyra. All major highways and arterial roadways that crossed perpendicular to the network roads were included. These cross streets were modeled to a distance of approximately half a mile or to the first traffic signal. Supply data, including number of lanes, speed limit, lane width, traffic signal timings, etc. were obtained from various state and local agencies. Demand data was estimated from empirical traffic data. The microsimulation model VISSIM was used in this project and the model was calibrated to empirical traffic data.

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iii. The model can be used when explaining complex transportation projects to the general public. The graphics of VISSIM are fairly sophisticated and can be used readily to illustrate complex topics during public meetings.

1.3 Organization of the Report

The report is organized into five chapters. Chapter 1 provides an overview of microsimulation modeling with an emphasis on the VISSIM software. It also summarizes the main objectives of the study. Chapter 2 describes the test bed and data, and it also discusses the steps involved in developing the supply components of the model. Traffic demand estimation and traffic assignment are discussed in Chapter 3. Chapter 4 discusses model calibration. Chapter 5 concludes the report and also highlights the challenges encountered in the study, as well as the potential benefits and applications of the final model. Lastly, Appendix A describes the input data sets in detail.

Chapter 2 Model Development

In recent years, traffic microsimulation packages have become an important modeling tool for various aspects of transportation planning, design, and operations. This chapter provides a brief overview of microsimulation models and describes the development of the Nebraska VISSIM-based microsimulation model. Specific topics includes the demand information (e.g., point-to-point trip movements, link volumes, vehicle routes, etc.), the supply information (e.g., links, nodes, traffic control system), and their interaction. The demand estimation and model calibration procedures are described in Chapters 3 and 4, respectively.

2.1 Traffic Microsimulation Model Overview

Traffic microsimulation models attempt to represent the interaction of the physical transportation system or the supply (e.g., roadways, intersections, traffic control, etc.) and the users of the transportation system or demand (e.g., routes, driver characteristics, etc.). The term "micro" refers to the fact that these models operate at an individual unit level (e.g., vehicles, people). This is in contrast to macroscopic models which operate at an aggregate level, which might be represented as veh/h.

Figure 2.1 provides an overview of the information flow for a generic microsimulation model. There are two basic inputs: supply (box I) and demand (box II). The supply consists of 1) the physical attributes of the network, and 2) the operating strategies of the transportation agency. An example of the former would be a one-lane roadway. If the roadway width were expanded to two lanes then the capacity would increase, as would the network supply. An example of the latter would be a traffic signal at an intersection that operates according to the transportation agency's signal timing plan. If the traffic signal timing were optimized, the capacity would increase, as would the network supply.

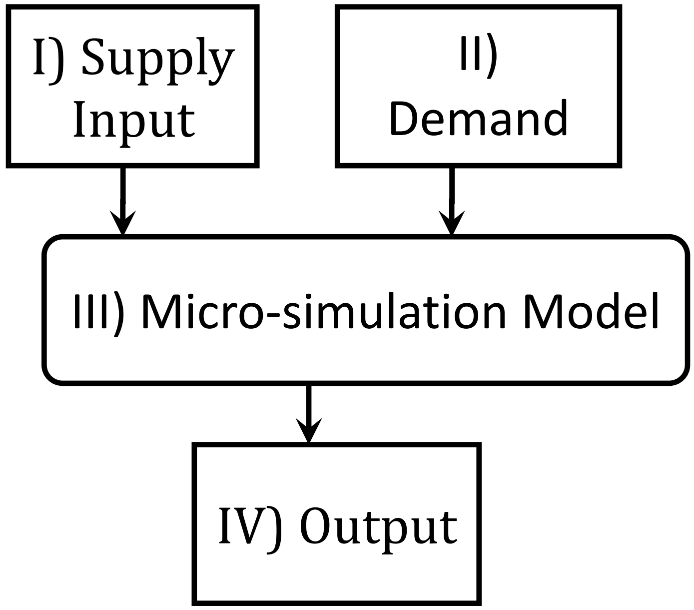


Figure 2.1 Overview of the modeling process

Note that the supply is typically under the direct "control" of the decision makers in charge of the transportation network. For example, they can add more lane-miles, change the use of lanes (e.g., high occupancy vehicles), or change signal timing plans with the hope of improving performance. In contrast, transportation authorities have limited ability to manage demand. For example, often they do not have control over prices for using the network and have to use indirect approaches to control prices such as ramp metering or managed lanes techniques.

Most transportation models treat the physical component of the supply as a mathematical representation of nodes and links/connectors, and VISSIM is no exception. The attributes of nodes typically include location coordinates—x, y, and possibly z—and type of signal control, as in, uncontrolled, stop sign, or traffic signal. The nodes often represent intersections, although strictly speaking they are used to represent the beginning and end of a link. The links connect nodes and represent homogeneous sections of the roadway network, and their attributes could include number of lanes, speed limit, grade, and so on.

For illustration purposes, figure 2.2 shows a section of a VISSIM traffic network in Omaha, Nebraska, and it can be seen that the traffic network is represented by a series of links and nodes. Figure 2.3 presents a snapshot of a microsimulation from this network. This figure features a signalized intersection located at an off-ramp along the interstate highway. It can be seen that different vehicle types and traffic control can all be modeled and displayed to the user. The visualization aspects of microsimulation models make them powerful tools for communicating with decision-makers and the public. It should be noted that it is relatively easy to code these types of networks, run the microsimulation model, and display the results. It is considerably more difficult to confirm that the model is actually an appropriate representation of reality.

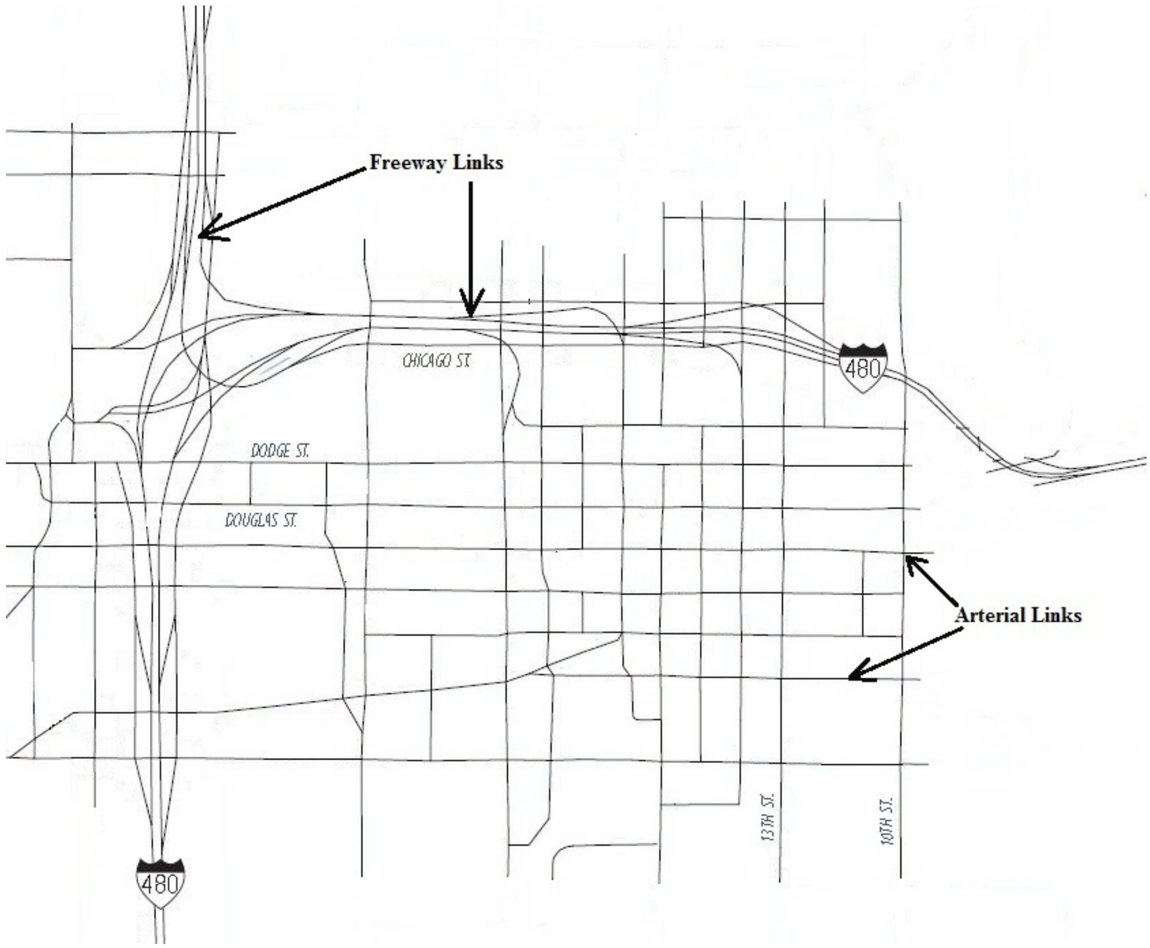


Figure 2.2 Schematic of small network in Omaha, Nebraska

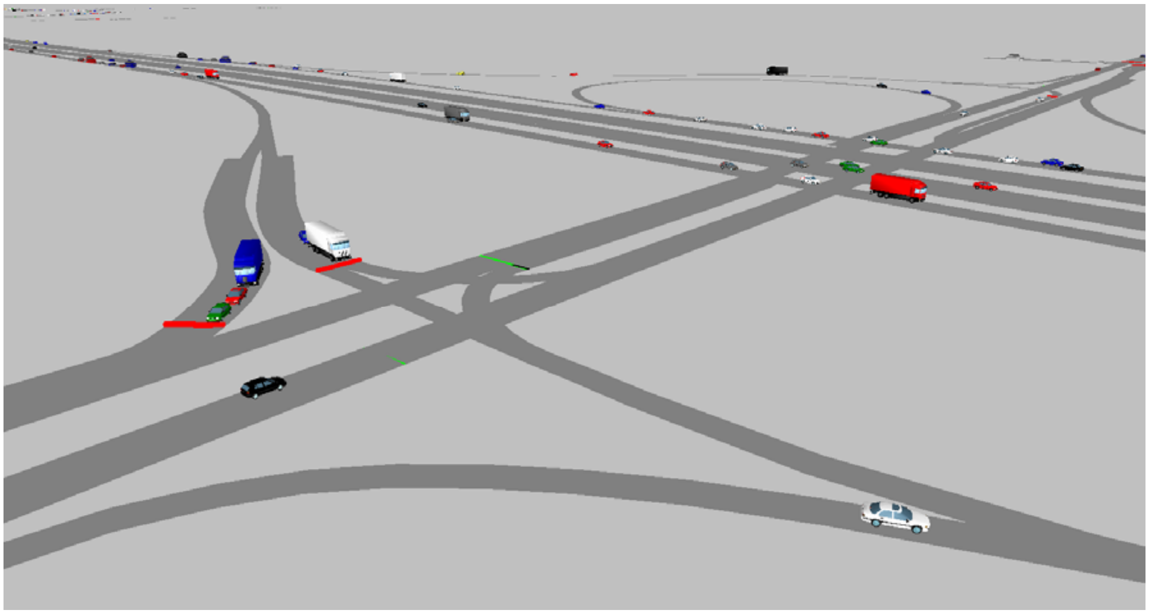


Figure 2.3 Snapshot of VISSIM simulation of Omaha interchange

Figure 2.4 shows a detailed view of an interchange from the Omaha network. The nodes (circles) and links (solid lines) are shown explicitly. In this figure, the direction of movement is indicated by the arrows. It should be noted that nodes are sometimes used to represent locations where the roadway characteristics change. Also, because two links cross on a two-dimensional plan view of the network, there is a node located at the intersection of the links. Grade-separated road crossings, for example, would not have a node.

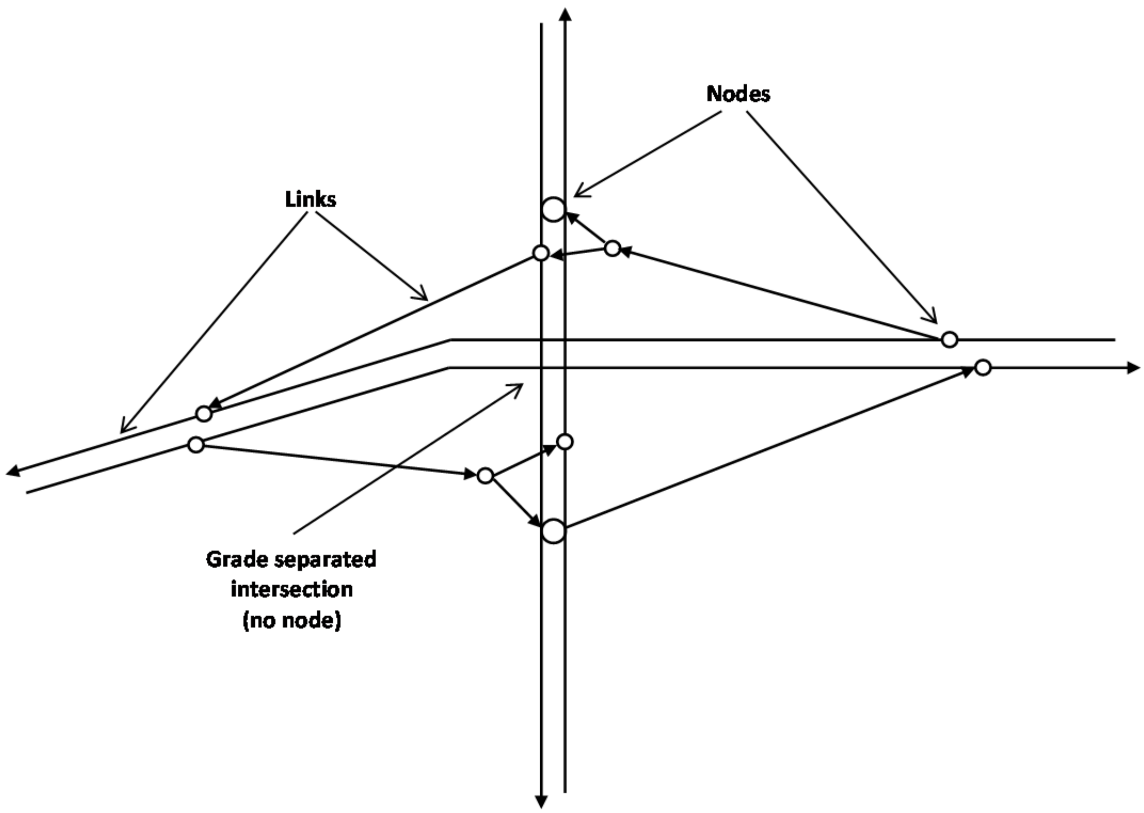
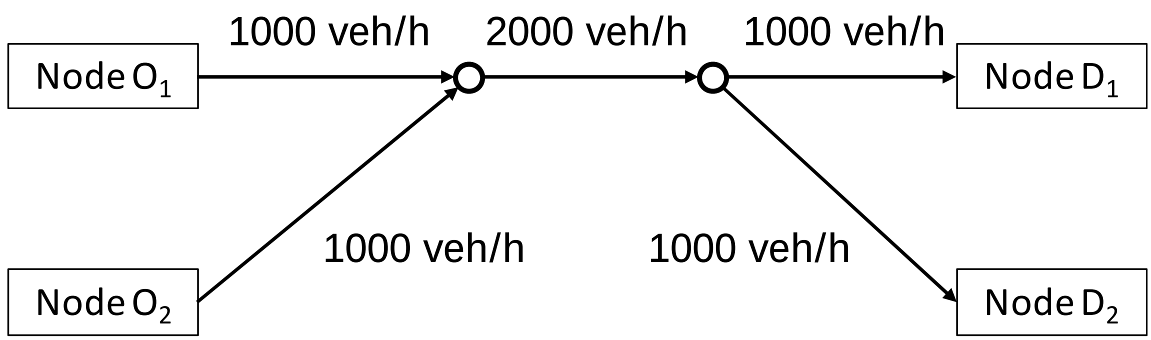


Figure 2.4 Detailed view of Omaha interchange showing nodes and links

The second input (shown in box II in figure 2.1) is the transportation demand. The demand typically takes the form of an Origin-Destination matrix where the number of vehicles is defined by drivers who wish to travel from a given node *i* to a given node *j* and those drivers who wish to depart their origin within a specific time period. The input for each OD pair also includes the percentages of each vehicle types (e.g., passenger cars, buses, tractor trailers, etc.), the characteristics of each vehicle type (e.g. acceleration and braking capabilities), the driver types, and the driver type attributes (e.g. perception reaction time, driving aggressiveness, etc.). If the traffic demand does not change over the course of the simulation, then the model is defined as a static; otherwise, it is defined as dynamic.



OD Matrix I: No Weaving		
From\To	**Node D_1**	**Node D_2**
Node O_1	**1000**	**0**
Node O_2	**0**	**1000**

OD Matrix II: Weaving		
From\To	**Node D_1**	**Node D_2**
Node O_1	**0**	**1000**
Node O_2	**1000**	**0**

Figure 2.5 Example of OD matrices and effect on weaving

It should be noted that some packages, including VISSIM, allow the user to input demand in the form of 1) observed volumes entering the links and 2) turning movement percentages at intersections. The main advantage of this approach is that field data of the latter type is much easier to obtain than an OD matrix. The disadvantage of this approach is that the modeler has little to no control over route choice and the interaction of vehicles. For example, consider figure

2.5, which shows a simple network with observed volumes and two potential OD matrices. It is relatively easy to show that there are a large number of OD matrices that would result in the observed volumes and turning movements. For example, if VISSIM were to run OD atrix I to represent the demand, there would be little to no weaving. Conversely, if OD Matrix II were used to represent the demand, there would be considerable weaving. Needless to say, the amount of weaving will affect the simulation results, and the only way for a user to control this aspect of the microsimulation is to use an OD matrix. The latter approach is recommended and was the method used in this report. As will be discussed later, estimating and/or observing large OD matrices is not a trivial problem (Cascetta et al. 1993; Davis and Nihan 1991).

In general, the user defines a specific length of simulation time (e.g., from 3 PM to 8 PM) as part of the input. The microsimulation program progresses through the modeling process in small time increments while simultaneously modeling the interaction between the individual units or vehicles as they enter the network at their origin nodes, traverse it while interacting with the traffic control as well as other vehicles, and depart at their destination nodes. This process is represented by box III in figure 2.1. The time step in VISSIM is user-defined and can vary from 0.1 sec to 1 sec. In this report, a value of 0.1 sec was used.

Note that the demand is typically entered as a deterministic number (veh/hr) rather than an individual vehicle movement. In figure 2.5, for example, the demand from Node 1 to Node 3 might be input as 1,000 veh/hr. The user would input this along with attributes such as origin node, destination node, vehicle type percentages, and driver type percentages. This approach saves significant time because the user does not have to input data for all 1,000 vehicles. Instead, the program translates this deterministic number into individual vehicle movements that have specific attributes which correspond to the macroscopic input.

Modeling large networks at a decisecond (e.g., 0.01 second) time step interval will result in a considerable amount of data available for analysis. Consequently, the user typically has discretion in the information that is output (e.g., box IV in figure 2.1) as part of this process, the form it should take, and its frequency. Typical output may be categorized as 1) information related to the individual vehicles statistics, 2) information related to specific links and/or intersections, and 3) information related to the system as a whole. In addition to aggregated data from the entire simulation, users can typically request output in specific time periods (e.g., xx minute increments where xx is typically set to 5, 15, 30 or 60 min).

Lastly, the microsimulation program developers assume the user is familiar with the assumptions underlying the logic of the model. The standard microsimulation models all have default parameters, such as a value for lambda in the Poisson distribution for vehicle departures. As a result, the user does not necessarily need to calibrate the model before running it. Consequently, if users provide input in the proper format and runs the microsimulation program, they will get output. It is then up to the user to decide how "good" the simulation results are, a concept which will be explored further in Chapters 3 and 4.

2.2 Test Bed

In conjunction with the Technical Assistance Committee (TAC), the Interstate 80 freeway travel corridor between York, Nebraska, and Omaha, Nebraska, was identified as the microsimulation network. This corridor is a major conduit for both freight and passenger trips in the United States (NDED 2011). Figure 2.6 shows the 200 miles of roadway that comprised the network used in this report. It can be seen that the main roadways include:

i. 102 miles of Interstate 80. The western boundary is the I-80/US 81 interchange in York, Nebraska, and the eastern boundary is the Nebraska-Iowa border;

ii. 4 miles of Interstate 480/US-75 in Omaha, Nebraska. The southern boundary is the I-480/I-80 interchange and the northern boundary is the I-480/Storz Expressway interchange;

iii. 5 miles of the Storz Expressway in Omaha, Nebraska. The western boundary is the US 75 interchange and the eastern boundary is the Lindberg Drive intersection near Eppley Airfield;

iv. 3.2 miles of US-75 in Omaha, Nebraska. The northern boundary is the I-80/US 75 interchange and the southern boundary is the Chandler Road intersection;

v. 13 miles of Interstate I-680 in Omaha, Nebraska. The western/southern boundary is the I-80/I-680 interchange and the northern/eastern boundary is the Nebraska-Iowa border;

vi. 4 miles of Interstate I-180 in Lincoln, Nebraska. The northern boundary is the I-80/I-180 interchange and the southern boundary is R Street;

vii. 49 miles of US Highway 6. The western boundary is the Highway 6/I-I80 interchange in Lincoln, Nebraska, and the eastern boundary is Highway 275, and specifically the I-80 and L Street interchange; and

viii. 20 miles of State Highway 2. The western boundary is the US Highway 77 interchange in Lincoln, Nebraska, and the eastern boundary the A Street intersection in Palmyra, Nebraska.

Figure 2.6 Nebraska I-80 test bed (© 2011 Google)

It is important to note that the network is current as of August 2010. Any changes to the network from that date will need to be added.

In addition, all major highways and arterial roadways that crossed perpendicular to the network roads were included. These cross streets were modeled to a distance of approximately half a mile or to the first traffic signal. Figure 2.7 shows a diagram of one highway-arterial roadway intersection in Omaha.

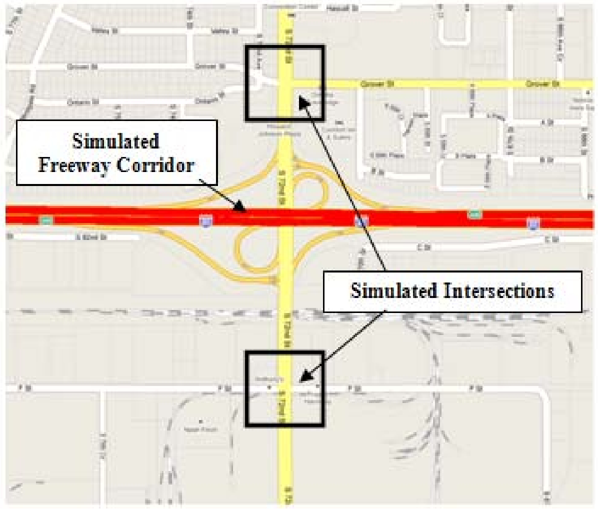


Figure 2.7 Omaha intersection showing simulated intersections on either side of I-80 (© 2011 Google)

The highway sections were selected for simulation based on the availability of supply data such as lanes, lengths, traffic signal timing plans, and ramp locations; the availability of demand data such as traffic volumes and vehicle types; the availability of ITS data; and the relative importance of the sections to NDOR. In all, there are 1,346 nodes, 6,803 links, 170 signalized intersections, and approximately 200 mi of roadway in the network.

2.3 Test Bed Supply and Demand Data

The primary supply input required for modeling the test bed included background maps, roadways, intersections, and traffic control information. Roadways were coded as links and connected to intersections, which were coded as nodes. The major attributes of the coded supply elements included:

i. Link attributes: number, length, width, grade, and any distinguishing features of the link such as the location of lane drops, auxiliary lanes, the presence and location of speed reduction zones, and how links connect to each other and to nodes in the network;
ii. Node attributes: locations of on-ramps of off-ramps, weaving sections, intersections and the number of approaches, lane widths, and degree and length of curvature; and
iii. Type of intersection control: signal-controlled, stop-controlled, or uncontrolled, and the corresponding attributes of each control type, including signal and detector locations, signal timing plans, and priority rules for conflicting traffic.

The majority of the supply input data were obtained from engineering drawings and signal timing plans provided by the public works departments of the cities of Lincoln and Omaha. Other supply data sources included background images downloaded from Google Earth and still photographs captured with standard cameras during a physical tour of the network. A comprehensive listing of network elements, attributes, and access information is provided in Appendix A. A CD-ROM containing the various files is also provided with this report.

Demand data in the form of point-to-point trip movements as represented by an Origin-Destination trip matrix were not available. Instead, annual daily traffic (ADT) data were obtained from the Metropolitan Area Planning Agency (MAPA) of Omaha-Council Bluffs, the Nebraska Department of Roads (NDOR), and the cities of Lincoln and Omaha. The ADT data were used to estimate the OD flows. The OD estimation procedure is discussed in Chapter 3.

2.4 Model Development

2.4.1 Supply: Network Geometry

Like most simulation models, VISSIM requires a detailed description of network geometry (of the site under study) in order to produce a realistic output. In VISSIM, the recommended method for entering the geometric data is to construct a scaled map. The scaled map is displayed as a background image in the program. This allows the user to easily trace the links, connectors, and other elements that constitute the supply side of the model.

Because of the large size of the network used in this project, multiple images were downloaded for various sections of the test bed. These images were imported into VISSIM and then carefully merged to provide a detailed and consistent view of the network geometry. The simulation network was then traced on the background as combinations of links, nodes, and connectors. Detailed attributes of the network such as number of lanes, lane widths, elevation, and curvature were coded.

2.4.2 Supply: Traffic Control

The successful modeling of a transportation network in VISSIM depends to a large extent on how well the traffic control logic operating in the field is emulated. A combination of signal heads, stop signs, and priority rules may be used to control traffic in the microsimulation model. VISSIM allows the user to model traffic signals with three different control types: pre-timed; NEMA standard signal control emulator operating in a fully actuated, coordinated, or semi-actuated coordinated mode; and vehicle actuated programming (VAP). For stop-controlled intersections and certain signal-controlled types such as those that allow permissive movements, priority rules were used to designate the right-of-way to potentially conflicting traffic. Priority rules were set to conform to those specified in the Nebraska Driver's Manual (Nebraska Driver's Manual 2010).

In this study, the NEMA standard signal control emulator was used to model traffic control at signalized intersections. The NEMA emulator replicates standard or typical traffic signal controller operations specified by the National Electrical Manufacturers Association. Signal control information provided by the cities of Lincoln and Omaha was coded into a graphic user interface (GUI) in the VISSIM emulator. This information included phase assignments, maximum and minimum green times, detector lengths and locations, passage times, and detector call options.

The latest version of VISSIM, referred to as version 5.30, has replaced the NEMA control emulator with a Ring Barrier Control (RBC). However, as of December 2011 this version had a number of unresolved issues that prevented it from running the Nebraska network. Based on personal communications with PTV America this had to do with the large number of signalized intersections included in the network discussed in this report. Consequently, version 5.2 of VISSIM was used as it was able to run the network.

The information from the traffic detection type—either video or loop—at each intersection was obtained from intersection blueprints and coded accordingly. Video detection was coded in VISSIM using single detectors of lengths 50 ft per lane.

2.4.3 Demand: Vehicle Types, Vehicle Characteristics, and Traffic Composition

An unlimited number of vehicle types exist in VISSIM, allowing the user to model a full range of multimodal operations (VISSIM Manual 2009). Vehicles of the same type share common performance attributes. These attributes include vehicle model, minimum and maximum acceleration, minimum and maximum deceleration, weight, power, and length. Each vehicle that enters the simulation network is stochastically assigned a unique set of attributes which it maintains as it travels through the network. The speeds and positions that are actually realized in the course of the simulation are the result of interactions among system entities (vehicle-vehicle, vehicle-roadway, and vehicle-control device). Dynamic behavior is modeled by scanning the network every second or microsecond and updating speeds and positions based on specific car-following and lane-changing models (Kim 2006). For this research, three vehicles types were used: “Car,” “HGV,” and the “Pedestrian.” Default performance attributes for these vehicle types were utilized (VISSIM 2009). The composition of the traffic generated at a given source in the simulation network is a combination of the simulated vehicle types.

2.4.4 Traffic Demand

In addition to the supply components described above, VISSIM requires the appropriate traffic demand data. In VISSIM, traffic demand can be defined in one of two approaches. The first approach is to use aggregate vehicle volumes and to route or direct traffic using turning ratios at intersections, which are input by the user based on observed or assumed data. The alternative, and more realistic approach, is to define traffic demand as a set of Origin-Destination matrices. Basically, the OD matrix provides the average number of vehicles of a given class going from every origin to every destination in the network at specified time intervals. That is, in addition to assigning a set of vehicle and driving behavior characteristics, each randomly generated vehicle-driver unit is assigned a preferred destination as well as a preferred route. In this way the interaction between vehicles as they travel through the network can be explicitly modeled. A detailed description of the traffic demand estimation process used in this study is described in the next chapter. Other tasks involved in the model development process included assigning the demand to the simulation network and calibrating the model to local conditions. Traffic assignment is also described in the next chapter while model calibration is described in Chapter 4.

2.5 Concluding Remarks

This chapter introduced the key concepts about microsimulation models, including supply, demand, and their interactions. The test bed for the Nebraska network and the input data were both described. Specific information related to the data files may be found in Appendix A. The following chapters will described the OD estimation and model calibration processes.

Chapter 3 Demand Estimation and Traffic Assignment

A fundamental input to transportation systems analysis tools, including traffic microsimulation models, is the traffic demand. As discussed in Chapter 1, for large networks such as the Nebraska I-80 network, it is best if the demand information takes the form of an Origin-Destination (OD) trip matrix. The OD matrix reflects the spatial and temporal distribution of traffic between all origins and destinations in a transportation network over a given time interval. This means it can provide more realistic simulation results. While it is relatively straightforward to build the supply component of a traffic microsimulation model and run the model, it is considerably more difficult to measure and/or estimate a reliable Origin-Destination (OD) demand matrix.

In the past, simplified versions of the OD matrix were measured directly, albeit with much effort and at great cost, by conducting individual interviews, license plate surveys, or by taking aerial photographs. Certain networks, such as toll roads, can measure the OD directly. However, this is not the case for roadway networks such as the Nebraska I-80 network. Because collecting direct measurements to populate a traffic matrix tends to be cost-prohibitive, there has been considerable effort to develop synthetic techniques that provide "reasonable" estimates for the unknown OD matrix. Not surprisingly, these estimation techniques use readily available data, such as link volume counts, and will be discussed in the next section.

3.1 Overview of Synthetic OD Estimation Techniques

Numerous approaches to synthetic OD matrix estimation have been proposed in the literature (Bierlaire 1995; Dixon and Rilett 2000). In general, these techniques attempt to replicate the “true” OD matrix based on readily available data source(s). In other words, there is not a direct observation of the “true” OD matrix but rather a consistent OD matrix is estimated for the observed data.

Information used in synthetic OD estimation techniques includes i) OD matrices from previous studies; ii) growth rate over a given time span; iii) some combination of the expected total number of trips originating from and attracted to each traffic analysis zone (origins and destinations); iv) travel costs (time, toll, distance, etc.) on links and/or between OD pairs; and v) the volumes of traffic on links connecting various OD pairs. Depending on what information is available, a number of synthetic estimation techniques may be employed. These include growth factor models, gravity model, entropy-maximizing and information-minimizing models like traffic count-based model, or a combination of these (Ortuzar and Willumsen 2001).

3.1.1 Growth Factor Models

The growth factor method updates an old OD matrix—sometimes called base, prior, or reference matrix—using information on the observed or projected growth rate, information on the expected number of trips originating from or attracted to each zone, or both.

If the only information available is a uniform growth rate over time for the entire study area, then the old matrix is updated by applying this factor to every cell in the old matrix (Ortuzar and Willumsen 2001).

$$T_{ij} = \tau t_{ij} \tag{3.1}$$

where,

T_{ij}: Expected number of trips from origin i to destination j in updated OD matrix;

t_{ij}: Number of trips from origin i to destination j in reference OD matrix;

τ : Uniform growth factor.

In cases where information is available on either the expected total number of trips originating from (origin constrained) or attracted to (destination constrained) each zone, then the reference matrix is updated by substituting an origin-specific growth factor, τ_i or a destination-specific growth factor, τ_j for the uniform growth factor in equation 3.1. On the other hand, if information is available on the expected total number of trips at both trip-ends (doubly constrained), then a bi-proportional algorithm, may be employed to calculate factors a_i and b_j (equation 3.2) such that both the origin and destination constraints are satisfied.

$$T_{ij} = a_i b_j t_{ij} \tag{3.2}$$

The bi-proportional algorithm updates the old matrix by successively adjusting the factors a_i and b_j in an iterative manner until convergence is reached.

The growth factor method is simple to understand and may be readily implemented in a spreadsheet. However, the multiplicative nature of the updates suggests that if any cell of the reference matrix is unobserved (or zero) they will remain so in the updated matrix (Bierlaire 1995). Another drawback is that the method does not use information on travel costs thus making it unattractive for the analysis of policy options involving new links, pricing, and so on (Ortuzar and Willumsen 2001).

When available, information on travel costs may be combined with the trip end totals in a tri-proportional approach to improve the doubly-constrained growth factor method. The travel costs are aggregated into small number of cost bins (or ranges). The method updates the old matrix by successively adjusting the elements of the matrix until the trip end totals as well as the trip length (cost) distribution constraints are met. While the tri-proportional method is a slight improvement over the growth factor method, it implicitly assumes that the trip length distribution does not change. This limits its application to only short term updates when this assumption is fairly reasonable (Bierlaire 1995; Ortuzar and Willumsen 2001).

3.1.2 Gravity Model

The gravity model has been in existence for over a century. It is based on an analogy between the spatial interaction of trip making and Newton's gravitational law (Meyer and Miller 2000). In its simplest form, it is assumed that the number of trips T_{ij} between origin i and destination j is proportional to the number of trips leaving i, O_i and the number of trips attracted to j, D_j but inversely proportional to the square of the cost, c_{ij} of traveling from i to j. Mathematically,

$$T_{ij} = \alpha \frac{O_i D_j}{c_{ij}^2} \tag{3.3}$$

where,

α : Constant of proportionality.

In most practical applications, a more realistic and flexible formulation that does not restrict the effect of travel costs is employed. In this case, the effects of the travel costs are model by incorporating an "impedance" function of the costs $f(c_{ij})$ such that

$$T_{ij} = O_i D_j f(c_{ij}) \tag{3.4}$$

The impedance function, $f(c_{ij})$ typically has one or more parameters that need to be calibrated depending on the particular contest. To solve the gravity model, the calibrated impedance function is used to estimate an unconstrained trip matrix, meaning trip-end totals may not match, T_{ij}^{u}. The unconstrained matrix may be scaled to match the total trips variable $T_{..}$ and then adjusted to match the trip-end totals (O_i and D_j) using the bi-proportional algorithm with the unstrained matrix serving as the prior or reference matrix.

Much of the representational and policy relevance of the gravity model lies in the impedance function. Whereas the growth factor methods do not use information on travel costs or, at best, uses only aggregate cost information, the gravity model incorporates travel costs for all cells into the OD matrix estimation process.

3.1.3 Link Traffic Count Based Models

The OD matrix can be viewed as an input to a traffic assignment process, the outputs of which are the traffic volumes on the network's links. As a result, an alternative and increasingly popular approach to OD matrix estimation is to start with observed link traffic volumes and somehow "invert" the traffic assignment procedure to obtain the OD matrix (Davis and Nihan 1991).

The challenge with estimating the unknown OD matrix using link volume count data is that the problem is generally underspecified. That is, the number of OD estimates required is often considerably greater than the number of observations from the system. Consider the Nebraska network, for example, and assume that the external nodes serve as potential origins and destinations, or, that it is assumed that a trip can't begin or end at a signalized intersection. In this case there are approximately 145 origin nodes, 145 destinations, which translates to 20,880 OD pairs. If each link on the network were monitored, that would result in approximately 6,800 observations. For example for this network it is theoretically possible to observe the traffic volume on the 6,800 links that make up the network. Because the user needs to estimate significantly more parameters (e.g., 20,880 OD flows) than the available number of traffic count observations (6,800), the problem is underspecified. The end result is that an infinite number of feasible OD trip matrices can reproduce a given set of traffic count data. A simplified version of this problem was shown in figure 2.5. Consequently, various forms of additional constraints and *a priori* knowledge are needed to establish the "best" solution out of the set of possible solutions. Additional criteria might be in the form of metrics related to the "closeness" of the results to i) observed link travel speeds or travel times; ii) average travel time/distance on the network; iii) empirically estimated path choice proportions; and iv) a prior or sampled OD trip matrix.

The OD trip matrix estimation problem seeks to find the OD matrix, closest to a prior matrix (or consistent with some other *a priori* information), and that when assigned to the transportation network reproduces the link volume counts as closely as possible. A weighted formulation is often adopted to combine the link volume count data and the *a priori* information as shown in the equation below:

$$\min f(V_a, T_{ij}) = \beta_1 f_1(V_a, v_a) + \beta_2 f_2(T_{ij}, t_{ij}) \tag{3.5}$$

where,

T_{ij}, t_{ij}: Estimated and target (*a priori*) values of "additional criteria" for OD pair *ij*, respectively;

V_a, v_a: Estimated and observed link volume counts for link *a*, respectively;

f_1, f_2: Distance measures; and

β_1, β_2: Weighting factors.

The distance measures, f_1 and f_2, provide an indication of the "closeness" between the observed link volume counts and the estimated counts and the "closeness" between the values of the estimated and observed values of the *a priori* information, respectively. The *a priori* information may include the OD matrix, travel times, and travel speeds. The functional form of the functions f_1 and f_2 depends on the available information, as well as the probability laws associated with such information (Cascetta 2001). A number of functional forms have been proposed in the literature. The most common ones are based on the concepts of maximum likelihood, generalized least squares, Bayesian inference, information minimization, and entropy maximization. The values of the weights β_1 and β_2 are determined based on the accuracy or reliability of the observed link volume counts and the *a priori* information. If the additional information is reliable and accurate, β_2 is large compared to β_1 and results in a T_{ij} close to t_{ij}. If, on the other hand, the observed link counts are more reliable compared to the prior OD matrix, then the magnitude of β_1 is larger than that of β_2. This produces an estimated OD matrix that reproduces link volume count estimates closer to the observed link volume counts, while allowing a larger deviation between the estimated and target values of the *a priori* information. The choice of a particular synthetic OD estimation procedure for a study depends on the type of information available, the purpose of the study, and other available resources.

3.2 Estimating the OD Matrix for the I-80 Network

3.2.1 Data

With respect to the Nebraska I-80 network, a total of 20,880 OD volumes need to be estimated. Note that the OD matrix is considered sparse, in that many of the estimated volumes may be quite low or even zero. As discussed earlier, the origins and destinations were set to match the points of entry to and exit from the network. The total number of trips, known as trip end totals, originating from and attracted to each origin and destination point during the peak hour were calculated from archived average daily traffic (ADT) data using equation 3.6 (Nebraska Department of Roads 2005).

$$TE_{ki} = a_i + b_i(ADT_k) \tag{3.6}$$

where,

TE_{ki}: Total number of trips originating from or attracted to an origin or destination k;

ADT_k: Total ADT on links associated with origin or destination k;

i: 0 for urban interstate, 1 for other highways and streets;

b_i: Regression coefficient (0.476 for i =0 and 0.464 for i =1); and

a_i: Constant term (118.08 for i = 0 and 50.51 for i = 1).

3.2.2 OD Estimation Algorithm

With the trip end totals known, a gravity model in the form shown in equation 3.7 was used to populate the cells of the OD matrix.

$$T_{ij} = a_i b_j f(c_{ij}) \tag{3.7}$$

where:

T_{ij}: Number of trips between origin i and destination j;

a_i, b_j: Trip end adjustment factors;

$f(c_{ij})$: Deterrence function of the form;

$$f(c_{ij}) = \sum_m F^m \delta_{ij} \tag{3.8}$$

where:

F^m: Deterrence factor for cost bin m; and

δ_{ij}: 1 if c_{ij} falls in the range of cost bin m and, 0 otherwise.

This formulation of the gravity model was used in this study because it offers flexibility when choosing a deterrence function; it is also relatively easy to calibrate. This is because it allows the user to define any number of cost bins, and the deterrence function can take any positive value for them (Ortuzar and Willumsen 2001). In this study, this flexibility was particularly useful because of the bimodal nature of the distribution of expected travel times for inter-city and intra-city trips within the test ted. The expected trip length frequency distribution was adapted from that of the city of Lincoln-Lancaster county (Lincoln MPO) travel demand model (Lima and Associates 2010).

Calibration of the gravity model involved finding suitable values for the deterrence factor for each cost bin so that the number of trips undertaken at that cost is as close as possible to the observed number. A tri-proportional algorithm was used. Starting with a value of one for the deterrence factors, the tri-proportional algorithm was used to successively correct the deterrence factors and the parameters a_i and b_j until the target trip end constraints as well as the trip length frequency distribution were matched.

Figure 3.1 summarizes values of the deterrence factors obtained after 1,000 iterations of the algorithm. The corresponding estimates of the number of trips per cost bin and their expected values are also shown in figure 3.2. The balancing factors a_i and b_j converged to approximately 1.0 in all cases.

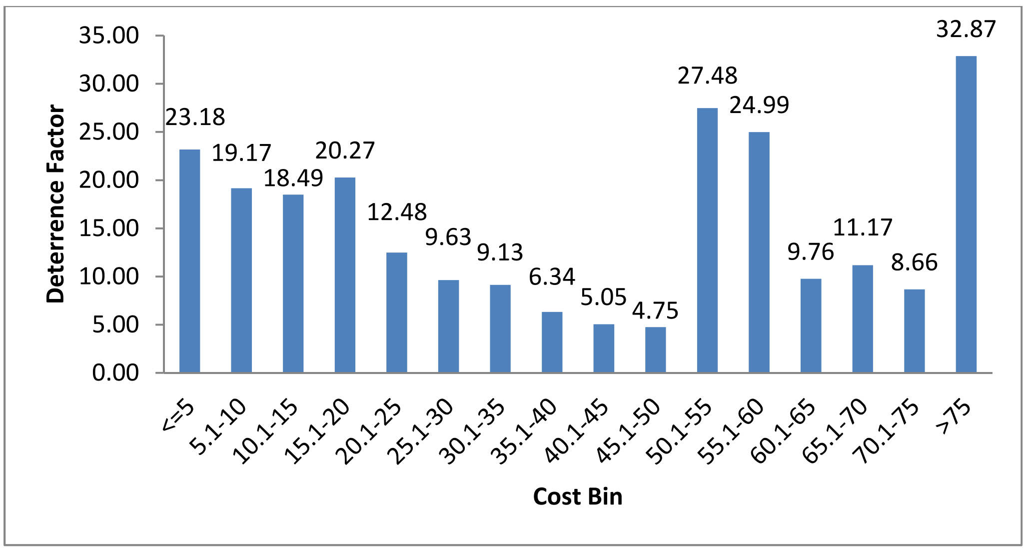


Figure 3.1 Deterrence factors for gravity model

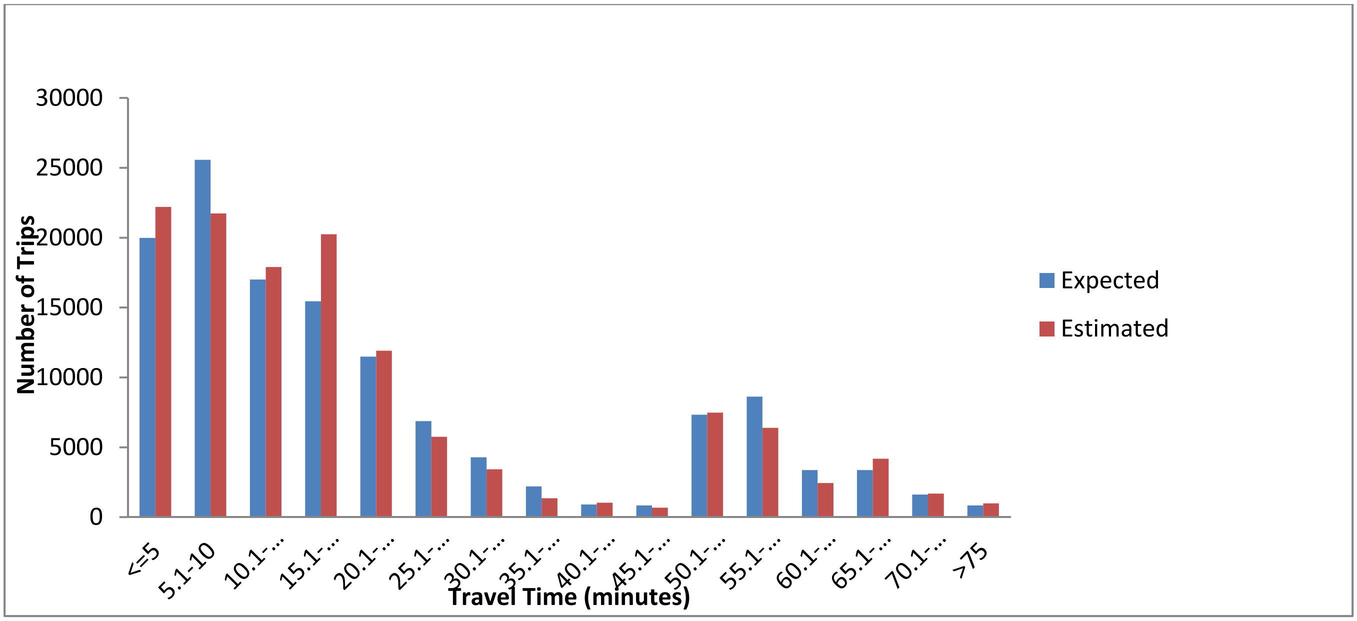


Figure 3.2 Trip length distributions

3.3 Traffic Assignment

With the supply components in place and the traffic demand estimated, the next task was to specify routes used by drivers to travel from their origins to their intended destinations. Even though the test bed is for the most part linear and route choice was generally not expected to be an issue, it was not very feasible to trace the routes manually in VISSIM because of the large size of the simulation network and the large number of OD pairs (20,880). Consequently, the dynamic traffic assignment (DTA) routine in VISSIM was used to “identify” reasonable routes and to assign the OD demand to the network.

The VISSIM DTA routine uses an iterative simulation approach to dynamically assign traffic to the network. In essence, a modeled network is simulated repeatedly, and drivers choose their routes based on the travel costs experienced in preceding simulations, including travel time, delay, toll, and so on,. For a given OD pair, the simulations begin with the travel costs on all routes set proportional to the sums of the lengths of the links that constitute the route. Subsequent iterations are performed with the travel costs set equal to a weighted average of all previous iterations, such that higher weights are assigned to the most recent iterations. The iterations are typically continued for a pre-specified number of maximum iterations or until the link volumes and travel times on all edges remain fairly constant. A flowchart of the DTA process is shown in figure 3.3 (VISSIM Manual 2009).

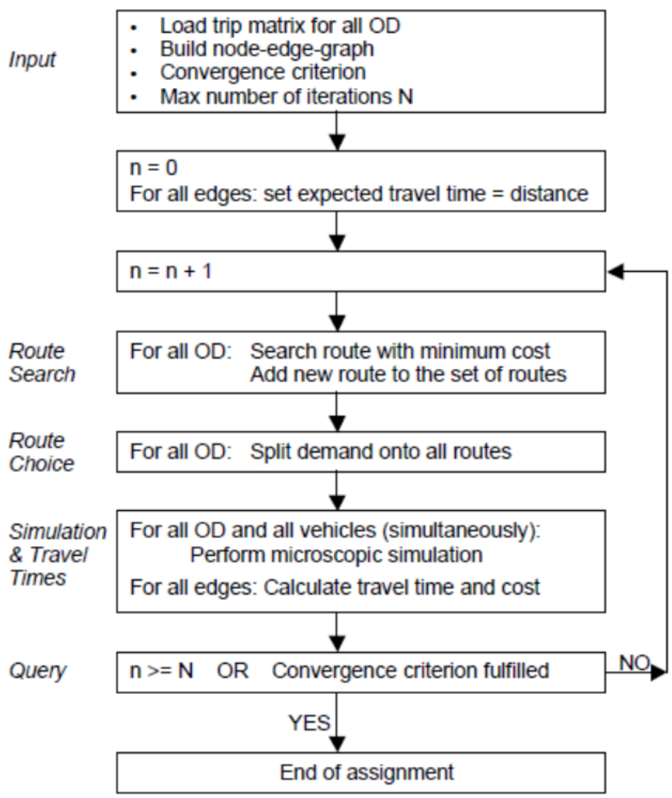


Figure 3.3 Flowchart of dynamic traffic assignment

A total of 20 DTA iterations were performed. To avoid unrealistic levels of congestion during the first few iterations, the travel demand was applied to the network in stages. The first iteration was performed with only 10% of the OD demand and then increased by 5% on subsequent iterations, such that by the twentieth iteration, all the demand was assigned onto the network.

3.4 Concluding Remarks

This chapter dealt with the estimation of the OD matrix for the I-80 network. Note that the model can be adapted if other or additional traffic information becomes available. As well, the OD model can be defined based on specific times of day, such as the PM peak period, if required. In addition, it was assumed that a full OD matrix was required. However, if the user needs only a small subset of the network, then other techniques can also be used.

Careful coding of network geometry and signal control logic and the availability of a reliable estimate of traffic demand are essential for the proper functioning of a traffic microsimulated model. However, these steps do not guarantee realistic model results for all situations. In general, the default parameter values incorporated into microscopic traffic simulation models are not directly applicable to all transportation networks and driver populations. In order for the model to yield realistic results for a particular study, it is often necessary to adjust the default model parameter values such that the model reasonably reproduces local driver behavior and matches local field data. This is the subject of the next chapter.

Chapter 4 Model Calibration

Microscopic traffic simulation models have default parameters that might not be representative of the conditions that prevail at a particular site of interest. It is therefore important that these default values are adjusted for a given project so that the output of the simulation model accurately reflects observed traffic conditions. Proper calibration is essential if the model is to accurately replicate both supply and demand characteristics and their interactions in the transportation system. This is crucial if the model is to be perceived as credible both to engineers and planners as well as the general public. This is the focus of this chapter.

4.1 Model Verification, Calibration, and Validation

While the terms *verification*, *validation*, and *calibration* have been defined in different ways over the years, the following definitions are used in this report (Spiegelman et al. 2011).

Model verification is the process of determining if the logic that describes the underlying mechanics of the model, as specified by the model developer(s), is faithfully replicated by the model. It is important to note that model verification is not concerned with whether the logic is correct. For example, if the model developers intended that a stream of vehicles approaching an isolated intersection follow the Poisson distribution, then model verification will “confirm” that the modeled vehicles are indeed distributed according to a Poisson probability density function. The question of whether this distribution is “correct” is not part of model verification.

Model validation is the process of determining to what extent the model’s underlying fundamental rules and relationships are able to adequately capture the targeted emergent properties of the model. As the name implies, emergent properties “emerge” from the model and are not defined *a priori*. In traffic microsimulation models, for instance, link capacity, density, and speed are often defined as emergent properties. Note that the emergent property might be compared to theoretical values or empirically collected data. For the capacity example, validation might involve comparing the simulated link capacity with the Highway Capacity Manual values (HCM 2010) and/or observed data.

Model calibration is the process of modifying the default microsimulation parameters so that the model replicates the observed traffic conditions as accurately as possible. For example, if a Poisson distribution is deemed appropriate for modeling a given stream of vehicles arriving at a traffic signal, then the model calibration would identify the best value for the parameter λ of the Poisson distribution. A more detailed overview of model calibration will be provided later in this chapter. It is generally good practice to use separate data sets for the model calibration and model validation processes. In addition, the calibration step is commonly performed before the validation step.

Model verification and validation were not considered in this project, as VISSIM has been used in many applications over the years. Rather, the focus has been on model calibration. The model calibration problem can be viewed as an optimization problem that seeks to match simulation model output and observed values or field values. A number of research projects related to the calibration of microscopic traffic simulation models can be found in the literature (Kim and Rilett 2003; Mark et al. 2008). The methods range in level of sophistication from simple manual adjustments to automated adjustments using evolutionary algorithms. A genetic algorithm (GA) based calibration procedure was adopted for this research because the GA searches over multiple locations and therefore has a very high likelihood of identifying a globally optimal solution. As will be discussed in section 4.9, the GA helped improve the model results. The objective function value, which is the mean absolute error ratio, is improved by approximately 70%.

4.2 Overview of Genetic Algorithms

Genetic algorithms are stochastic algorithms whose search methods are based on the evolutionary ideas of natural selection or the survival of the fittest. The procedure starts with a randomly generated set or population of chromosomes each of which represents a potential solution to the model calibration problem. The individual chromosomes undergo selection in the presence of variation-inducing operators such as mutation and crossover. A fitness function is used to evaluate each chromosome. Reproductive success varies with fitness. The processes of evaluation, selection, crossover, and mutation are repeated until a satisfying solution is found.

It has been shown that the GA has advantages in dealing with non-convexity, locality, and the complex nature of transportation optimization problems. Though it might not always find the best solution, more often than not, it would converge to a nearly optimal one. Additionally, genetic algorithms only require the evaluation of an objective function with no need for gradient information. They are also rather robust when used in conjunction with simulation model calibration and can overcome the combinatorial explosion of model parameters (Kim and Rilett 2004).

A conceptualization of the genetic algorithm based model calibration methodology used in this study is provided in figure 4.1.

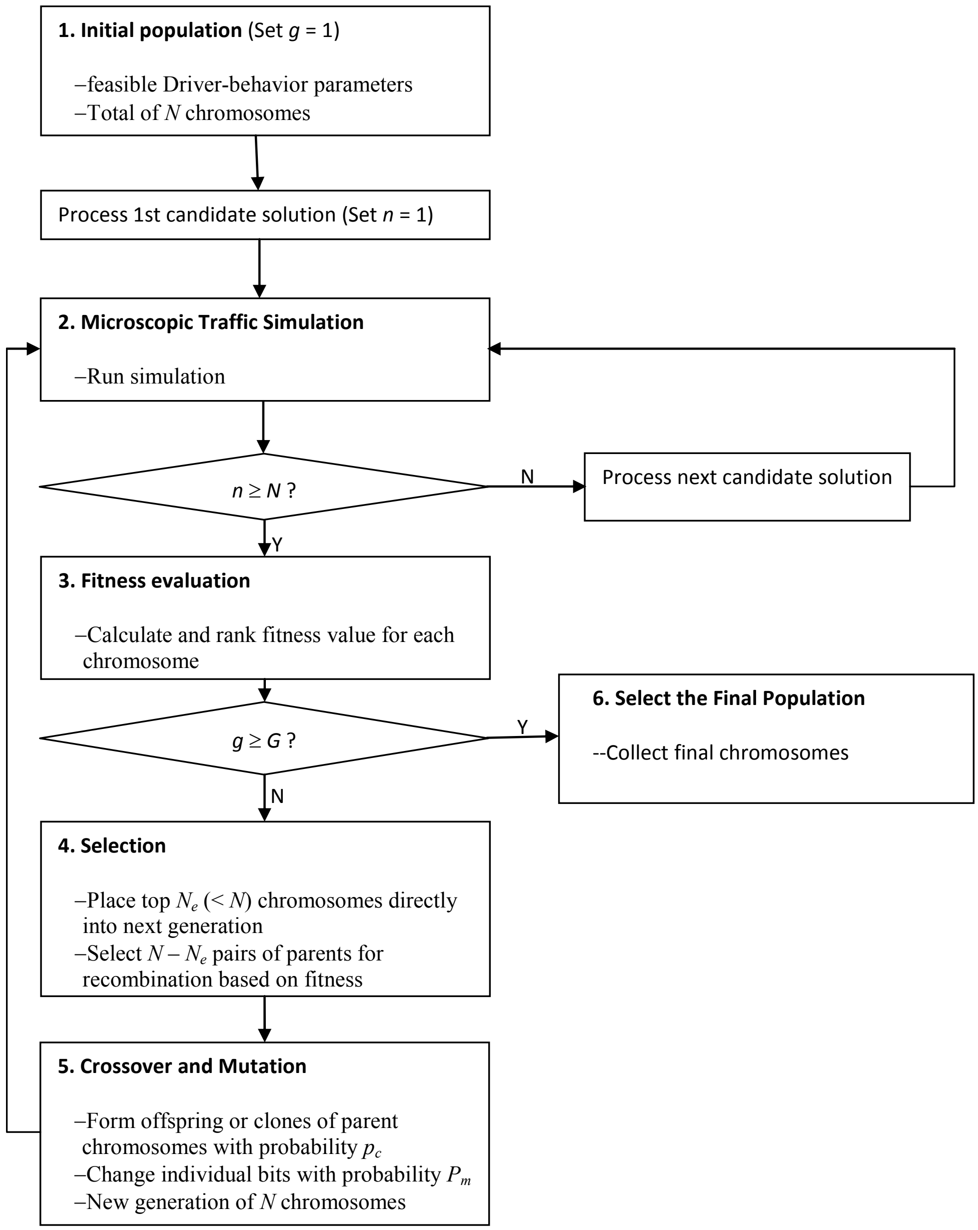


Figure 4.1 Flowchart of calibration procedure

The figure shows the sequence of basic operators used in the GA. First, the supply elements (links, nodes, traffic control, etc.) of the model are constructed. A randomly generated set of feasible solutions or chromosomes is then generated. Every member of this generation of chromosomes is input into the microscopic traffic simulation model. The output obtained from running the model with each chromosome is compared with observed data and a fitness value is assigned. Next, a new generation of chromosomes is produced by selecting a subset of chromosomes from the current generation according to their fitness values. That is, pairs of chromosomes are selected from the current generation and crossover is performed. With a certain probability, genes are mutated before the new generation of chromosomes are used in the microscopic traffic simulation and evaluated again. The procedure is repeated until a certain pre-specified maximum number of iterations are performed or an acceptable level of error between simulated and observed data is obtained. A detailed description of each step of the process follows.

4.3 Step 1: Initial Population

Consider a transportation network with *n* origins and *m* destinations. The GA process starts with an initial guess of a set of candidate solutions. Suppose there are *K* driving behavior parameters to calibrate and denote the *k*th parameter for the *r*th candidate solution by $p_{k,r}$. Then, in vector form, the *r*th candidate solution has the representation:

$$S_r \equiv [p_{1,r},\ldots,p_{K,r}] \qquad (4.1)$$

4.3.1 Binary Representation of Potential Solutions

In the GA procedure, each potential solution is typically encoded as a binary bit string called chromosome. Other representation schemes such as ternary, integer, and real value are available. However, binary encoding is the most commonly used and is adopted in this research. The first step in binary encoding is to define an appropriate range for each individual parameter and then encode and map the range to a bit string occupying a specific length of the chromosome. If the real value of a parameter k for chromosome r, $p_{k,r}$ has domain in the range $[p_{min}, p_{max}]$, then the length of the binary string corresponding to $p_{k,r}$ is the minimum integer value that satisfies the inequality below (Schultz 2003).

$$b_k \geq \log_2\left(p_{\max} - p_{\min}\right) \tag{4.2}$$

where,

b_k: Length of binary string required to represent parameter $p_{k,r}$.

The overall length of a chromosome is the sum of the component bit string lengths. If the overall length of a chromosome is denoted L_c, then a representative binary bit encoding of the rth candidate solution could be the vector S_r^* of length L_c.

$$S_r^* \equiv [10110000101...10011]_{1\times L_c} \tag{4.3}$$

4.3.2 Driving Behavior Parameters

VISSIM has an extensive number of driver behavior parameters that can be adjusted by the user to ensure that the simulated output matches field data. The set of driving behavior parameters that were changed from their default values in VISSIM and ranges that were considered reasonable in this research are described below.

i. Lane change distance: Distance in anticipation of a lane change at which a driver will begin maneuvering towards the desired lane. Range = [200, 400].
   Default = 200.

ii. Maximum decelerations for the leading and trailing vehicles: Associated with the aggressiveness of the lane change process. The range for the leading vehicle is
   [-6.5, -3.0]. Default = -4.0. For the trailing vehicle, Range = [-5.0, -2.0];
   Default = -3.0.

iii. Standstill distance (CC0): Defines average desired distance between stopped vehicles. Range = [1.0, 1.7]. Default = 1.5.

iv. Headway time (CC1): Defines the time headway that a driver desires to keep at a given speed. Range = [0.30, 1.20]. Default = 0.90.

v. Following variation (CC2): Defines longitudinal variation while a driver follows another vehicle. Range = [2.0, 6.0]. Default = 4.0.

vi. Threshold for entering "following" mode (CC3): Defines when a driver starts to decelerate before reaching the desired safety distance. Range = [-12, -4]. Default = -8.

vii. Following thresholds (CC4 and CC5): Define the speed difference between the leading and trailing vehicles. Range of CC4 = [-0.50, -0.20]. Default = -0.35. Range of CC5 = [0.20, 0.50]. Default = 0.35.

viii. Speed dependency of oscillation (CC6): Defines the distance on speed oscillation. Larger values result in greater speed oscillation. Range = [7.00, 15.00]. Default = 11.44.

The expected range of values of the driving behavior parameters and their corresponding required level of precision was used to define the length of the binary bit string corresponding to each candidate chromosome. The first generation of chromosomes was formed by randomly populating bit strings of appropriate lengths with binary values and mapping them to real values (for use in the microscopic traffic simulation model) using equation 4.4 (Shultz 2003).

$$p_k = p_{\min} + A \times \frac{p_{\max} - p_{\min}}{2^{b_k} - 1} \tag{4.4}$$

where,

p_k: Real value of parameter k;

p_{min}: Minimum value of parameter k;

p_{max}: Maximum value of parameter k;

b_k: Length of binary bit string corresponding to parameter k; and

A: Value of binary bit string to base 10 of parameter k.

4.4 Step 2: Traffic Microsimulation

Each member of the first generation and subsequent generations of chromosomes was input into VISSIM and the model run for 3,600 simulation seconds. The output of travel times and speeds on selected links obtained from running the model with each chromosome was collected and compared with observed data. The individual chromosomes were then evaluated for fitness, selection, and onward progression into subsequent generations.

A program was written in the Perl programming language to automate the processes of performing the GA and collecting potential candidates for input into VISSIM, running VISSIM, and collecting the output for further analysis by the GA routine.

4.5 Step 3: Fitness Evaluation

One of the most critical steps of the GA is the identification of a suitable fitness function. The value of the function is utilized to identify how well each candidate solution or chromosome meets the overall objective of the algorithm and to determine the likelihood of a chromosome's progression into subsequent generations. A number of functions—including exponential functions, power functions, linear functions, or a combination of these—are used to transform the basic fitness function values into a measure of relative fitness. In general, the higher the relative fitness of a candidate solution, the closer it is to solving the optimization problem. For minimization problems, the most competitive chromosomes are those with the lowest numerical values of the associated fitness function. Likewise, chromosomes with high numerical values of the fitness function are the most competitive in a maximization problem (Schultz 2003).

A number of aggregate goodness of fit measurements can be used to quantify the degree to which the model results fit the field data. The term aggregate is used because all the measurements are combined into a single metric. Some calibration objective functions commonly used include the root mean square error (RMSE), the mean absolute error ratio (MAER), the mean absolute percentage error (MAPE), and the Geoffrey E. Havers (GEH) statistic (Mark et al. 2008). All of these objective functions have a common goal of minimizing errors between observed and simulated values of various performance metrics, such as volume, travel time, and delay.

The MAER, defined as the average ratio of all deviations to their observations taken without regard to sign (equation 4.5), was chosen for this study because it is unit free, fairly easy to implement, and widely used in transportation systems analysis.

$$MAER = \frac{1}{N}\sum_{a}\frac{|D_a - d_a|}{D_a} \tag{4.5}$$

where:

d_a, D_a: Simulated and observed data on segment a, respectively; and

N: Number of segments for which data are compared.

An exponential function was used to transform the MAER minimization objective function into a maximization function. This transformation or scaling was done to avoid a common problem that can occur with selection operations that are based on unscaled fitness values, that a chromosome with dominant fitness value will be selected most of the time, thus reducing the search space and increasing the chances of the GA ending abruptly in a local optimum.

Metrics used in this study were "closeness" of the simulated travel times to the observed travel times and the "closeness" of the simulated speeds to the observed speeds as measured by the MAER. A control factor *α* was used to determine the weight to place on travel times and speeds as shown in the equations below:

$$h(S_r) = \alpha h_1(S_r) + (1-\alpha)h_2(S_r) \tag{4.6}$$

where,

$$h_1(S_r) = Ce^{-\beta_1 \times g_1(S_r)} \tag{4.7}$$

$$h_2(S_r) = Ce^{-\beta_2 \times g_2(S_r)} \tag{4.8}$$

$$g_1(S_r) = \frac{1}{N}\sum_{a=1}^{N}\frac{|T_a - t_{ar}|}{T_a} \tag{4.9}$$

$$g_2(S_r) = \frac{1}{N}\sum_{a=1}^{N}\frac{|S_a - s_{ar}|}{S_a} \tag{4.10}$$

where:

S_r: *r*th candidate solution (or chromosome);

$h_1(S_r)$: travel time fitness function for the *r*th candidate solution;

$h_2(S_r)$: speed fitness function for the *r*th candidate solution;

$g_1(S_r)$: travel time objective function;

$g_2(S_r)$: speed objective function;

t_{ar}: travel time on segment *a* during simulation of *r*th candidate solution;

T_a: observed travel time on segment *a*;

s_{ar}: speed on segment *a* during simulation of *r*th candidate solution;

S_a: observed travel time on segment *a*; and

N: number of segments being compared.

Thus, evaluating a candidate solution of calibration parameters involved running the VISSIM model with specific parameter values, extracting the from the VISSIM output files the simulated travel times and speeds on those segments which were available through field data, computing the absolute error ratio for each segment and then averaging over all segments to obtain a MAER. This MAER value was then input into equation 4.6 to calculate the total fitness function value for the candidate solution.

4.6 Step 4: Selection and Elitism

The central idea in GA is to move a set of chromosomes—a population—from an initial collection of values to a point where the fitness function is optimized. After evaluating the fitness function for the current population of chromosomes, a subset of chromosomes is selected for use as parents in succeeding iterations or generations. The chromosomes are chosen according to their fitness value. In this project, an "elitist" selection strategy was used to ensure that the best chromosomes were preserved at each generation (Gentle et al. 2008). This involved directly placing the best N_e ($N_e < N$) chromosomes as determined from their fitness evaluations into the next generation.

A roulette wheel (fitness proportionate) selection scheme was used for the process of choosing parents for subsequent recombination. That is, each chromosome was assigned a slice on a Monte Carlo-based roulette wheel proportional to its fitness. The "wheel" was "spun" in a simulated fashion $N – N_e$ times and the parents were chosen based on where the pointer stopped (Gentle et al. 2008).

4.7 Step 5: Genetic Operators

The crossover operator was used to create offspring of the pairs of parent chromosomes identified from the selection step. The offspring could be either a blend or a clone of the two parents depending on a pre-specified probability of crossover P_c. If no crossover took place, then the two offspring were clones of the two parents. On the other hand, if crossover occurred, then the two offspring were formed by an interchange of parts of the two parents.

While keeping the elite N_e chromosomes, the remaining $N – N_e$ chromosomes were replaced by the offspring produced from crossover. Because the initial population might not contain enough variability to find the solution via crossover alone, a mutation operator was used to introduce some variability in the new set of chromosomes by randomly changing individual bits with probability P_m (Gentle et al. 2008). Introducing some variability through mutation also increased the chance that the algorithm did not converge prematurely to a local optimum.

4.8 GA Control Parameters

The primary control operators used in this project were: 1) population size N = 30, 2) maximum number of iterations or generations G = 30, 3) probability of crossover p_c = 0.7, and 4) probability of mutation p_m = 0.01. Other parameters included the constants α, β_1, β_2, and C in the fitness function, which were set equal to 0.5, 5.0, 2.5, and 100, respectively. These were used to systematically adjust the default parameter values until the simulated travel times and speeds on selected links were "reasonably close" to their corresponding field values, as discussed in section 4.5. Field data were obtained from MAPA in 2009 and were mainly from the Omaha area of the network.

4.9 Calibration Results

The GA routine developed in this project was used to search for the best combination of lane-changing and car-following model parameters that would minimize the resulting MAER. The best MAER value obtained after 30 iterations of the GA was approximately 17% (see fig. 4.2).

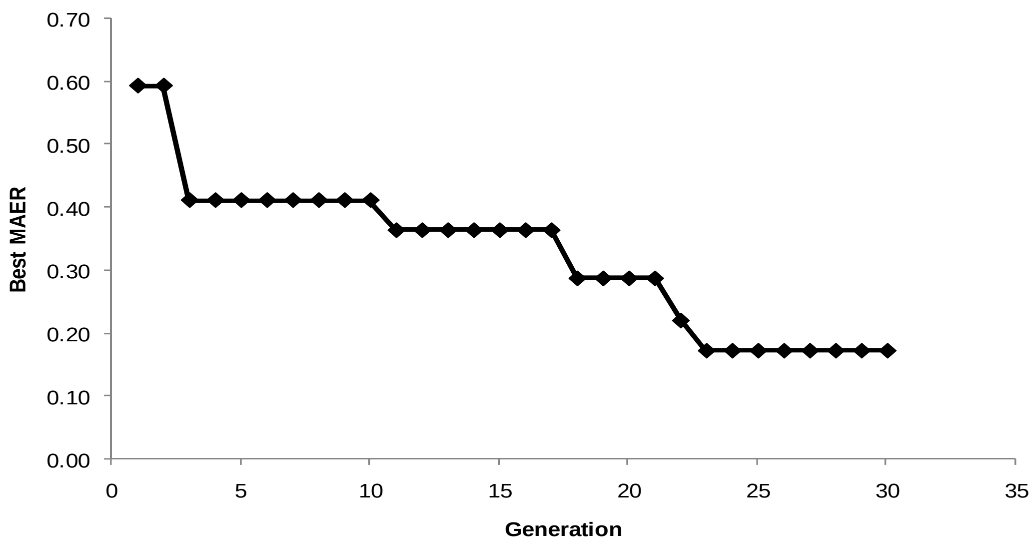


Figure 4.2 Trajectory of best MAER values

The calibrated lane-changing and car-following behavior parameter values that resulted in this MAER value are summarized in table 4.1.

Table 4.1 Calibrated driving behavior parameters

Parameter (units)	Range	VISSIM Default	Calibrated Value
Lane-change distance (m)	[200, 400]	200	240
Maximum deceleration of leading vehicle (m/s^2)	[-6.5, -3.0]	-4.0	-4.0
Maximum deceleration of trailing vehicle (m/s^2)	[-5.0, -2.0]	-3.0	-2.0

Standstill distance - CC0 (m)	[1.0, 1.7]	1.5	1.7
Headway time - CC1 (m)	[0.30, 1.20]	0.90	0.30
"Following" variation -CC2 (s)	[2.0, 6.0]	4.0	2.6
Threshold for entering "following" - CC3 – (s)	[-12, -4]	-8	-9
"Following" threshold -CC4 (m/s)	[-0.50, -0.20]	-0.35	-0.50
"Following" threshold -CC5 (m/s)	[0.20, 0.50]	0.35	0.50
Speed dependency of oscillation (1/rad)	[7.00, 15.00]	11.44	14.27

As can be seen in figure 4.2, the GA helped improve the model results. The best MAER value improved by approximately 70%, that is, from 0.59 in the initial population to 0.17 in the final population.

Note that the number of iterations or generations was limited to 30 due to the rather high computational requirements of the calibration process. It should also be noted that both the OD estimation and model calibration were initially done for a subsection of the test bed between Lincoln and Omaha. The OD was later redone to reflect the expanded scope of the network. However, the calibrated parameter values were assumed to be applicable to the entire network and therefore the calibration was not redone.

4.10 Concluding Remarks

Because the ability to accurately and efficiently model traffic flow characteristics, driver behavior, and traffic control operations is critical for obtaining realistic microsimulation results, the model developed in this project was calibrated to Nebraska conditions. The calibration procedure involved adjusting model parameters until the simulation output and field data were reasonably well-matched. While it is relatively straightforward to run a microsimulation model, it is considerably more difficult to calibrate it. The GA procedure used in this project is generic and can readily be updated as more information becomes available, such as ITS data related to speed, volume, occupancy, and so on. The availability of more data will also allow the calibration to be done at a more disaggregate level. In these situations, more statistically based measures of fitness—such as differences in distributions of observed and simulated traffic data—can be employed, rather than measures of central tendency (Kim et al. 2005). Because the calibration step has been done, the marginal cost of all future applications involving this VISSIM network will be considerably lower.

Chapter 5 Summary and Conclusions

Microscopic traffic simulation models are increasingly being used for analyzing many complex transportation problems. Because of the wide variety of end-users, these models are often built and calibrated for specific applications. They are rarely updated as new information or ITS data becomes available and are often developed in isolation. Consequently, their use for a wide-range of applications can often be limited. In addition, most applications to date are to small-scale networks.

The main objective of this research was to develop a large-scale microsimulation model that can be used by NDOR designers, planners, and traffic engineers. The network consisted of 200 miles of roadway including 102 miles of Interstate 80 between York, NE and Omaha, NE; 49 miles of US Highway 6 between Lincoln, NE and Omaha; NE and 20 miles of State Highway 2 between Lincoln, NE and Palmyra, NE. All major highways and arterial roadways that crossed perpendicular to the network roads were included. These cross streets were modeled to a distance of approximately half a mile or to the first traffic signal. Supply data, including number of lanes, speed limit, lane width, traffic signal timings, etc. were obtained from various state and local agencies. Demand data was estimated from empirical traffic data. The microsimulation model VISSIM, version 5.2, was used in this project and the model was calibrated to empirical traffic data.

5.1 Expected Benefits

This work demonstrates the feasibility of building a large-scale traffic microsimulation model in VISSIM using the readily available data from local agencies. The potential benefits of having a model of this kind are:

i. Large-scale simulation models allow for more accurate analyses such as predictions of vehicle emissions, evaluation of ITS applications, and planning for emergency evacuation at a system level.

ii. It is much more economical to have a single state-of-the-art model rather than having different groups develop individual models for specific operations. While it is relatively straightforward to run a microsimulation model, it is considerably more difficult to calibrate. Consequently, doing the calibration once means that the marginal cost of all future applications will be considerably lower.

iii. The model can be used when explaining complex transportation projects to the general public. The graphics of many models are fairly sophisticated and can be used readily to illustrate complex topics during public meetings.

iv. Large-scale simulation models could become generic databases of both supply data (i.e., link characteristics, traffic control devices, lane widths, etc.) and demand data (Origin-Destination movements by vehicle type, etc.).

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Appendix A

Quick Guide to Using the I-80 VISSIM Model

1. Introduction

This CD contains all files required to run the traffic microsimulation model built in accordance with the attached NDOR Research Project RHE 13: Development of a State-of-the-Art Traffic Microsimulation Model for Nebraska. The specific sections of roadway that are modeled are presented in table 1. The model was designed so that a wide range of applications can be analyzed at a system level.

The model was developed on a VISSIM platform. VISSIM is a microscopic, time step and behavior-based simulation software developed to model urban traffic and public transport operations. In order to use and make changes to the I-80 simulation model, one needs to have a licensed version of VISSIM 5.2 installed. Specific details related to the VISSIM software may be found on the following website: http://www.ptvamerica.com/.

The I-80 simulation model was created so that the major components of the corridor could be modeled for various applications for a low marginal cost. It may be particularly useful for analyzing proposed design and operation changes and their effects on traffic and the environment along the corridor.

These instructional notes assume the user has little to no background knowledge of VISSIM. They are only intended to serve as a quick reference to working with the I-80 simulation model. Sample applications of the simulation model are identified in the next section, along with a brief description of how VISSIM could be used in each case.

Table 1 Modeled roadway sections

Roadway Section	Extent		Length
	From	To	
1. Interstate 80	US 81 interchange, York	Nebraska-Iowa border	102 miles
2. Interstate 480/US 75	I-480/I-80 interchange, Omaha	I-480/Storz Expressway, Omaha	4 miles
3. Storz Expressway	US 75 interchange, Omaha	Lindberg Drive intersection, Omaha	5 miles
4. US Highway 75	I-80/US 75 interchange, Omaha	Chandler Road intersection, Omaha	3.2 miles
5. Interstate 680	I-80/I-680 interchange, Omaha	Nebraska-Iowa border	13 miles
6. Interstate 180	I-80/I-180 interchange, Lincoln	R Street, Lincoln	4 miles
7. US Highway 6	US6/I-80 interchange, Lincoln	US 275/I-80 interchange, Omaha	49 miles
8. State Highway 2	US 77 interchange, Lincoln	A Street intersection, Palmyra	20 miles

2. Getting Started

2.1. Create a folder and name it (e.g., “2011 - I-80 Simulation”). The folder can be kept on the computer’s desktop or in a dedicated folder in the “My Documents” folder, which is recommended.

2.2. Insert the project CD (attached to report) into the computer CD-ROM drive.

2.3. Copy ALL files that are on the project CD into the folder that was created in step **2.1**.

2.4. Open the VISSIM program by either by

- Double clicking the VISSIM shortcut icon on the desktop, or
- Selecting **Start → All Programs → PTV_Vision → VISSIM 5.20 → VISSIM 5.20**.

2.5. Go to the **File menu** at the top left hand side of the screen and from the drop down menu select **Open**.

2.6. In the window that opens, navigate to the “I-80 Simulation” folder created in step **2.1.**, and select the VISSIM input file named “*lincoln-omaha-network-20070626.inp.*”

2.7. The I-80 network will be visible at this point.

2.8. Section 4.2.1 of the VISSIM User Manual describes the process for viewing the network elements.

2.9. Section 8.1 of the VISSIM User Manual describes how to run the microsimulation.

3. Loading Background Images

The easiest way to edit the I-80 corridor network is to use background images that can be read into the VISSIM software. Editing might include, for example, incorporating new lanes, new roadways, and so on. The user may then "trace" the new road geometry and also identify attributes such as number of lanes; lane widths, and stop lines.

Multiple images for the various sections of the I-80 network were downloaded. These images are available in the "Images" folder.

The image files (*.BGR) can be imported into the VISSIM model. Go to **View → Background → Edit...**, press **Load...**, navigate to the "Images" folder and select the desired image file (*.BGR) in order to import it.

Alternatively, the user can convert the original image files (*.JPEG) to background maps as discussed in section 4.4.2 of the VISSIM User Manual.

4. Model Visualization

This I-80 simulation model can be used for explaining complex transportation projects to the general public. VISSIM allows fairly sophisticated graphical representation that can be readily used to illustrate complex topics during public meetings.

4.1. The 2D graphics mode is the standard method of visualizing the network as described in section 4.2 of the VISSIM User Manual.

4.2. Section 4.3 of the VISSIM User Manual describes how to view the microsimulation in three dimensional graphics mode

4.3. Section 8.1 of the VISSIM User Manual describes how to run the simulation in two or three dimensions.

4.4. Section 9.1.1 of the VISSIM User Manual describes how to create animation files.

5. Sample Applications

5.1. Effects of Adding or Removing Lanes

5.1.1. Open the VISSIM program and the I-80 simulation input file.

5.1.2. Zoom to the specific location on the I-80 network where lanes are to be added or removed.

5.1.3. Add or remove lanes by drawing links and connectors. A description of how to do this is Section 6.3.1 of the VISSIM User Manual.

5.1.4. Check effects by evaluating section travel times, traffic volumes, or vehicle speeds before and after the change in lane configuration.

Section 11.1 of the VISSIM User Manual describes how to analyze the travel times along a given section;

Section 11.3 of the VISSIM User Manual describes how to analyze traffic volumes and speeds along a given section.

5.1.5. The link could also be evaluated as a whole as described in Section 11.11 of the VISSIM User Manual.

5.1.6. To run the simulation see Section 8.1 of the VISSIM User Manual.

5.2. Effects of Changing Signal Timings

5.2.1. Open the VISSIM program and the I-80 simulation input file.

5.2.2. Zoom to a specific signalized intersection at which the timing plans are to be revised on the I-80 network.

5.2.3. To create additional signal heads and groups see section 6.7.1 of the VISSIM User Manual.

5.2.4. Section 6.7.3 of the VISSIM User Manual describes how to edit the signal timings.

5.2.5. Observe the queue lengths, occupancy time, vehicle emissions and/or vehicle delay before-and-after changes in timings. The VISSIM User Manual describes how to do this for various measures of effectiveness:

- To analyze queue lengths (Section 11.4).
- To analyze occupancy time (Section 11.3).
- To analyze vehicle emissions (Section 11.6).
- To analyze vehicle delay (Section 11.6).

5.2.6. Section 11.5 of the VISSIM User Manual describes how to observe the green time distributions/

5.2.7. Run the simulation. Directions are provided in Section 8.1 of the VISSIM User Manual.

5.3. Effects of Converting Intersection (e.g., Stop Control to Signalized)

5.3.1. Open the VISSIM program and the I-80 simulation input file.

5.3.2. Zoom to a specific intersection on the I-80 network where a conversion is suggested.

5.3.3. In order to edit the intersection geometry, draw links, and/or draw connectors see Section 6.3.1 of the VISSIM User Manual.

5.3.4. Include desired speed change locations as described in Section 6.3.3.

5.3.5. Edit priority rules as described in Section 6.6.1.

5.3.6. Create signal groups and signal heads as described in Section 6.7.1.

5.3.7. Add detectors on an approach that is actuated. The steps for doing this are described in Section 6.7.2.

5.3.8. Create a signal controller and enter timing data as described in Section 6.7.3.

5.3.9. Observe various Measures of Effectiveness (MOEs) such as queue length, occupancy time, vehicle emissions, and/or vehicle delay before-and-after changes to the intersection control. The methods for observing these MOE's can be found in the VISSIM User Manual in the following sections:

- queue lengths (Section 11.4).
- occupancy time (Section 11.3).
- vehicle emissions (Section 11.6).
- vehicle delay (Section 11.6).

5.3.10. Run the simulation as described in Section 8.1 of the VISSIM User Manual.

6. CD Contents

There are two main folders on this CD-ROM: "IMAGES" and "SIMULATION MODEL." The "IMAGES" folder contains three subfolders that contain Google images of the various roadway sections that were modeled. The three subfolders are "INTERSTATE 80," "HIGHWAY 6," and "HIGHWAY 2."

The "SIMULATION MODEL" folder contains ALL the files required to run the traffic microsimulation model. There are a total of 345 files on this CD. The different file types are defined below.

6.1. *.ERR – run time warning file containing warnings of non-fatal problems that occurred during the simulation run.
6.2. *.IN0 – automatically created backup of the *.INP file.
6.3. *.INP – input file containing all the traffic network input.
6.4. *.KFG – configuration file of columns for detector/signal display record.
6.5. *.LDP – signal detector record file containing log of all signal display changes and detector actuations.
6.6. *.LSA – signal changes file containing a chronological record of all signal changes occurring during a simulation run.
6.7. *.LZV – signal timing log file containing green and red times for all signal groups for all controllers.
6.8. *.NSE – NEMA standard editor file containing description of NEMA signal control logic.
6.9. *.PUA – VAP start-up stage file containing definition of stages for signal controllers with VAP logic.
6.10. *.SZP – configuration file of the sequence of signal groups and detectors for dynamic signal timing plans.
6.11. *.VAP – VAP logic file containing description of a user-defined traffic responsive signal control logic.

7. Vehicle Types and Classifications

The vehicle types, classification, and speed distributions that were defined for the model are presented below.

Table 2 Vehicle types

Vehicle Type	Performance Attributes (Acceleration/Deceleration, Weight, Power, Length)
Car	Default
HGV	Default
Pedestrian	Default

Table 3 Vehicle compositions

Name	Vehicle Type	Relative Flow	Desired Speed, mph
10% HGV 55 mile	Car HGV	90% 10%	(40, 60)
10% HGV 45 mile	Car HGV	90% 10%	(35, 50)
10% HGV 40 mile	Car HGV	90% 10%	(35, 45)
10% HGV 35 mile	Car HGV	90% 10%	(30, 40)
10% HGV 30 mile	Car HGV	90% 10%	(20, 35)
Pedestrians	Pedestrians	100%	(3, 4)