A PRACTICAL PERSPECTIVE ON THE BENEFITS OF COMBINED TRAFFIC ASSIGNMENT AND CONTROL MODELS

by

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ABSTRACT

As the nation's traffic system becomes more congested for various periods of the day, more research in the area of intelligent transportation systems is needed. Traditional solutions of adding more highways and widening the existing system are not feasible anymore due to rapidly increasing demand and lack of room for expansion. The national interest is therefore focused on congestion mitigation methods that promote efficient use of existing infrastructure. Some of the key aspects of congestion management techniques include Intelligent Transportation Systems (ITS) elements. These ITS elements can play a role in drivers' interaction, route choice, and traffic controls. Combined Traffic Assignment and Control (CTAC) framework-based models can capture the ITS elements-based control-driver interaction in traffic systems.

The CTAC method has been the topic of scientific research for the last three decades. Several solution algorithms, model formulations, and implementation efforts have been well documented. Although proven in research, the use of the combined traffic assignment and control modeling framework is rare in practice. Typically, the engineering practice tends to keep Traffic Assignment and Control Optimization processes separate. By doing so, the control-driver interaction in the traffic system is ignored. Previous research found that CTAC models could capture the control-driver interaction and the combined modeling framework should be used in practice.

This research evaluates the benefits of CTAC models. Several models were developed and tested employing different route choice and control strategies on small, subregional and regional networks. Benefits of CTAC models were evaluated in terms of total travel time and total delay. In selected experiments, various proportions of route guidance system features were added to the CTAC framework to evaluate the system-wide benefits in terms of travel time improvement and delay reductions.

The results show that total-delay reductions and total-travel time improvements were the smallest when only traffic controls were improved and the highest when the drivers had network travel time information from past travel experience in conjunction with improvements to traffic controls. Further experiments are needed to compare the benefits of CTAC models using other simulation software for regions of different sizes and location.

To my lovely wife, my brothers, and above all, my parents

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ACRONYMS

ATCS	Adaptive Traffic Control Systems
ATIS	Advanced Traveler Information Systems
BPR	Bureau of Public Roads
CORSIM	Corridor Simulation
CTAC	Combined Traffic Assignment and Control
CUBE-DYNASIM	Cube-Based Dynamic Simulation
DTA	Dynamic Traffic Assignment
DYNASMART	Dynamic Network Assignment-Simulation Model for Advanced Road Telematics
FHWA	Federal Highway Administration
ITS	Intelligent Transportation Systems
NEMA	National Electrical Manufacturers Association
OD	Origin Destination
RGS	Route Guidance System
SCATS	Sydney Coordinated Adaptive Traffic Systems
SCOOT	Split Cycle Offset Optimization Technique
STA	Static Traffic Assignment
UDOT	Utah Department of Transportation
VDF	Volume Delay Function
VISSIM	Verkehr In Stadten SIMulation (Traffic in Towns Simulation)
WFRC	Wasatch Front Regional Council

LIST OF PUBLICATIONS

Paper 1: Farhan, M., Stevanovic, A. and Martin, T. P., A practical perspective on the benefits of combined traffic assignment and control method. Presented at the 89th Annual Transportation Research Board Meeting, Washington D.C., January 2010.

Paper 2: Farhan, M. and Martin, T. P. Evaluation of the system wide benefits of capturing control-driver interaction in a traffic-system. Presented and published at *17th world Congress on Intelligent Transportation Systems*, Busan, South Korea, October 2011.

Paper 3: Farhan, M. and Martin, T. P. Evaluation of the benefits of route guidance system using combined traffic assignment and control framework. Presented and published at *17th World Congress on Intelligent Transportation Systems*, Busan, South Korea. October 2011.

Paper 4: Farhan, M. and Martin, T. P. Benefits of route guidance system in a combined modeling framework with variance in intervals and equipped demand, In Press, *Journal of Basic and Applied Scientific Research*, Text Road Journals, 2011

Paper 5: Farhan, M. and Martin, T. P. Combined traffic assignment and control method: Benefits of capturing interaction between drivers' route choices and flow responsive traffic controls, In *Journal of Basic and Applied Scientific Research*, Text Road Journals, 2011, pp 251-258

Paper 6: Farhan, M. and Martin, T. P. Implementation of combined traffic assignment and control framework based regional model for the Wasatch Front Region. In Press *Journal of Engineering and Applied Sciences*, APRN Journals, 2011.

CHAPTER 1

INTRODUCTION

This chapter presents an argument and a methodology for evaluating the benefits of Combined Traffic Assignment and Control (CTAC) models. A review of various types of traffic controls and traffic assignment models is summarized, which eventually leads to the research problem presented in the dissertation. The publication-based format of this dissertation and the outline of subsequent chapters are presented in the final section of this chapter.

1.1 Background

Growth in traffic demand has increased steadily over the last century in terms of vehicle miles traveled and delay. Over the last three decades alone the Vehicle Miles Traveled (VMT) has tripled to nearly three trillion (FHWA 2007). Coupled with an expanding driver population and less room for roadway expansion, traffic congestion has become a serious problem with significant negative impacts (Lewis, 2008). Some of the key negative impacts of traffic congestion include longer travel times, unreliable trip times, and increased delays in personal trips.

With growing traffic congestion in the nation’s metropolitan areas and relatively less room for capacity building, engineers and planners are focusing on new methods to improve the traffic flow. From the aspect of simulation modeling for traffic congestion mitigation, researchers have been investigating the effectiveness of combined traffic assignment and control models for several years. These models, when used in simulations, were found to be able to capture the interaction between driver's route choice and traffic signal control. Past research recommends testing of combined models in a real setting. This dissertation describes the research on the benefits of combined traffic assignment and control models in terms of total travel time improvements and total delay reductions using micro- and mesoscopic simulation environments.

1.2 Traffic System

A traffic system consists of three components: traffic control policies, the driver, and the interaction between the control policies and the driver (control-driver interaction) (Meneguzzer, 1997). The traffic control policies and the driver may have competing objectives. For instance, the traffic control policies may try to achieve the best for the whole community in terms of total travel time improvements, delay reductions, pollution reduction, and safety improvement. On the other hand, the driver strives to reach his destination in the shortest possible time without consideration of his possible negative impacts on the system. Figure 1.1 displays a traffic system with a signalized intersection.

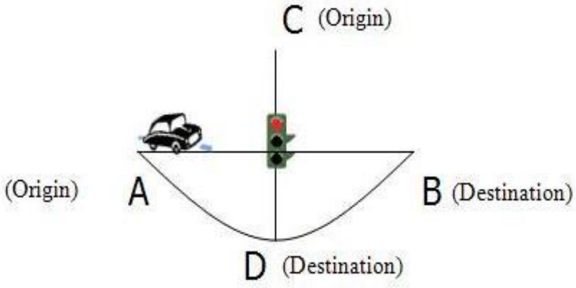

Figure 1.1 Traffic System Interactions

There are two routes for travel between A and B. The routes include route AB, a route through a signalized intersection, and a longer bypass ADB without a signalized intersection. For travel between C and D, there is only one route CD that passes through a signalized intersection.

The driver starting his trip at A would like to travel to his destination B in the shortest travel time, while another driver starting his trip at C may have the same objective of reaching his destination D in the shortest travel time. The traffic manager may determine green times at the intersection of the routes AB and CD with a different objective than the two drivers. Based on system-wide analysis, the traffic manager may give route CD a preferential treatment by allocating 60% of the green time available at the intersection. The traffic manager's decision on controls at the intersection, although good for the system, may impact differently the route choice of both drivers on route AB and CD. With more time allocated to route CD at the signalized intersection, the driver on route AB may switch to route ADB, which is a bypass and a longer route with no delays caused by this signalized intersection at route AB. The other drivers in the system who are planning to travel on route AB based on their previous day's travel time experience on route AB may follow the same route choice behavior until the delays caused by congestion on bypass route ADB become the same as traveling on the signalized route AB. The traffic system components are therefore interdependent from each other, and a slight change in traffic control strategies could impact the traffic system positively or negatively. Some of the key components of traffic systems are briefly explained in the next section.

1.3 Traffic Control Systems

For many decades, the technological advancements have brought many revolutionary changes to communication, controls, and intelligent transportation systems. These improvements have brought many scientific changes to traffic control systems as well. At present, the traffic control systems can be grouped into three major categories: fixed-time, actuated, and Adaptive Traffic Control Systems (ATCS). Fixed time traffic controls are also referred to as pretimed controls and ATCS are referred to as dynamic controls.

1.4 Signal Timing Parameters

Some of the parameters that define a traffic signal timing plan include cycle length, phase, interval, split, and offset. These parameters are briefly defined in Table 1.1.

Table 1.1 Traffic Control Systems

Variable	**Definition**
Cycle Length	The time required for one complete sequence of signal intervals (phases)
Phase	The portion of a signal cycle allocated to any single combination of one or more traffic movements simultaneously receiving the right-of-way during one or more intervals.
Interval	A discrete portion of the signal cycle during which the signal indications (pedestrian or vehicle) remain unchanged.
Split	The percentage of a cycle length allocated to each of the various phases in a signal cycle
Offset	The time relationship, expressed in seconds or percent of cycle length, determined by the difference between a defined point in the coordinated green and a system reference point.

1.5 Fixed-Time Traffic Controls

Fixed-time controls are the simplest form of traffic control and usually operate on a predetermined and repeated sequence of signal plans. The fixed-time controls require fixed cycle length and splits. Signal timing plans for fixed-time controls are developed off-line and optimized based on historical traffic flow data. A series of predetermined plans can accommodate variations in traffic flow during the day such as during peak and off-peak periods. Signal plans can be modified for a specific period of the day or day of the week, provided that there is some good consistency in traffic flows.

Fixed-time controls are best for intersections with predictable and fairly stable traffic flows (or demand). Once the timings are set, they can be modified to accommodate the changes in traffic flow. They do not require traffic detection and the right-of-way is assigned based on a predetermined schedule; cycle length, splits, and phasing sequences are all fixed. Fixed-time signals are relatively inexpensive and work well with stable traffic flows. However, they do not accommodate short-term fluctuations in traffic demand and may cause excessive delays when such demands are not met.

1.6 Actuated Traffic Controls

Actuated controls differ from fixed-time controls because their signal indications are not of fixed duration, but rather change to accommodate the changes in the demand and speed of approaching traffic. Traffic actuated controls are typically used where traffic volumes fluctuate irregularly.

The actuated traffic controls can be grouped into two types: semi-actuated and fully actuated. Semi-actuated systems primarily apportion green time to the road with the major traffic movement and they assign green time to minor streets only when vehicles are detected. Therefore, detection is required only on minor approaches. Although the cycle length is set, any unused green time for the minor approaches will be allocated for the major approach. Semi-actuated controls can be further grouped into coordinated or uncoordinated. In semi-actuated coordinated controls, the major movement is always coordinated and detection is along minor movement. This means that the major movement is always green for a certain fixed time during a signal cycle, thereby providing progression along the corridor. For the remaining duration of the cycle, the minor street receives green time only if a vehicle is detected. If no vehicle is detected along the minor movement, the additional green time is given to the major movement.

In semi-actuated uncoordinated control, detection is similar to semi-actuated coordinated control but the major movement is not under progression. The major movement remains green until a vehicle is detected along the minor movement, in which case the minor movement receives green until traffic is clear or it reaches the maximum (whichever occurs earlier) and then green is transferred back to the major movement. Coordinated semi-actuation is used for corridors while uncoordinated semi-actuation is used for isolated intersections. Semi-actuated controls are good for intersections with very low volume on minor streets.

Fully actuated controls systems detect vehicles on all approaches of the intersection and make adjustments according to the demand. Fully actuated controls require more programming data than pretimed control to accommodate minimum and maximum phase times. Fully actuated signals are used at intersections that exhibit large fluctuations of traffic volumes from all approaches during the day. Detectors are placed on all approaches. Right-of-way is assigned based on the amount of traffic detected on all approached. There is a set minimum and maximum green time for each phase. The minimum green time is often the same as the time required for pedestrians to safely cross the intersection. Maximum green time is the length of time a phase can hold green in presence of conflicting call. Vehicle (extension) interval is a preset time interval extending the green time for each actuation.

Figure 1.2 shows an example of actuated phase intervals where after the minimum

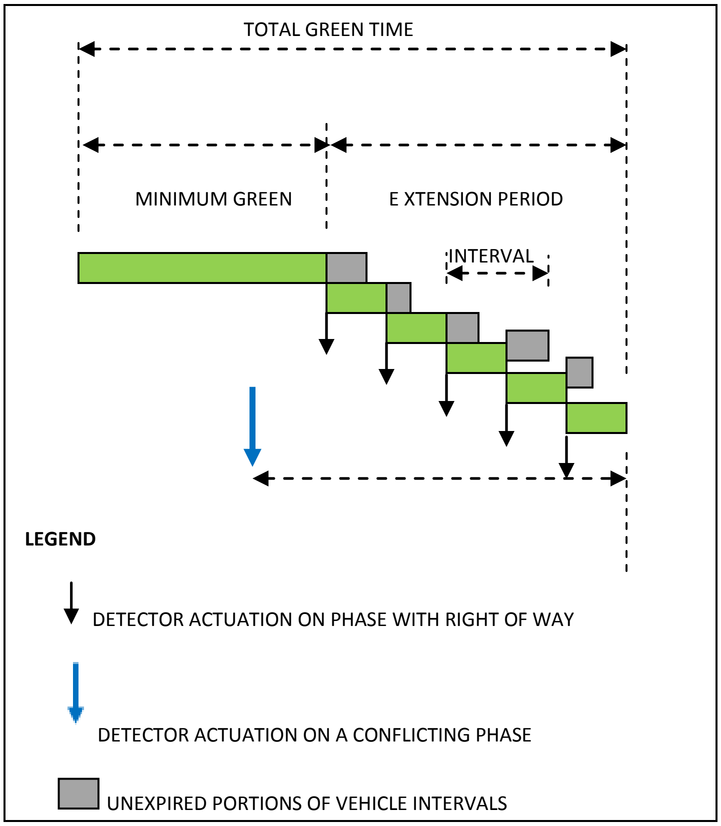

Figure 1.2 Actuated Phase Intervals
(Reprinted with Permission from Federal Highway Administration, Manual on Uniform Traffic Control Devices, 2009)

green, the green time is extended based on detector actuations on phase with right of way. The actuated control will keep extending green time as long as vehicles are detected on the approach.

1.7 Adaptive Traffic Control

Adaptive traffic controls optimize signal timings based on real-time traffic data unlike fixed-time and actuated controls which calculate plans off-line. The signal timings are adjusted in response to changing traffic demand. The detectors are placed upstream or at stop lines to measure real-time traffic information. The information is then used to predict the flow parameters such as queues, turning movements, and vehicle arrivals, which in turn are used to optimize the signal timing on a real-time basis, thus reducing delay, travel time, and emissions.

The commonly used ATCS include SCOOT (developed in the United Kingdom) (Hunt et al., 1981), and SCATS (developed in Australia) (Lowrie, 1982). Other ATCS include RHODES (Head et al., 1992) (developed in the USA), and OPAC (Gartner, 1983). Adaptive controls are one of the most advanced traffic control methods. As compared to actuated controls, adaptive controls need more sensor data to get information on all movements at the intersection. The sensor data are then used by algorithms to meet the changing demand.

While both actuated and adaptive controls can measure changes in traffic demand, only adaptive controls fully utilize the demand data and respond accordingly to the demands.

1.8 Factors Impacting Route Choice

Changes in the traffic controls are not the only factors that impact a traffic system. There may be other factors that can play a role in drivers' route choices in a traffic system, including those pertaining to incidents, environmental hazards, demographics of drivers, vehicle or driver characteristics, and traffic conditions. Traffic assignment models are widely used to predict drivers' route choices in a traffic system.

1.9 Traffic Assignment

Traffic assignment models estimate drivers' route choices to find routes on a street network. An Origin Destination (OD) matrix comprising the total number of origin-destination pairs that wish to travel through the traffic system is typically required to implement traffic assignment. A traffic system must be represented by a road network in the form of nodes for intersections and links for the links between the nodes. The traffic assignment methods are classified into two categories, i.e., Static Traffic Assignment (STA) and Dynamic Traffic Assignment (DTA).

1.10 Static Traffic Assignment

STA uses the trip maker's choice of path between the zones and loads the resulting vehicular flows on a transportation network. STA uses a cost function defined by a set of variables based on traffic system interaction. The cost function could be defined as a combination of the weight on time that it may take to travel between the origin and the destination and the weight on distance between the origin and the destination, or it may use a combination of prevalent variables based on the urban geography of the traffic system.

STA, however complex and defined, does not capture the time varying effects of traffic. When a queue occurs, the duration of the queue and the actual delay are not modeled correctly. Figure 1.3 explains the STA on a simple four legged signalized intersection with an option of a longer distance nonsignalized bypass route ADB as compared to shorter route distance on AB through a signalized intersection.

Figure 1.3 outlines an example of STA with a combined cost function based on time and distance. The figure shows the result of three cost functions for 100 trips bound to travel on route AB with origin at A and destination at B. There are two possible routes for the trips: Route 1(Route AB) is a shorter route through a signalized intersection and Route 2 (Route ADB) through a bypass but a relatively longer route.

For simplicity, the writer assumes that the cost function will assign trips consistent with weight (percentages) of travel time and distance.

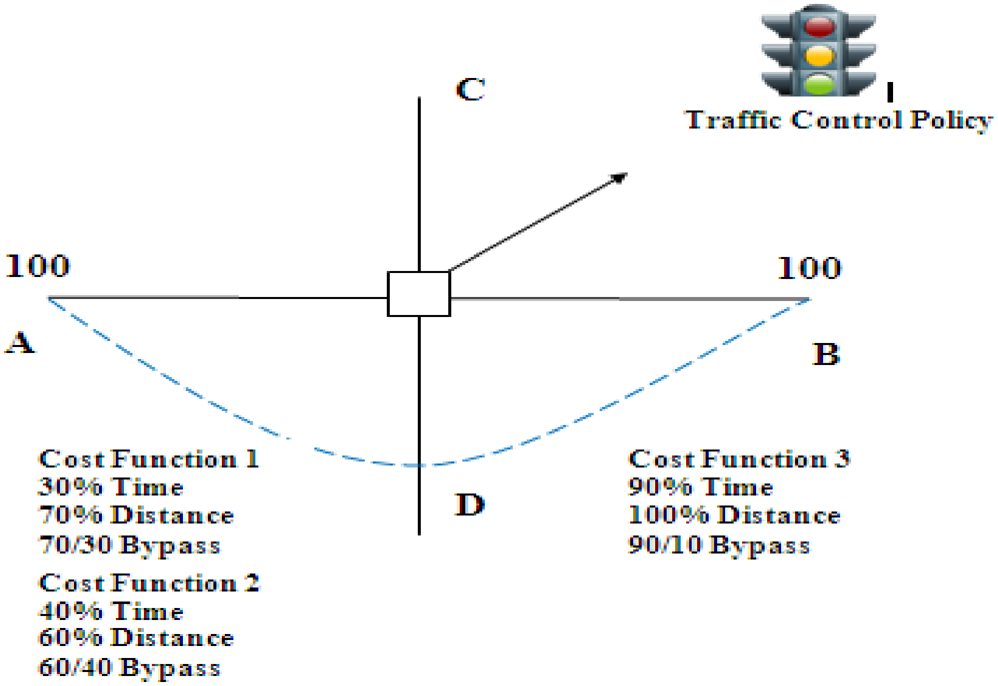

Figure 1.3 Static Traffic Assignment

In case of cost function 1, 30% weight is on travel time between AB and 70% weight is on distance between A and B on route AB. Due to a higher weight on travel distance, the STA based on cost function 1 will assign 70 trips to the shorter route between AB, the route through the signalized intersection, and due to relatively low weight on travel time, 30 trips will be assigned to the longer bypass route between ADB.

In case of cost function 2, a 40% weight is on travel time between AB and a 60% weight is on distance between AB. The STA based on the cost function 2 will assign 60 trips to the shorter route AB through the signalized intersection due to a relatively higher weight on distance and 40 trips will be assigned on the longer bypass route between ADB. In case of cost function 3, a 90% weight is on travel time between AB and a 10% weight is on distance between AB. The STA based on cost function 3 will assign 90 trips to bypass route ADB with no signalized delay, and only 10 trips through route AB with the signalized intersection where travel time may increase due to delay at the signalized intersection. Static assignment methods rely on cost functions to assign traffic to the road network. While cost functions can help estimate the shortest routes with respect to cost, they are unable to capture the change in drivers' route choice based on past or prevalent experience in a congested traffic network.

1.11 Dynamic Traffic Assignment

The DTA-based simulations can capture the real-life day to day route choice behavior of drivers. Figure 1.4 shows a simple four legged signalized intersection where route AB and route CD intersect; in addition there is a nonsignalized route ADB. Drivers traveling between origin A and destination B have two route options: route AB, a shorter route through a signalized intersection and a longer distance, bypass route ADB with no signalized intersection. Under DTA for a traffic system shown in Figure 1.4, On Day 1 a majority of drivers traveling between origin A and destination B may choose to travel on route AB through the signalized intersection. On Day 2, based on their previous day experience with congested traffic and delays due to traffic control, some drivers who travelled on shorter route AB on Day 1 may choose to travel through longer bypass route ADB. Under the DTA-based simulation, as the congestion increases through the route with signalized intersection, more drivers may choose a longer bypass route ADB to travel between AB to avoid delays. This driver behavior to choose a longer bypass route may switch back to shorter route AB if the travel cost on bypass route ADB becomes higher on a previous day travel experience. In DTA, the drivers travel on the routes with the smallest travel cost based on their day to day travel experience or even based on the information on prevailing traffic conditions.

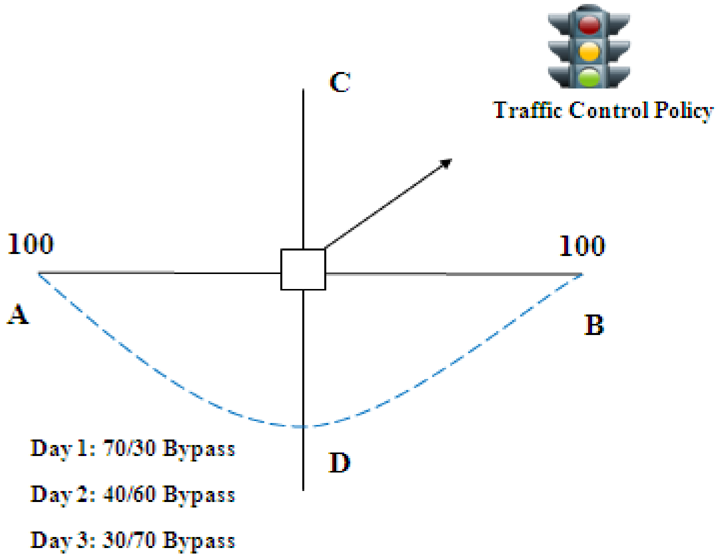

Figure 1.4 Dynamic Traffic Assignment

1.12 Problem Definition and Methodology

In travel demand modeling practice, travel demand models generally do not include traffic controls in the traffic assignment process. The road capacities are kept fixed and free flow speeds are adjusted to accommodate the impacts of the traffic controls. Similarly, in current traffic engineering practice, traffic flows are considered fixed inputs to the optimization process and the impacts of postoptimization traffic flows are not considered. By keeping the two processes separate, the current practice tends to ignore the interaction between the drivers' route choice and the traffic control (control-driver interaction). This indicates the need for development of new methods and tools that integrate the traffic control-driver interaction that happens in the traffic system. Figure 1.5 outlines the flow diagram of CTAC framework.

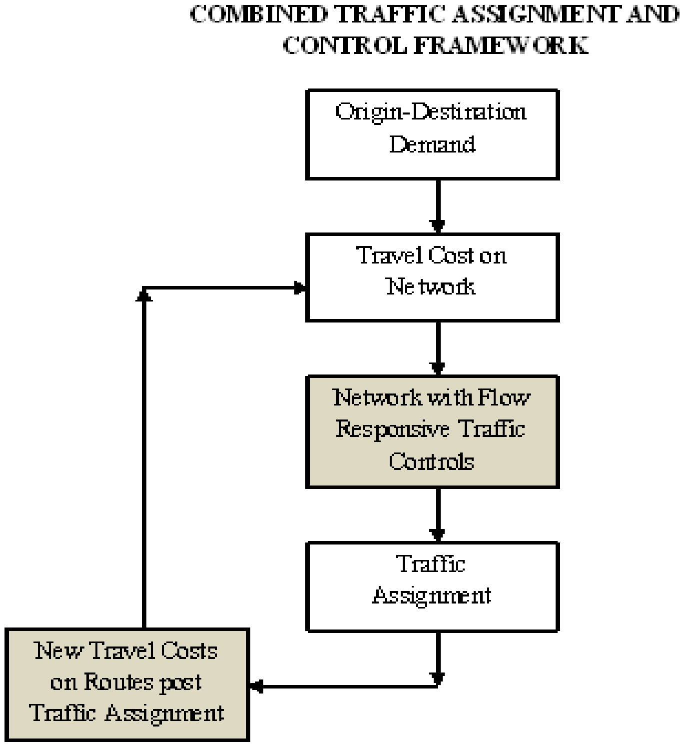

Figure 1.5 Combined Traffic Assignment and Control Framework
(Reprinted with Permission from Text Road Journals: Journal of Basic and Applied Scientific Research, No. 2090, pp. 808-817)

To study the effects of control-driver interaction, researchers have been investigating the Combined Traffic Assignment and Control (CTAC) (Meneguzzer, 1997) framework for many years. The framework allows a user to simulate a traffic system under the combined effect of traffic control and drivers' route choice.

One of the hurdles for implementing the concept until the mid-1990s was a lack of computer technology to perform complex calculations. Advance computers and software like DYNASMART (Abdelfetah and Mahmassani, 1998), VISSIM (Bloomberg and Dale, 2000), and CUBE-DYNASIM (Yaldi and Yue, 2006) can now simulate complex real-life networks.

Because of the availability of advanced computer technology, implementation of CTAC has been the topic of extensive research in academia. However, very little research has been done to identify the benefits of CTAC in terms of providing network travel time information to drivers for route choice in comparison with improvements to traffic controls. The CTAC framework could be used to capture those benefits by using STA- and DTA-based simulations with improvements in traffic control strategies.

1.13 Research Goal and Methodology

The goal of this research work is to show that the CTAC modeling framework when used in the traffic models can help improve the traffic systems in terms of travel time improvement and delay reduction. The objectives of the research, or steps to reach the goal, are focused on evaluating the different CTAC models on different geographic resolutions and comparing the results for different traffic system improvements. Two sections of the Salt Lake City, Utah road network, a section of Park City, Utah, and a regional road network of the Wasatch Front region, Utah were used as test networks. The research implemented a microscopic-simulation on the Salt Lake City and Park City road network, and a mesoscopic CTAC model for the Wasatch Front region. Several experiments were performed on the study areas using STA and DTA with fixed-time controls, vehicle-actuated controls, and adaptive controls. The experiments were performed using VISSIM for microscopic simulations and Cube-Avenue for mesoscopic simulations.

1.14 Objectives of the Research

The objectives of research are as follows:

1. Develop CTAC frameworks for the selected study area networks,
2. Collect data from transportation planning agencies, and process raw data for subsequent analysis.
3. Build the study area traffic networks on VISSIM, Cube, and Cube Avenue,
4. Calibrate and validate the models,
5. Model various traffic scenarios for fixed controls, vehicle actuated controls, and ATCS
6. Compare results and draw conclusions.

Figure 1.6 outlines the phases to evaluate the benefits of CTAC using various types of evaluations.

Phase 1 evaluates the benefits of CTAC models on different geographic resolutions using STA and DTA simulations with fixed-time controls, vehicle-actuated controls, and adaptive controls.

Phase 1

Evaluate the benefits of CTAC when simulated with the provision of previous day network travel time information to drivers with the possibility of improvements to traffic controls

Phase 2

Evaluate the benefits of Route Guidance Systems when simulated on CTAC in a microscopic-simulation environment

Phase 3

Evaluate the benefits of CTAC when implemented on a regional scale and compare the results with a traditional regional travel demand model

Figure 1.6 Phases to Evaluate the Combined Traffic Assignment and Control Framework

Phase 2 evaluates the benefits of route guidance systems when simulated on CTAC in a microscopic-simulation environment. The impacts of changes in proportion of RGS-equipped demand were used in the tests.

Phase 3 evaluates the benefits of CTAC models when implemented on a regional scale. The model was implemented on the regional road network of Wasatch Front region spanning four counties of Weber, Davis, Salt Lake, and Utah.

1.15 Format of Dissertation

This dissertation is founded upon technical papers submitted to conferences and publications. The publications out of the research work share co-authorship with professor Peter T. Martin. Each of the following five chapters have been individually presented at a technical conference, submitted to a journal, or both, as indicated in the following list.

Chapter 2 provides research on evaluation of the benefits of CTAC on two portions of Salt Lake City networks. It presented the benefits of CTAC modeling in terms of travel time improvements and delay reductions across the modeled scenarios for both networks. Chapter 2 relates to Paper 1 and Paper 2.

Paper 1: Farhan, M., Stevanovic, A. and Martin, T. P., A practical perspective on the benefits of combined traffic assignment and control method. Presented at *89th Annual Transportation Research Board Meeting,* Washington D.C. 2010.

Paper 2: Farhan, M. and Martin, T. P. Evaluation of the system wide benefits of capturing control-driver interaction in a traffic-system. Presented and published at *17th World Congress on Intelligent Transportation Systems*, Busan, South Korea. October 2011.

Chapter 3 takes the calibrated and validated CTAC base-run of Salt Lake City network 1 presented in Chapter 2, and evaluates the benefits of Route Guidance Systems. The scenarios were tested for increasing proportions of RGS-equipped demand ranging from 0% RGS-equipped demand in Scenario 1 to 100% RGS-equipped demand in Scenario 11. Increments of 10% were used to increase RGS-equipped demand across the eleven scenarios tested. The results were presented with benefits in travel time improvements and delay reductions. The Chapter 3 related to Paper 3 and Paper 4.

Paper 3: Farhan, M. and Martin, T. P. Evaluation of the benefits of route guidance system using combined traffic assignment and control framework. Presented and published at *17th World Congress on Intelligent Transportation Systems*, Busan, South Korea,

October 2011.

Paper 4: Farhan, M. and Martin, T. P. Benefits of route guidance system in a combined modeling framework with variance in intervals and equipped demand, In Press, *Journal of Basic and Applied Scientific Research*, Text Road Journals, 2011

Chapter 4 provides research on the benefits of CTAC modeling framework on the Park City network, a slightly larger study area. For the tests on the Park City network, the Traffic Control improvements from Fixed to ATCS were evaluated in combination with STA- and DTA-based simulations. The benefits were evaluated in terms of travel time improvements, and delay reductions across the scenarios. Chapter 4 relates to Paper 5.

Paper 5: Farhan, M. and Martin, T. P. Combined traffic assignment and control method: Benefits of capturing interaction between drivers' route choices and flow responsive traffic controls, In *Journal of Basic and Applied Scientific Research*, Text Road Journals, 2011, pp 251-258

Chapter 5 evaluated the benefits of CTAC models implemented on regional scales. A CTAC modeling framework was implemented on a Wasatch Front Region network and was compared to a traditional four step travel demand model for outputs. The regional travel demand model output measures of system-wide delay reductions, and system-wide vehicle miles traveled improvements were evaluated. Chapter 5 relates to Paper 6.

Paper 6: Farhan, M. and Martin, T. P. Implementation of combined traffic assignment and control framework based regional model for the Wasatch Front Region. In Press *Journal of Engineering and Applied Sciences*, Asia Pacific Research Network (APRN) Journals, 2011.

Chapter 6 presents conclusions of the research based on all the chapters, and recommendations.

Each chapter and related papers contain their own abstract, references, and other sections required by the respective conferences or journals yet have been reformatted to comply with dissertation guidelines. None of the text, figures, or references have been modified from the ones published in papers; so some overlap of information exists. Chapter 6 provides a summary of Chapters 2 through 5 as they relate to the overall intent of the research. A list of references follows the Chapter 6 to provide the sources of references used in the first and last chapters of this dissertation.

CHAPTER 2

A PRACTICAL PERSPECTIVE ON THE BENEFITS OF COMBINED TRAFFIC ASSIGNMENT AND CONTROL MODELS

2.1 Abstract

Combined Traffic Assignment and Control (CTAC) has been the topic of academic research for the last three decades. Its solution algorithms, model formulations, and implementation efforts have been well documented. Although proven in academic research, the use of CTAC-based models has been rare in engineering practice. Typically, the practice tends to keep traffic assignment and control optimization processes separate. By doing so, the control-driver interaction in the traffic system is ignored. Previous research concluded that CTAC models could capture the control-driver interaction well; hence, the combined modeling framework should be used in practice. The chapter presents a practical perspective on benefits of a CTAC model in terms of conveying network travel time information to the drivers from previous day's travel experience to make route choice with the possibility of improving the traffic controls. Four scenarios were tested on two areas of the urban area in Salt Lake City, Utah. Scenarios were tested using both STA and DTA with fixed and vehicle-actuated controls. The results show that total-delay reduction and total-travel time improvement were the smallest when only

traffic controls were improved in the study areas and the highest when the drivers had network travel time information based on their past travel experience in combination with improvements in the traffic controls. Further field applications are needed to compare the benefits by other control types and different simulation software programs.

2.2 Introduction

Traffic congestion mitigation is one of the key aspects of traffic engineering practice. Mitigation efforts are used by transportation planners to make the transportation systems efficient, especially in high-density urban areas with little room for expansion. In a real-world traffic system, the driver and the traffic control settings can have competing objectives. Typically, drivers intend to reach their destinations in the shortest possible time. Traffic control settings, on the other hand, are usually adjusted to achieve system-wide benefits. Once the signals are retimed (their settings are changed) drivers may respond to them by changing their route selection habits. In the perfect adaptive traffic control environment, the drivers' route choice may impact the traffic control settings which in turn may change drivers' route choices. This control-driver interaction over the course may lead the traffic system to a system optimum where the total-travel time or delay for the system is minimized. From drivers' perspectives, the control-driver interaction may lead to a user-equilibrium state where no matter what route the drivers choose to travel on, the cost of travel remains the same.

Typically, travel demand models do not include traffic controls in the assignment process. The road capacities are kept fixed and free-flow-speeds are adjusted to accommodate the impacts of traffic controls. Similarly, in traffic engineering practice, traffic flows are considered fixed input to the control's optimization process and the impacts of postoptimization traffic flows are not considered. By keeping the two processes separate, the practice tends to ignore the interaction between the drivers' route choice and traffic controls. This emphasizes the need for development of a new method and tool that integrate the control-driver interaction in traffic models.

To study the effects of control-driver interaction, the researchers have been investigating the Combined Traffic Assignment and Control (CTAC) *(1)* framework for many years now. The framework allows a user to simulate a traffic system under the combined effect of traffic control and driver's route choice. CTAC has been the focus of research for solution algorithms and theoretical modeling formulations for the last three decades. One of the hurdles for implementation of the CTAC modeling concept until the mid-1990s was lack of computer technology to perform complex calculations. Advances in computers, and software programs like VISSIM *(2)*, DYNASMART *(3)*, and CUBE-DYNASIM *(4)* can now simulate complex real-life networks. Due to the availability of advanced computer technology, implementation of CTAC has been the topic of extensive research in academia. However, from the perspective of practice, very little research has been done on CTAC framework to identify the benefits of providing near-perfect route choice information to drivers with the possibility of improvements in traffic control.

The objective of this chapter is to present quantification of the benefits of CTAC in terms of providing drivers network travel time information based on their past travel experiences (for better route choice) in comparison to improving the traffic controls. Several experiments were performed on two study areas using STA and DTA with fixed and vehicle-actuated controls. The study areas included two areas of Salt Lake City, Utah network.

2.3 Literature Review

The literature on CTAC research can be classified into two categories: solution algorithms and model formulations and implementation.

2.3.1 Review on Solution Algorithms and Model Formulations

Allsop conducted one of the first studies on CTAC problems in the 1970s. Allsop *(5)* suggested that the traffic controls impact route choice. Maher and Akcelik *(6),* Gartner *(7)*, and Allsop and Charlesworth *(8)* investigated CTAC on a conceptual level by studying the use of signal control to influence route choice. Dickson *(9)*, Smith *(10, 11)*, Sheffi and Powell *(12)*, and Marcotte *(13)* investigated the problem for the existence of equilibrium. Smith formulated conditions that theoretically guarantee the existence of equilibrium. Smith *(14, 15)* introduced a control policy P_o that ensures the existences of traffic equilibrium. These theoretical approaches by Smith paved the way for one of the initial CTAC implementation efforts by Smith and Van Vuren *(16).*

Heydecker *(17)* investigated the impacts of intersection modeling in traffic assignment on a policy level. The study found that at signal controlled intersections, the policy that is used to determine signal settings influences the traffic flow. Fisk *(18)* investigated the CTAC problem from a game theory perspective, suggesting that CTAC follows the hierarchical structure and presented an iterative approach to solve it. Smith and Ghali *(19, 20)* presented an algorithm that continued adjusting the controls after loading small portions of demand until the total demand is loaded. Yang and Yagar *(21)* worked on the optimization formulation of the CTAC problem. Chiou *(22, 23)* investigated different solution procedures for the optimization of the CTAC problem. Meneguzzer *(1)* and Taale and Zuylen *(24)* presented an overview of 25 years of research on combined traffic assignment and control. Granato *(25)* reported that the transportation planning agency in Iowa is using a CTAC model for limited use to long-range planning.

2.3.2 Review on Implementation

Early efforts on implementation of CTAC models began with a combined focus on solution algorithms and their implementation. Gartner and Al-Malik *(26)* derived an iterative approach for combined traffic and control problems using a link performance function. Gartner and Stamatiadis *(27)* presented a theoretical framework for implementation of a joint control and dynamic traffic assignment. Meneguzzer *(28, 29)* solved a combined route choice control problem using a diagonal algorithm. Taale and van Zuylen *(30)* investigated CTAC with STA on fixed-time, fixed-time-optimized, vehicle-actuated and vehicle-actuated-optimized control types. The study left other research options open, especially using adaptive controls and DTA on the latest simulation tools that are available now.

Mahmassani and Ta-Yin Hu *(31)* presented a DTA simulation procedure to investigate day-to-day network flows in combination with off-line and on-line traffic controls. The research concluded that real-time information and signal control strategies could reduce average delay system-wide. Abdelfatah and Mahmassani *(32)* presented a joint control and assignment problem to optimize the network performance with dynamic route guidance. The research concluded that a joint routing and control optimization can lead to an improved network performance. Cipriani and Fusco *(33)* investigated the interaction between signal settings and traffic flows for optimal control settings on CTAC framework. Varia and Dhingra *(34)* presented the DTA model for UE flows on traffic controlled intersections.

In summary, conventional traffic assignment and control optimization methods tend to ignore control-driver interaction. The CTAC method can capture control-driver interaction in a single framework. The investigations on solution algorithms, model formulations, and implementation of the method have been documented. However, there has been no study to date that captures the benefits of the CTAC model in terms of providing network travel time information to drivers (for better route choice) in comparison with the possibility of improving traffic controls on a CTAC framework.

2.4 Research Methodology

2.4.1 Test Scenarios

Four scenarios were tested using VISSIM-based microsimulation on two networks. A brief description of the test scenarios is given below. Table 2.1 displays the test scenarios.

2.4.1.1 Dynamic Assignment Scenarios

SCENARIO 1: Signal timings are fixed and controls do not respond to changes in traffic flow. Drivers have network travel time information from their previous travel experience and they are able to make route choices based on that. This scenario represents a situation where the traffic controls have not been upgraded for long time because better timings cannot be provided due to multimodal operation (vehicles, pedestrians, and public transit). The drivers, based on their past travel experience, would be able to make route choices.

SCENARIO 2: Signal timings may respond to changes in traffic flow. In addition, the drivers have network travel time information from their past experience and they are able to make route choices based on that. The scenario represents a situation where the

Table 2.1 Test Scenarios

Scenario Matrix	Dynamic Assignment	Static Assignment
Fixed Control	Scenario 1	Scenario 3
Vehicle- Actuated Control	Scenario 2	Scenario 4

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traffic flows are unpredictable and congested: for example, p.m. peak period traffic on a major street that goes through a series of intersections from an office research park to a residential community.

2.4.1.2 Static Assignment Scenarios

SCENARIO 3: Signal timings are fixed and do not respond to changes in traffic flow. Drivers do not have information on network travel times and they are not able to make route choice based on the network travel time information from their past experience. This scenario represents a situation in a Central Business District (CBD) where traffic signals have not been updated for decades. There is no need to install new signals which support traffic actuated operations because traffic flows are predictable and better signal timings cannot be provided due to multimodal operations. Figure 2.1 displays the sequence of scenario-testing processes, traffic control improvements, and exportation of static routes from DTA Scenarios.

SCENARIO 4: Signal timings may respond to changes in traffic flow while the drivers do not have information on network travel times from past travel experience and they are not able to change route choice based on that. The scenario represents traffic on

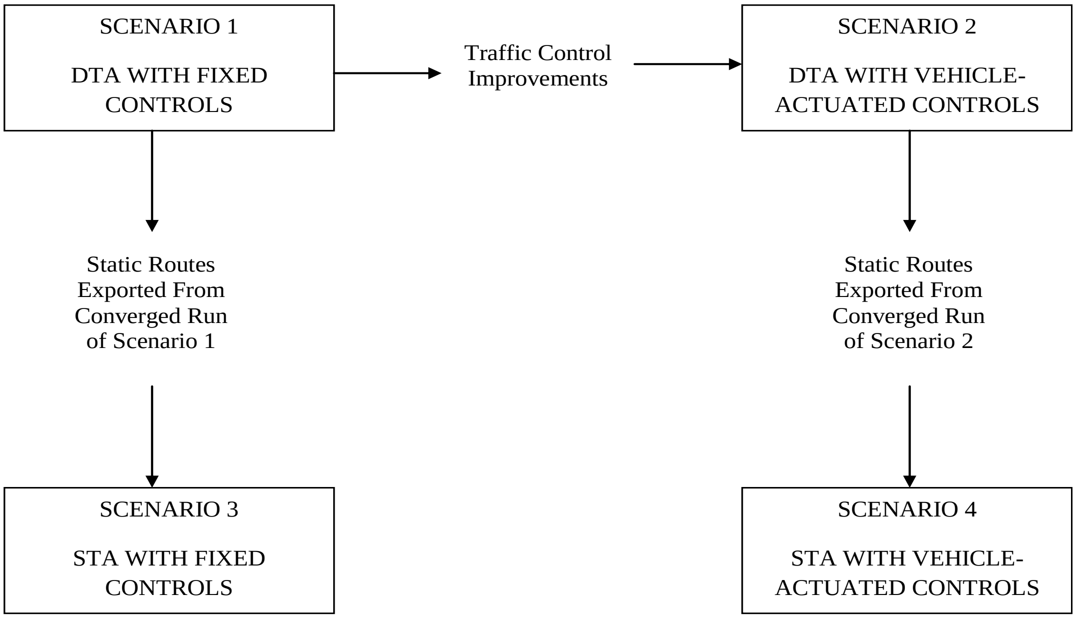

Figure 2.1 Sequence of Scenario Testing Process
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a street where due to unpredictable flows, traffic controls have been upgraded to vehicle actuated controls.

2.5 Overview of Traffic Analysis Tools

2.5.1 Modeling and Simulation Software

VISUM, a travel demand modeling software, and VISSIM, a microscopic traffic simulator by PTV, were used to model the test scenarios. VISUM 9.4 was used to calibrate the OD matrix. VISUM has an OD matrix correction module that has been proven as a reliable matrix correction tool *(35)*. VISSIM 5.00-08 simulation software was used to emulate a realistic traffic system of the study areas. VISSIM has been proven as a reliable microscopic simulation tool that produces virtual traffic flows similar to real traffic flows for the modeled traffic network *(36)*.

2.5.2 Dynamic Assignment

VISSIM applies DTA as an iterative simulation process. Drivers make the route choice based on their travel experience in the previous run. VISSIM computes the best paths in each run based on travel cost. Travel cost can be in terms of travel time, trip length, toll, or any other general costs associated with trip making. The changing traffic conditions in each run may change the travel cost, which leads to more routes with lower costs in subsequent runs. For convergence, VISSIM requires that all paths must have a relative change lower than the defined threshold. Acceptable convergence criteria define indicators such as verifying that 95% of all paths are within 10 to 15% of travel cost on previous run. Other standard practices look at mean errors in travel costs of the non-converging paths.

For this research, the travel time on paths was used as cost in DTA. A convergence criterion of 5% travel time difference (compared to travel time on previous run) on paths was used. For each run of DTA simulation, VISSIM compares the travel time on paths to the previous run. Based on the threshold, if the difference in travel time on all paths is less than or equal to 5% of the travel time in the previous run, the convergence criteria are met. Otherwise, the simulation continues until it reaches the maximum number of runs specified by the user or meets the convergence criteria, whichever comes first. Travel time evaluation files containing travel time for each OD pair were written for every run of DTA simulation using the “Evaluation Files” feature of VISSIM. In the tests for a smaller area network, random seed increment of 5 with initial random seed of 5 was used for the simulation in all four test scenarios. In the tests for a larger network (Network 2), the tests were conducted with the same initial random seed, as well as the increment of random seeds.

In case of Network 1, DTA-based Scenario 1 and 2 met the set convergence criteria after 13 iterations. STA-based Scenario 3 and 4 were run for 13 iterations for consistency on comparisons although the Scenarios 3 and 4 did not converge. In case of Network 2, DTA-based Scenario 1 and 2 met the set convergence criteria after 27 iterations. In case of Network 2, STA-based Scenario 3 and 4 were run for 27 iterations for consistency on comparisons and they did not converge.

2.5.3 Static Assignment

VISSIM provides an option to convert the current state of the DTA into a STA model through static routes, volumes on the routes, and current state DTA data files. The data files with extensions WEG, BEW, and FMA contain the list of discovered paths, costs for paths, and OD information, respectively. After the conversion process is complete; it is then possible to use the simulation without the DTA module of VISSIM. The use of static-routes-based assignment means the routes are frozen and vehicle inputs and routing decisions are created using the data files.

For STA scenarios, the static routes were exported from the converged DTA-based runs of Scenario 1 and 2. The static routes with the data files from converged runs of Scenario 1 and 2 were then used by Scenario 3 and 4 for simulation for both networks. In the case of Network 1, the STA simulation used initial random seed of 5 with increment of 5 for 13 runs. In the case of Network 2, the same initial random seed and increment of random seed were used and the STA was run for 27 iterations. For STA, VISSIM delivers the travel time information for user-defined travel time segments on the network. Travel time segments were defined on the network for all the static routes. For the system-wide measures like total travel time and total delay, VISSIM summarizes the output for both STA and DTA in the same fashion.

2.5.4 Signal Control Emulator

A National Electrical Manufacturers Association (NEMA) standard signal control emulator was used for traffic controls in test scenarios. This controller is available in North American releases of VISSIM and emulates common signal controllers used in North America. With this controller, VISSIM can simulate fully actuated signal control as well as coordinated and vehicle-actuated coordinated signal control. The interface to the controller is accessed through VISSIM but saves its settings to an external data file with the extension (NSE). To use the NEMA standard emulator in VISSIM, traffic control programs for each intersection in the study area network were exported to NEMA format using VISUM software.

2.5.5 Traffic Controls

Fixed Controls and Vehicle-Actuated Controls were used in the tests. Fixed controls usually operate on a predetermined and repeated sequence of signal plans with fixed cycle length and splits and offsets. The signal timing plans are developed off-line and optimized based on historic data of traffic flow. A series of predetermined plans can accommodate variations in traffic volume during the day. Fixed controls are best with predictable traffic volumes.

Vehicle-actuated controls differ from fixed control because they can respond to variations in traffic flow and are typically used in situations with irregular traffic flow.

The actuated controls can be grouped into two types: semi-actuated and fully actuated. Semiactuated systems primarily apportion the green time to the major movement of traffic and minor streets are accommodated when demand is detected. Fully Actuated control systems detect vehicles on all approaches of the intersection and make adjustments according to the prevailing flow. The vehicle actuated controls were used with the limitations that offsets and cycle lengths would not change, and only green splits within the given cycle length framework could be adjusted. The changes in green split could respond to the variation in traffic flow due to different route choices of drivers in DTA simulation.

2.6 Study Areas

Two portions of urban area from Salt Lake City, Utah were selected for testing. The first network was relatively small in size and the area consisted of sections of collector 500 East and principal arterial 700 East from 900 South to 2100 South with cross roads 1300 South and 1700 South in between (see Figure 2.2(a)). The second network area consisted of sections of collector 500 East and principal arterial 1300 East from 900 South to 2100 South.

The first network consisted of 25 nodes, including 8 signalized intersections and 3 intersections with 2-Way stop signs, and 14 zonal nodes. The second network consisted of 56 nodes, including 16 signalized intersections and 11 intersections with 2-Way stop signs, and 29 zonal nodes (see Figure 2.2(b)). Small and relatively larger sized study areas were selected to test the scenarios on both a simple and relatively larger network. Turning movements and traffic control data were collected from Utah Department of Transportation (UDOT).

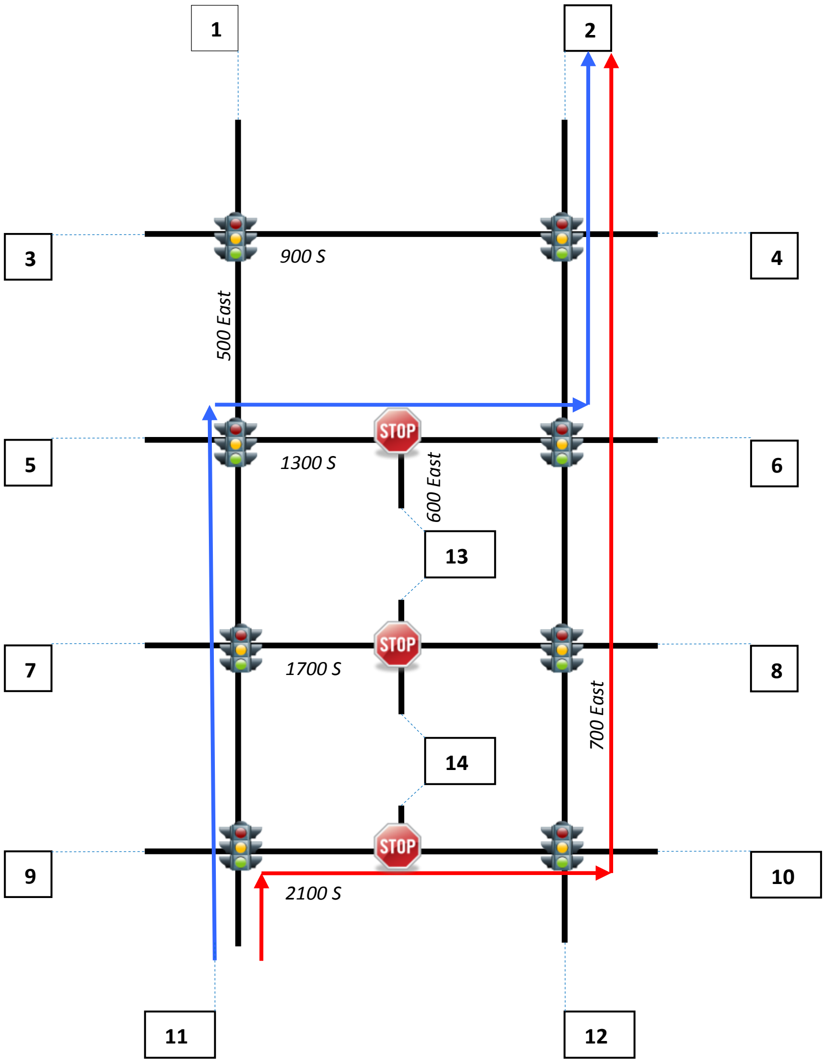

Figure 2.2 Networks from Salt Lake City Area (a) Network 1 from Salt Lake City Area (b) Network 2 from Salt Lake City Area

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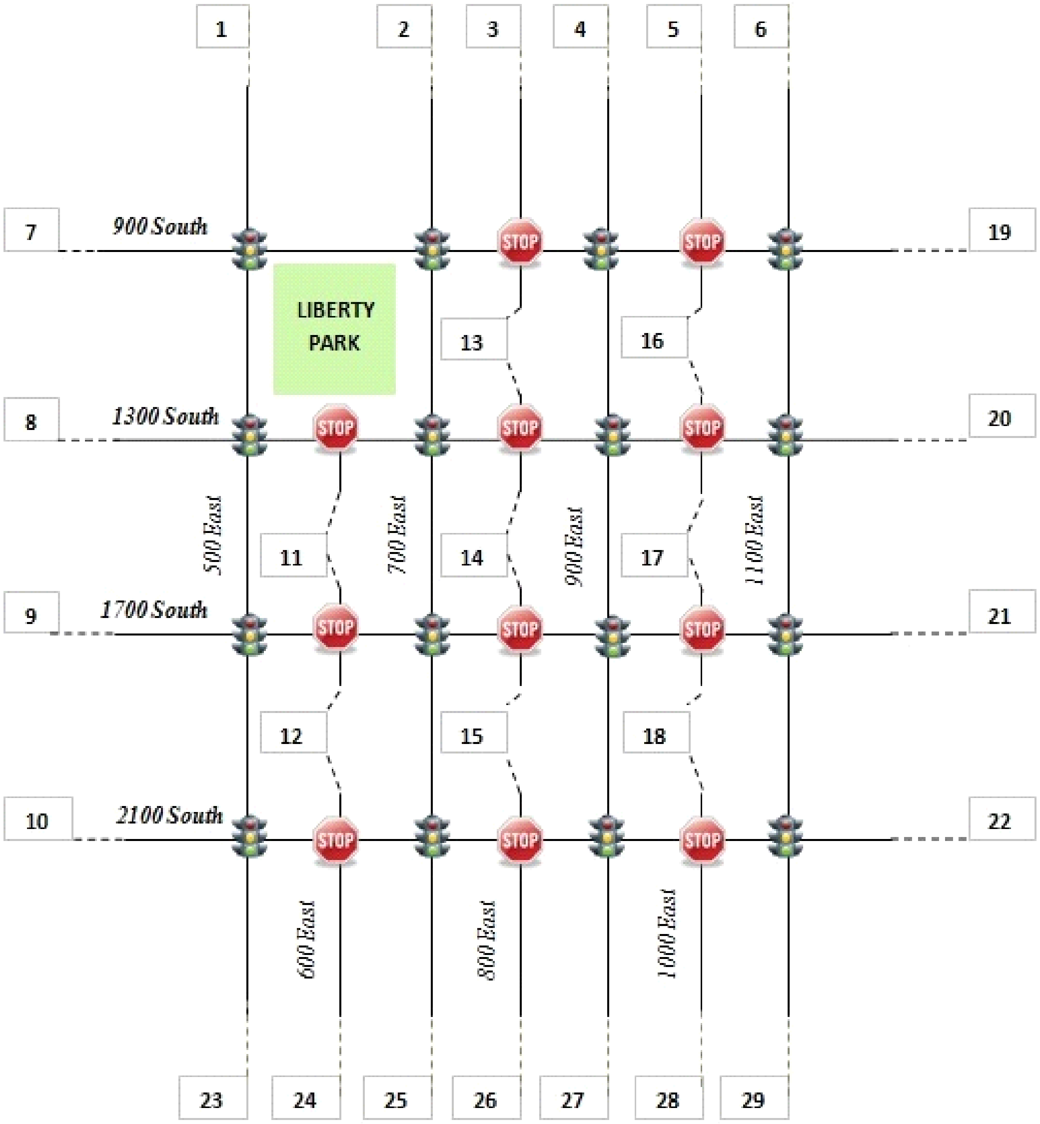


Figure 2.2 Continued

The turning movement data were then assembled for 3 hour p.m. peak period starting at 4 p.m. to 7 p.m. in a 3-hour interval. Figure 2.2 parts a) and parts b) display the study area network 1 and network 2, respectively.

2.7 Model Calibration and Validation

2.7.1 Origin-Destination Matrix Correction

Initial origin-destination (OD) matrices for the selected p.m. peak period were obtained from the regional travel demand model version 6.0 of Wasatch Front Regional Council (WFRC) by using a subarea extraction tool of cube software. The regional travel demand model of WFRC has been calibrated and validated for the region and is used for multimodal regional transportation planning in the region. Due to the macroscopic nature of the WFRC model, study areas' OD data extracted from the model was susceptible to some errors. The comparison of modeled volumes to field counts was therefore necessary. VISUM has several routines to assign travel demand specified in an OD-matrix (*37*). A multi-equilibrium assignment routine was used to assign demand in the initial OD matrix. The assignment process did not give a close match of modeled volume to the field counts. In order to better fit the field-counts, the initial OD matrices were calibrated using the VISUM-based TFlowFuzzy matrix correction module.

The matrix correction module is based on a well-known entropy maximization algorithm (*38*) and provides several options that may weigh in the correction process. The output from each run of OD matrix correction is a synthetic matrix, which by assignment reduces the difference between the counts and modeled data. For this chapter, the matrices were calibrated for the turning-movement counts only. The counts included left -turns, right-turns, and through movements at the intersections. The process with 43 iterations for network 1, and 72 iterations for network 2, led to an OD matrix that gave 100% match to the turning movement counts in network 1 and nearly 100% match in case of network 2. The matrix calibration process for larger areas may not achieve the same results. Figure 2.3 parts a), b), c), and d) display the scattered plot for modeled versus count data for initial and calibrated OD matrices for network 1 and network 2.

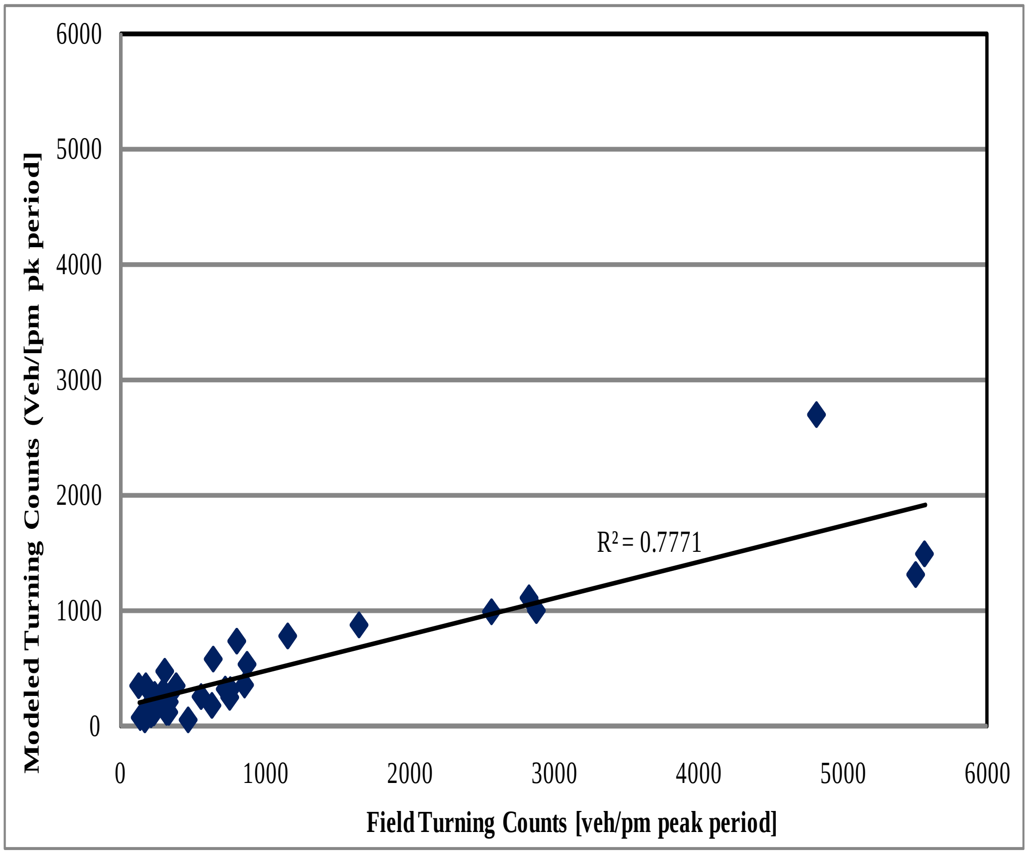
2.7.2 Model Calibration for Microsimulation

Microscopic simulation models have been widely used in both transportation operations and management analyses because simulation is safer, less expensive, and faster than field implementation and testing. While these simulation models can be advantageous to engineers, the models must be calibrated and validated before they can be used to provide meaningful results.

Microscopic simulation models contain numerous independent parameters to describe traffic control operations, traffic flow characteristics, and drivers' behavior. These models contain default values for each variable, but they also allow users to input a range of values for the parameters. Changes to these parameters during calibration should be based on field-measured conditions and should be justified and defensible by the user.

For this paper, the calibration and validation process was performed to closely match a) travel times data, b) speed data, and c) validation to match traffic counts on scenario with static assignment and vehicle-actuated control. The field data on counts, travel times, and speeds were collected from UDOT and WFRC.

Table 2.2 part a) and part b) show the p.m. travel time comparison for observed vs. modeled for selected Route 1 and Route 2 from network 2. Route 1 originates at the intersection of 700 East and 900 South and terminates at the intersection of 2100 South



(a)

Figure 2.3 Calibration of OD Matrix: a) Modeled vs. Field counts from initial OD Matrix from network 1 b) Modeled vs. Field counts from calibrated OD Matrix from network 1 c) Modeled vs. Field counts from initial OD Matrix from Network 2 d) Modeled vs. Field counts from calibrated OD Matrix from Network 2

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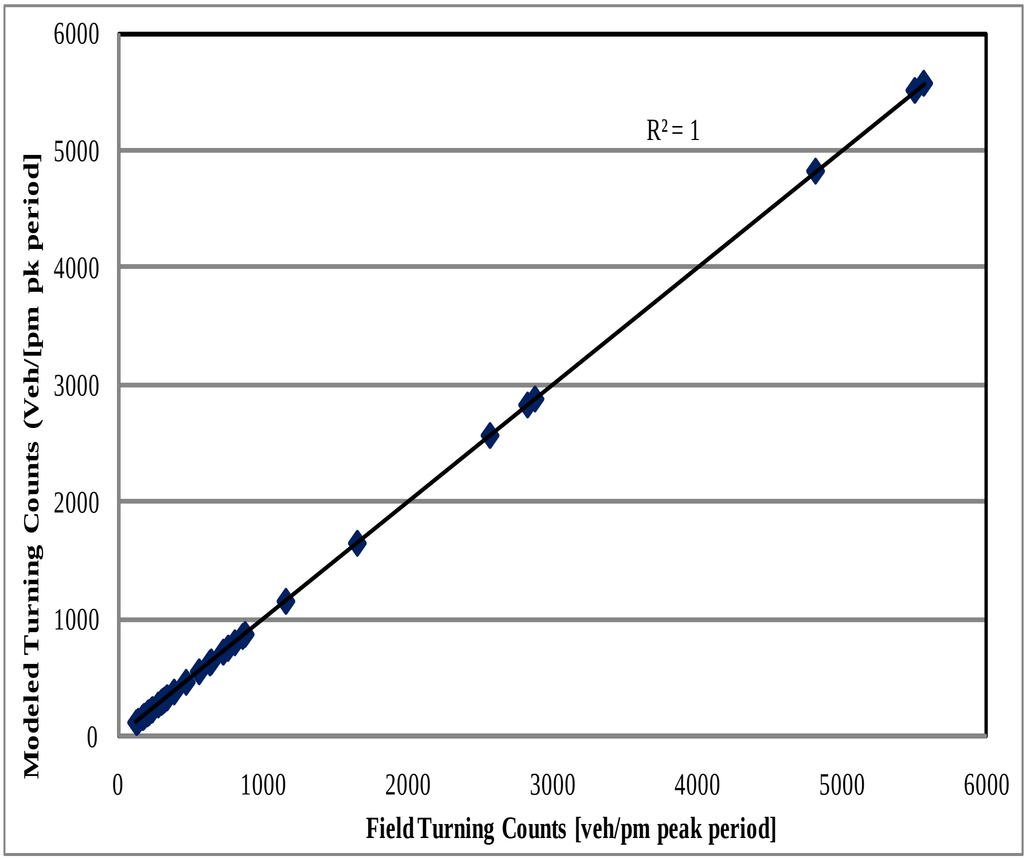
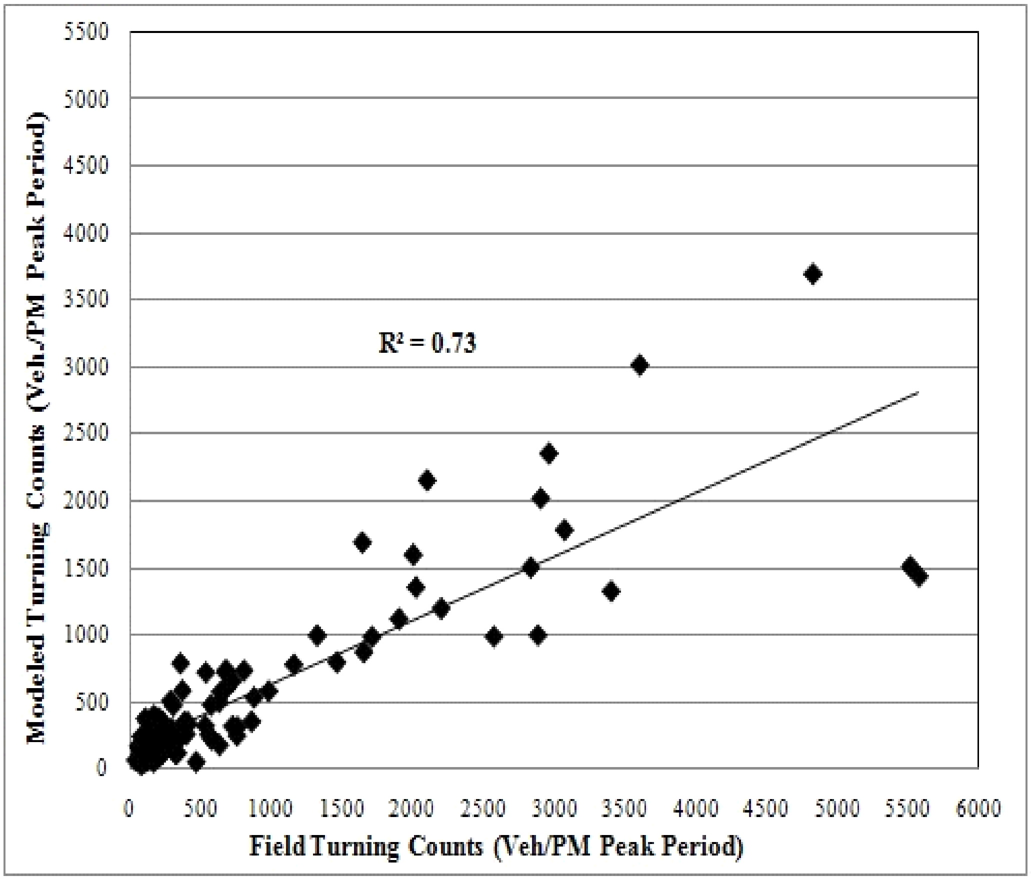


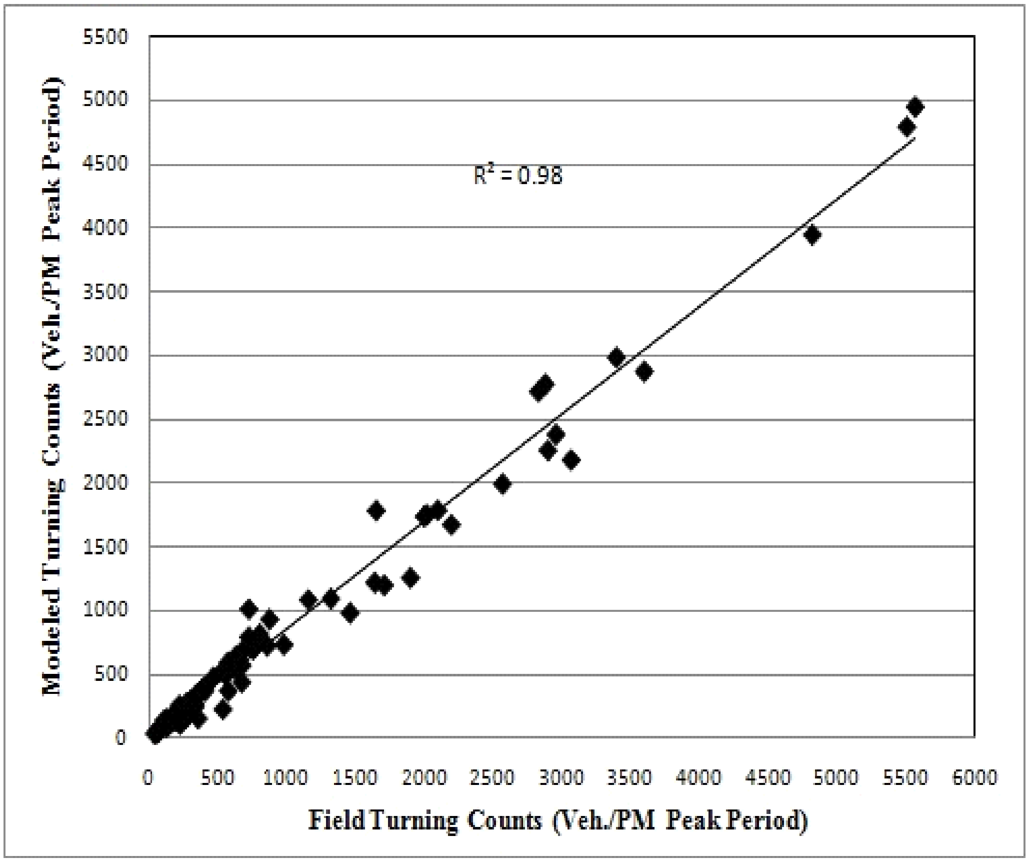
(b)

Figure 2.3 Continued



(c)

Figure 2.3 Continued



(d)

Figure 2.3 Continued

Table 2.2 Travel Time Comparisons Observed vs. Modeled a) Route 1 Travel Time Comparison b) Route 2 Travel Time Comparison

a)

Route 1: From 900 S to 2100 S on 700 East			
Test ID	Observed (minutes)	Average Travel Time Route 1 (minutes)	Percent Difference
1	8	8.3	3.8%
2	8	8.2	2.5%
3	8	8.2	2.5%
4	8	8.2	2.5%
5	8	8.2	2.5%
6	8	8.1	1.3%
7	8	8.1	1.3%

(b)

Route 2: From 900 S to 2100 S on 500 East			
Test ID	Observed (minutes)	Average Travel Time Route 2 (minutes)	Percent Difference
1	6	5.9	-1.7%
2	6	6.2	3.3%
3	6	6.2	3.3%
4	6	5.9	-1.7%
5	6	5.9	-1.7%
6	6	6.1	1.7%
7	6	6.0	0.0%

and 700 East. Route 2 originates at the intersection of 900 South and 500 East and terminates at the intersection of 2100 South and 500 East. The calibration was an iterative process.

Out of all the tests for calibration, test 7 was selected as the calibrated and validated base-run as it gave the best fit (observed vs. modeled) with travel times, speeds, and traffic counts for microsimulation on network 2. The similar calibration process was conducted on network 1 to get the calibrated base-run before testing the scenarios on network 1. Table 2.3 outlines the Average p.m. peak speed comparison for the selected spots on the network with observed speed data available. The comparison shows the average of speed on each spot from the seven test runs for the calibration.

Table 2.3 Speed Comparison Observed vs. Modeled

Speed Comparison Field vs. Observed			
ID	Observed (mph)	Average Modeled (mph)	Percent Difference
1	27.1	26.6	-1.8%
2	34.4	34.1	-0.9%
3	38.7	38.3	-1.0%
4	24.5	24.3	-0.8%
5	41.9	41.5	-1.0%
6	46.8	46.1	-1.5%
7	28.5	28	-1.8%
8	21.0	20.7	-1.4%
9	18.8	18.5	-1.6%
10	24.3	24.5	0.8%

2.8 Results and Discussions

2.8.1 Evaluation of Results

Table 2.4 Parts a) and b) display the means and standard deviations of total delay and total travel time from all simulation runs of the four test scenarios from network 1 and network 2, respectively. Percentage changes in mean delay and mean travel time were compared across the scenarios to compute the relative benefits. Figure 2.4 part a) and c) display percent reduction in total delay on network 1 and network 2 and part b) and d) display percent improvement in total travel time on network 1 and network 2.

Table 2.4 Total Delays and Total Travel Time Comparisons a) Total Delay and Travel Time Comparison on Network 1 b) Total Delay and Travel Time Comparison on Network 2

a)

Description	**SCENARIO 1**	**SCENARIO 2**	**SCENARIO 3**	**SCENARIO 4**
Mean Total Delay (Hours)	1023	736	2022	1916
Standard Deviation (Delay)	865	661	1346	1185
Mean Total Travel Time (Hours)	2085	1797	3018	2911
Standard Deviation (Travel Time)	313	216	142	89

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b)

Description	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean Total Delay (Hours)	2079	1349	4558	4140
Standard Deviation (Delay)	1698	1204	3052	2569
Mean Total Travel Time (Hours)	4979	4425	7012	6591
Standard Deviation (Travel Time)	709	557	304	219

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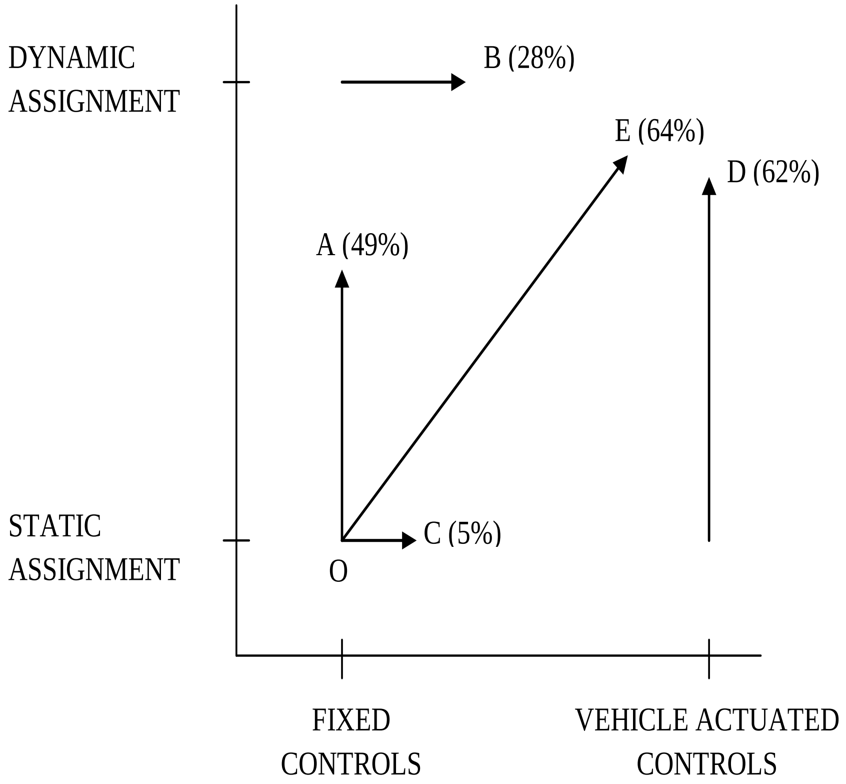

(a)

Figure 2.4 Total System-wide Delay Reductions and Total System-wide Travel Time Improvements a) Total Delay Reductions in network 1, b) Total Travel Time Improvements in Network 1 c) Total Delay Reductions in network 2 d) Total Travel Time Improvements in Network 2
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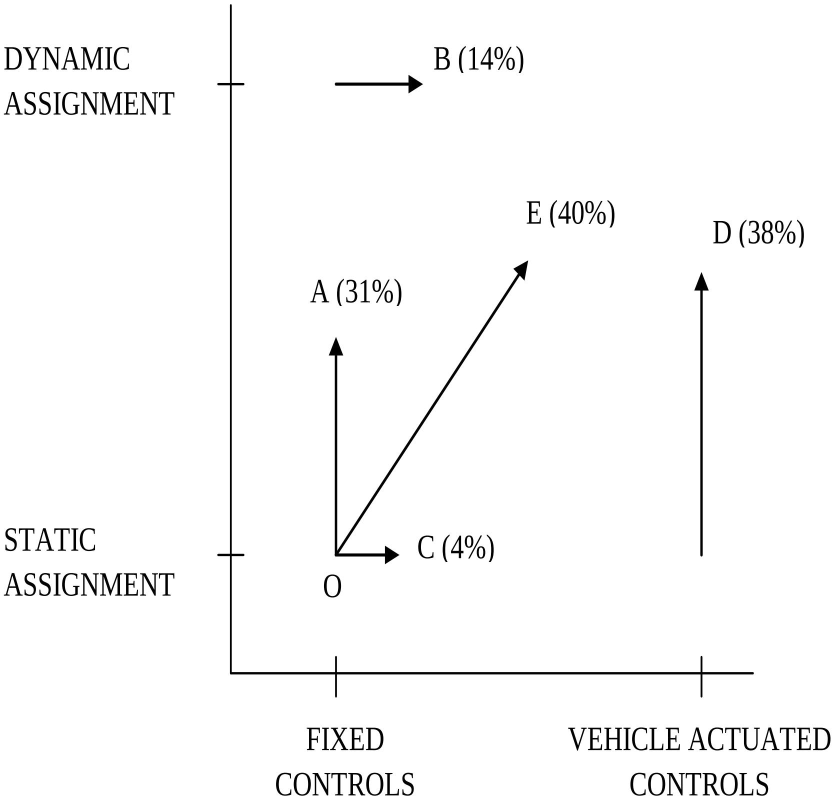

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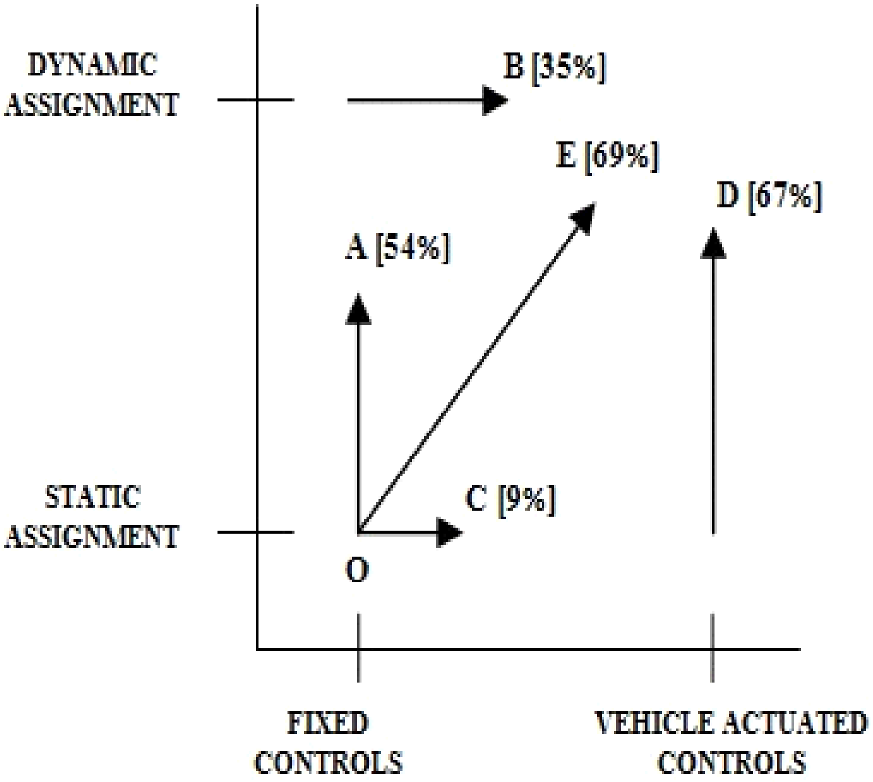
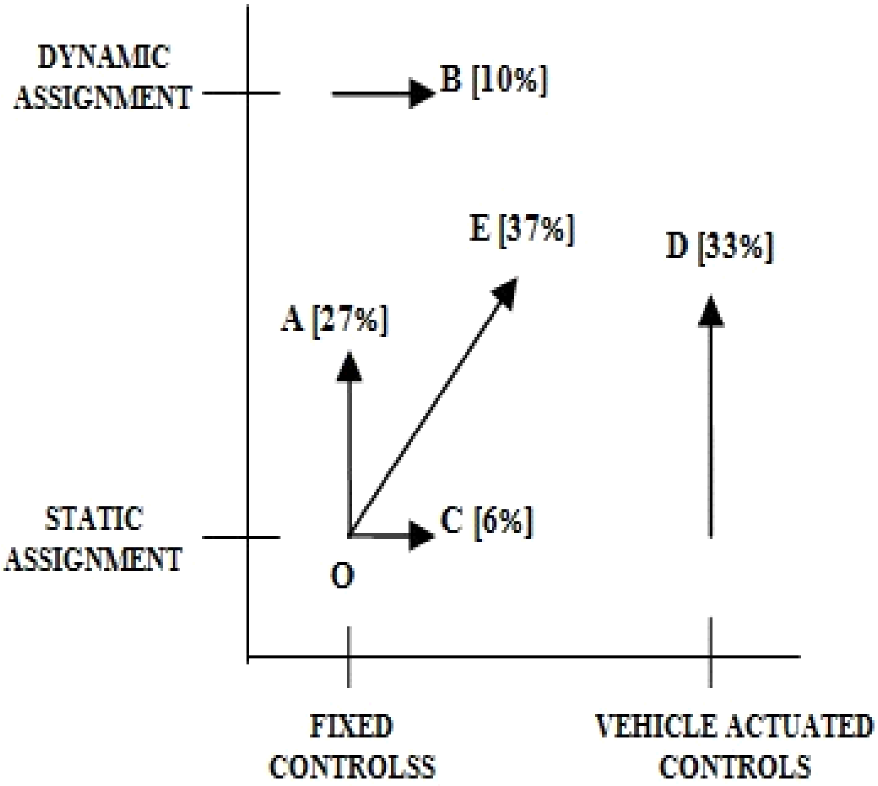
Figure 2.4 Continued



(c)

Figure 2.4 Continued



(d)

Figure 2.4 Continued

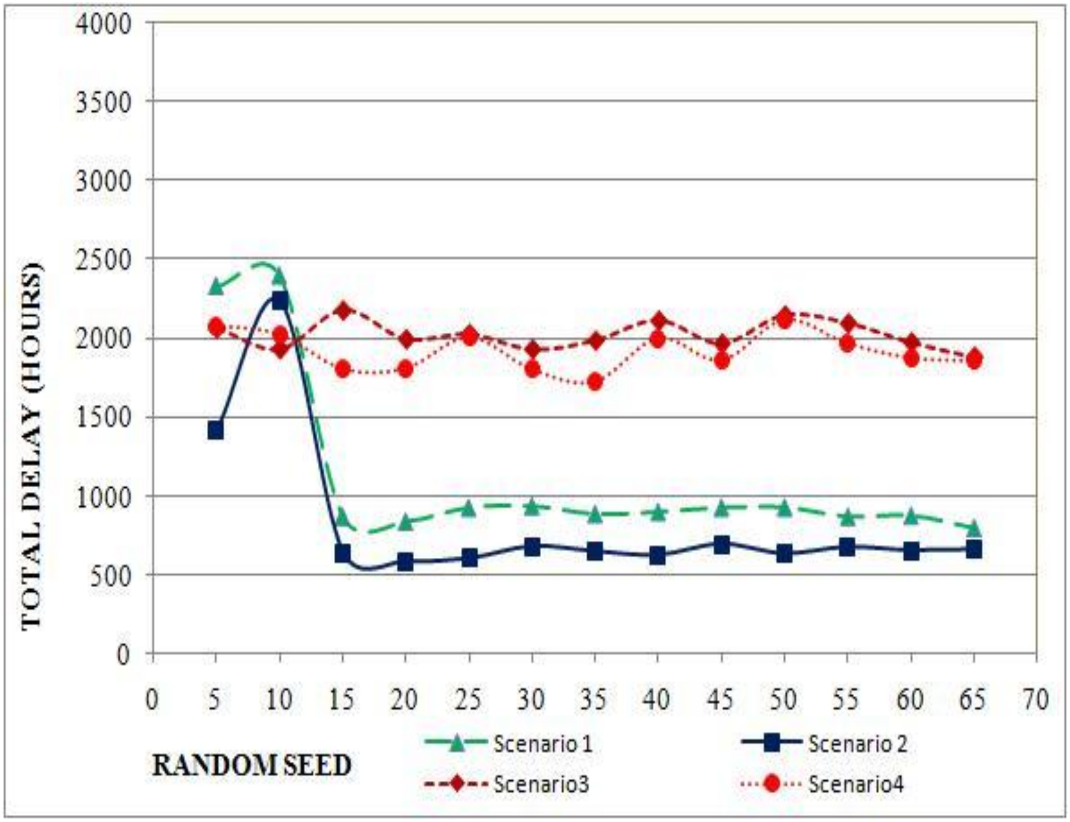
A brief explanation of various points in Figure 2.4 part a), b), c), and d) is given below:

- Pont O represents Scenario 3 with fixed controls and static routes where drivers did not have information to make route choice.
- Point A shows that if the traffic controls are kept fixed while the drivers have network travel time information based on past travel experience, the total delay can be reduced by 49% in network 1 and by 54% in network 2. The point A also shows that total travel time can be improved by 31% in case of network 1, and by 27% in network 2 .
- Point B shows that if in addition to network travel time information to drivers from past travel experience, the traffic controls are changed from fixed to vehicle-actuated; the total delay can be further reduced by 28% in network 1, and by 35% in network 2. Also, total travel time can be further improved by 14% in network 1, and by 10% in network 2.
- Point C shows that if only the traffic controls are changed from fixed to vehicle-actuated while drivers do not have network travel time information to make route choice, the total delay can be reduced by 5% in network 1, and by 9% in network 2. Also total travel time can be improved by 4% in network 1, and by 6% in network 2.
- Point D shows that in addition to changing the fixed controls to vehicle-actuated, if the drivers have network travel time information from past travel experience, the total delay can be further reduced by 62% in network 1, and by 67% in network 2. Also, total travel time can be further improved by 38% in network 1, and by 33% in network 2.

- Point E shows that if the traffic controls are changed from fixed to vehicle-actuated and at the same time if the drivers have network travel time information from past travel experience for better route choices, the total delay can be reduced by 64% in network 1, and by 69% in network 2. Also, the total travel time can be improved by 40% in network 1 and by 37% in network 2.

The above description shows that the traffic congestion reduced substantially when drivers had network travel time information from past travel experience information to make route-choice with improvements to traffic controls at the same time. Point A suggests that provision of network travel time information to drivers alone can reduce delays by half. To evaluate the convergence and existence of system-level stable traffic flows, the total travel time and the total delay from all the runs in test scenarios on network 1 and network 2 were compared.

Figure 2.5 parts a), b), c), and d) show that in scenario 1 and 2, with provision network travel time information to drivers based on their past travel experience, the traffic flow converged, and stabilized at lower congestion levels. On the other hand, in Scenario 3 and 4, with lack of information to drivers to make route choice, the traffic flow did not converge, and the flow stabilized at higher congestion levels. To evaluate the convergence and existence of user-level stable flows, network 1 was selected for further analysis. In network 1, routes between Zone 2 to 12 were compared for travel time in each run across the four scenarios. Figure 2.6 displays route choices A, B, and C for trips from Zone 2 to Zone 12 in each of the four scenarios. The travel time pattern on routes A, B, and C in test scenarios is described in Figure 2.7 parts a)-d). Figure 2.7 parts a) and b) show that when the drivers had network travel time information to make route choice, the



(a)

Figure 2.5 Total Delay and Total Travel Time a) Total Delay in Network 1 b) Total Travel Time in Network 1.c) Total Delay in network 2 d) Total Travel Time in network 2

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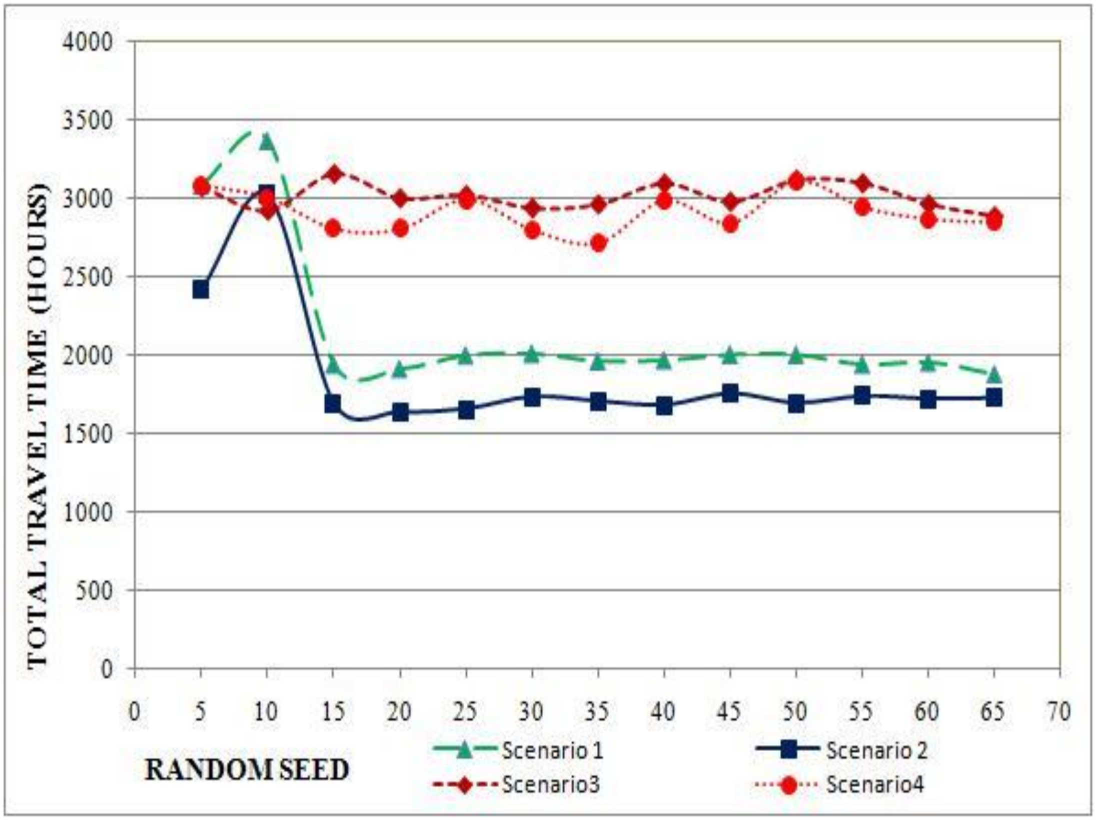
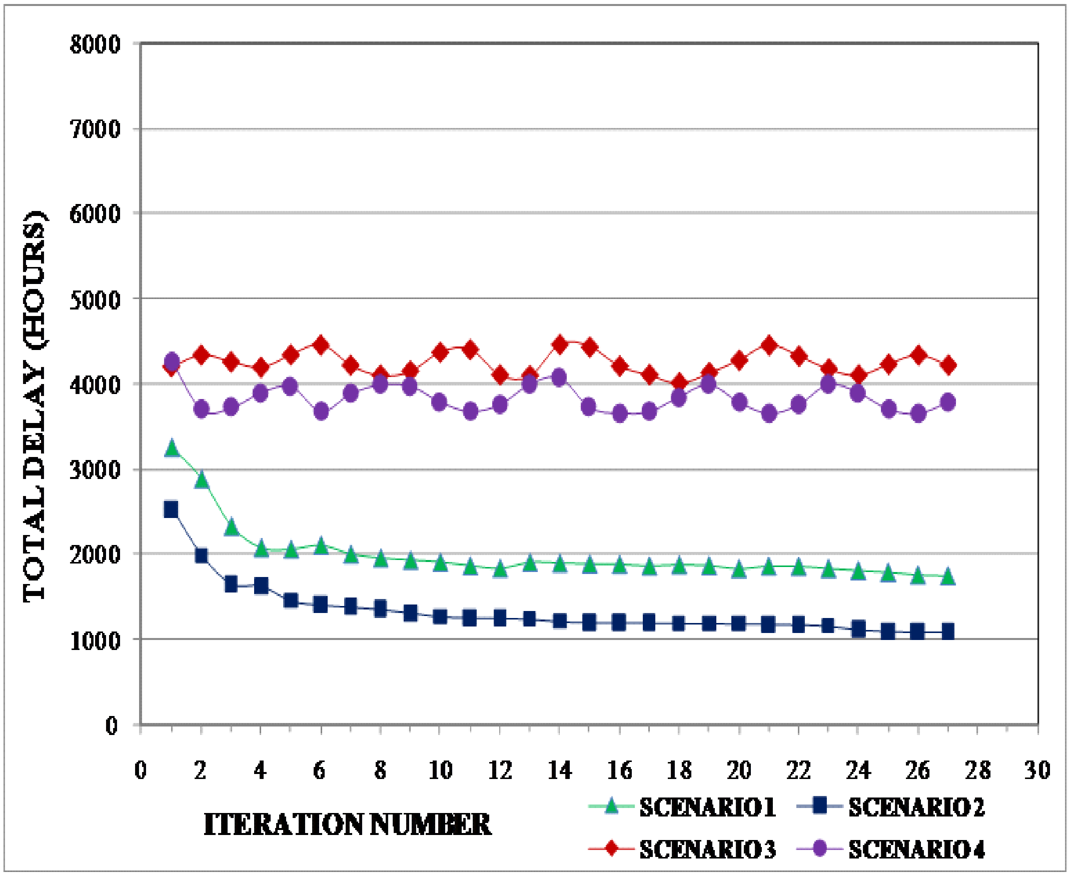


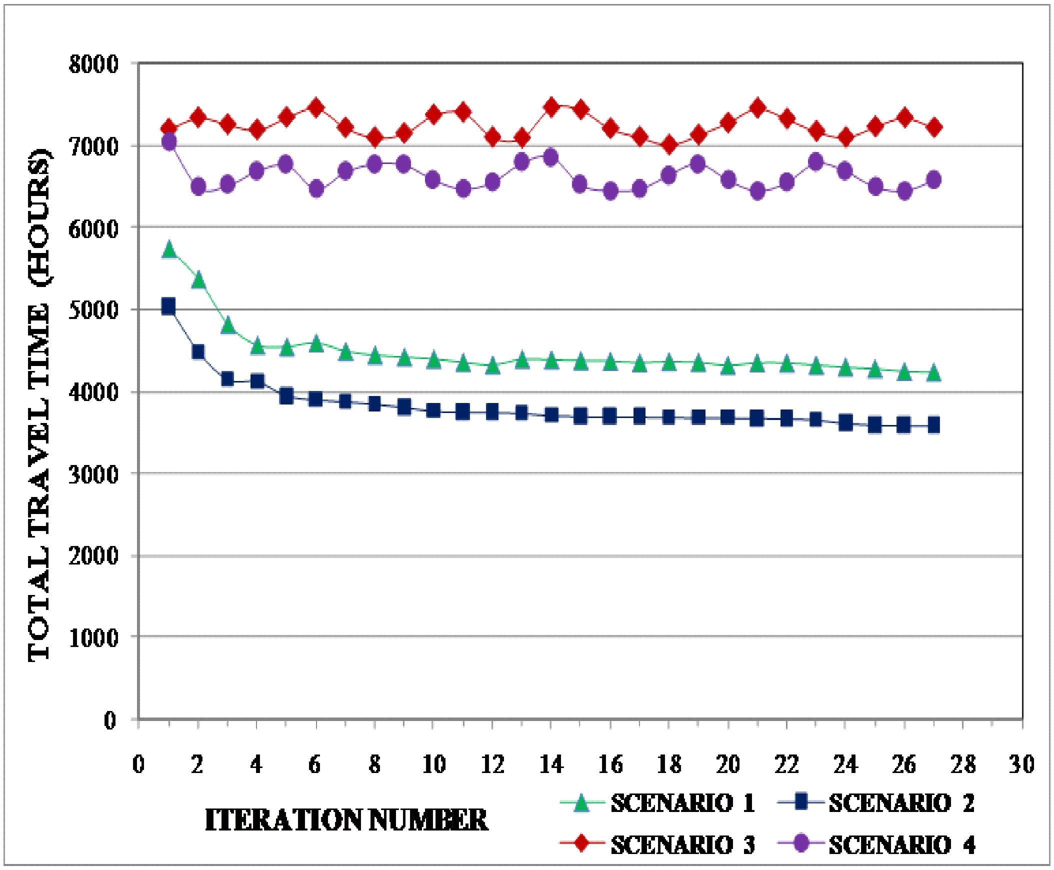
(b)

Figure 2.5 Continued



(c)

Figure 2.5 Continued



d)

Figure 2.5 Continued

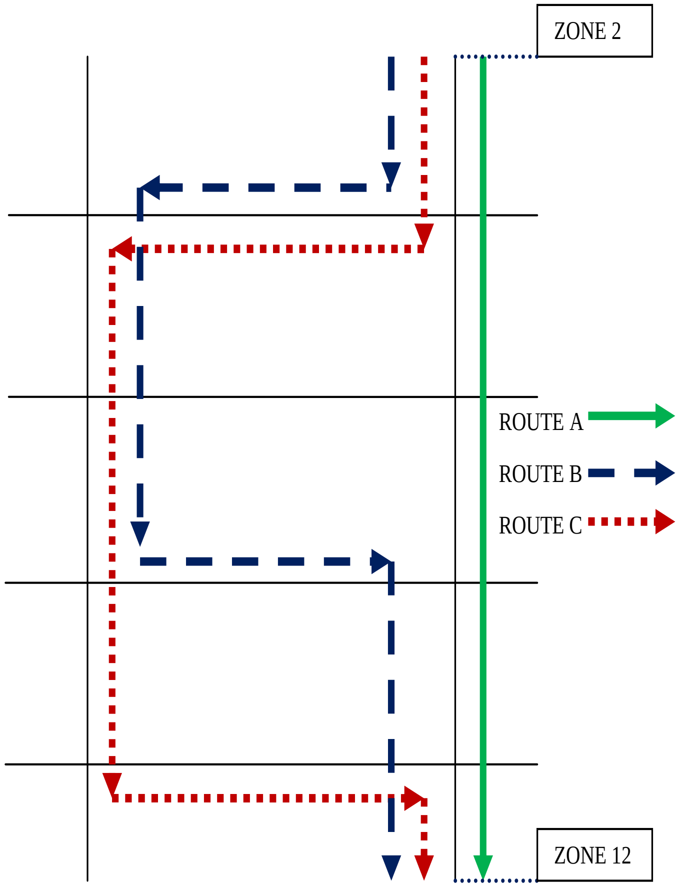


Figure 2.6 Route Choices from Zone 2 to Zone 12

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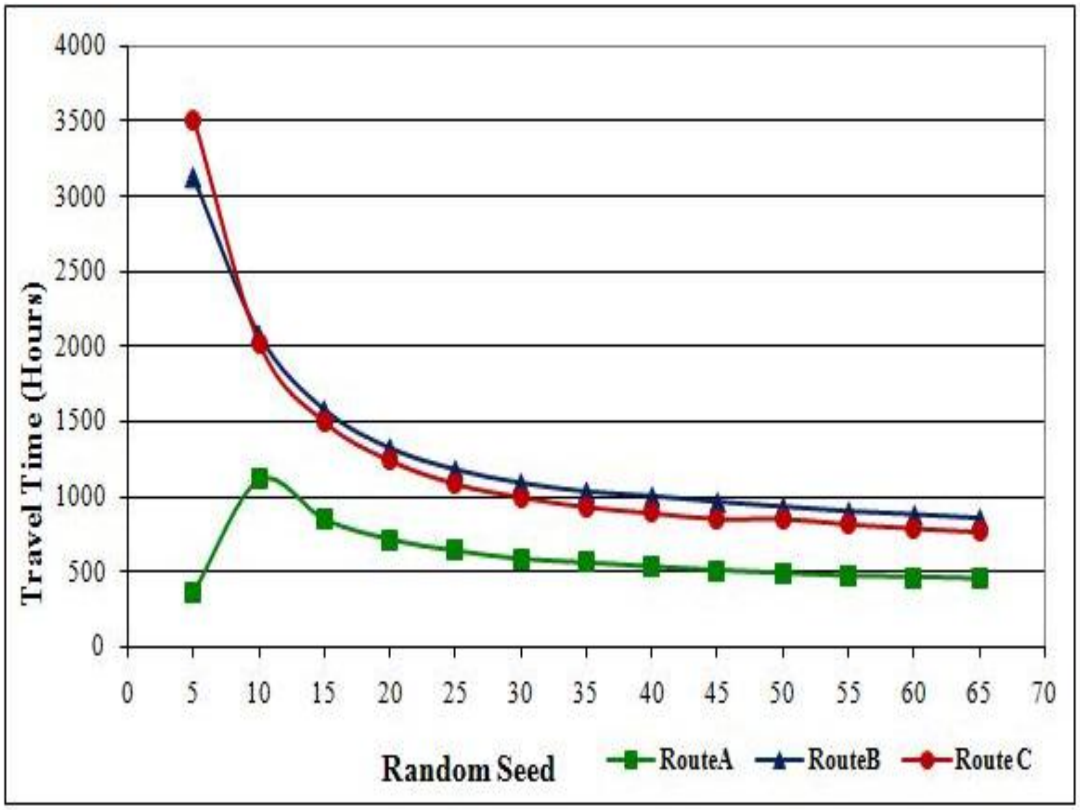
traffic flow converged, and stabilized with substantial reduction in travel times on all three routes.

Figure 2.7 is used to check existence of user optimization. Percentage in scenario 2, where DTA was used with vehicle-actuated controls, suggests that network travel time information to drivers from their past travel experience can play an important role in reducing the traffic congestion. Figure 2.7 part c) and part d) show that when drivers had no network travel time information to make route choice, the traffic flow stabilized at higher congestion levels but did not converge in Scenario 3 and Scenario 4, and the reduction in travel times was minimal.



(a)

Figure 2.7 Travel Time Comparisons on Route Choices from Zone 2 to Zone 12 a) Scenario 1, b) Scenario 2 c) Scenario 3 d) Scenario 4
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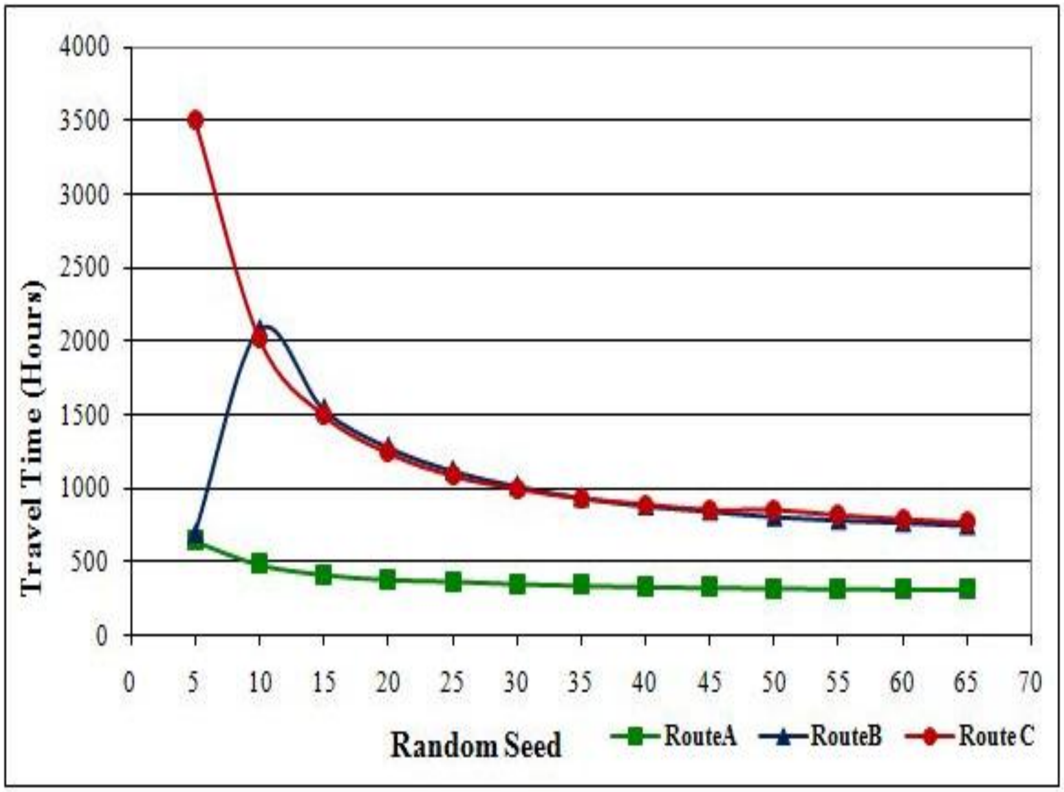
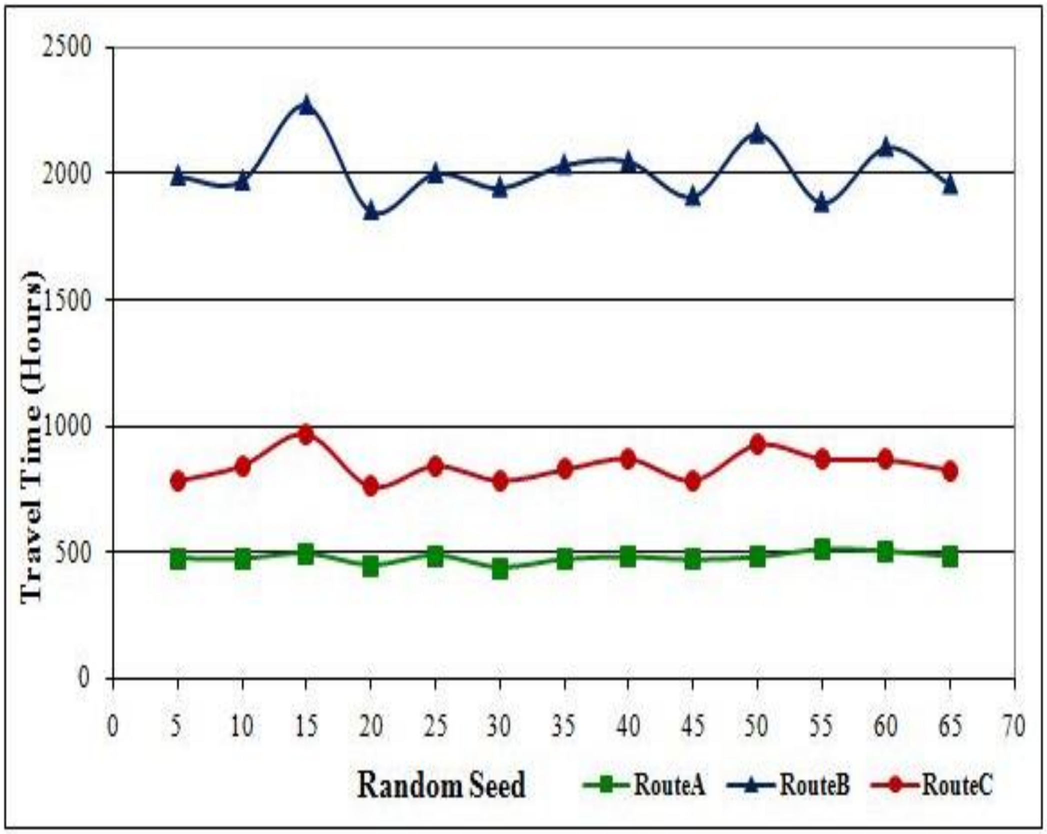


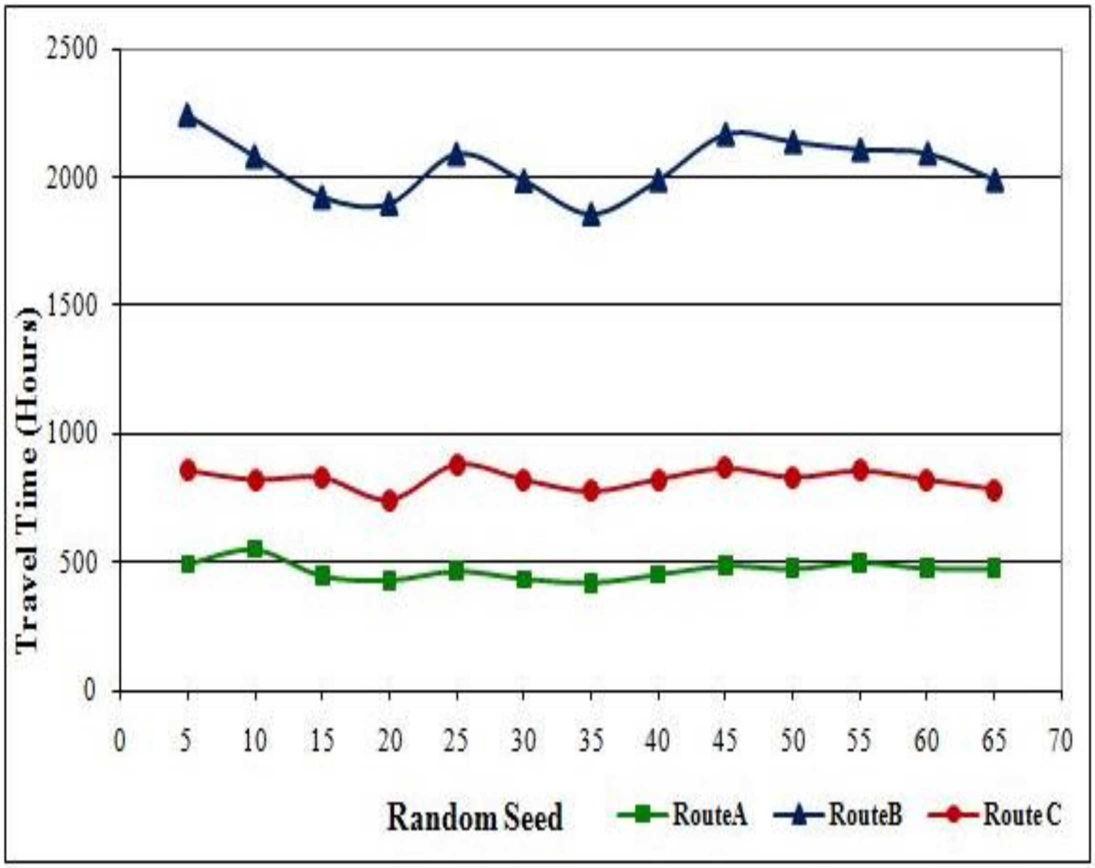
(b)

Figure 2.7 Continued



(c)

Figure 2.7 Continued



(d)

Figure 2.7 Continued

The results seem to align with the idea that integration of Advance Traveler Information Systems (ATIS) with traffic systems increases the efficiency of traffic system. DTA simulation process took a total of 20 hours for 27 iterations in the case of network 2. For larger networks, it may take more time for convergence on the same computer. However, should the development trends in computer technology continue, this may prove a smaller obstacle to researchers (31, 32). In addition to system-wide improvements, integration of ATIS can bring stable traffic flows with lower congestions on user level as well.

2.9 Limitations and Future Research

The test networks cover a relatively smaller portion of the Salt Lake City area. Larger study areas could be tested on the same test setup. Only fixed controls and vehicle-actuated controls were used. More tests can be done with optimized controls and adaptive traffic controls. Similar tests can be done using other software capable of simulating the DTA. A computer with an Intel ® Core ™ 2 QUAD CPU with a 2.66 GHz processor and 3.24 GB of RAM was used to perform simulations. Achieving model convergence through DTA simulation process took a total of 20 hours for 27 iterations in the case of network 2. For larger networks, it may take more time for convergence on the same computer. However, should the development trends in computer technology continue, this may prove a smaller obstacle to researchers.

2.10 Conclusion

Previous research conducted on CTAC models addresses issues related to solution algorithms, theoretical model formulations, and implementation. This chapter presents a practical perspective on the benefits of the CTAC on traffic flow by studying the impacts of providing network travel time information to drivers from their past travel experience with the possibility of improvements to traffic controls. Two portions from the Salt Lake City street network were used to test four scenarios using VISSIM simulations. The test results suggest that providing drivers with network travel time information to make route choice alone can substantially reduce the total delays in a traffic system with fixed time traffic controls. While the traffic assignment and traffic control improvements are typically taken as two separate processes in practice, the CTAC framework used in these tests was able to combine the two processes in a single combined modeling framework for the study areas tested. With growing use of adaptive and vehicle-actuated traffic signal controls to mitigate traffic congestion, the need for modeling methods that incorporate control-driver interaction is growing. CTAC models, therefore, can play an important role in congestion mitigation projects in practice.

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CHAPTER 3

EVALUATION OF THE BENEFITS OF ROUTE GUIDANCE SYSTEM USING COMBINED TRAFFIC ASSIGNMENT AND CONTROL FRAMEWORK

3.1 Abstract

The traffic congestion in large urbanized areas around the globe is a major issue faced by the transportation planning professionals. The traffic engineers and planners are exploring new ideas to tackle the issue. From the perspective of congestion mitigation, the transportation research is focused on development of solutions that increase the efficiency of existing infrastructure. In this context, the development and implementation of Route Guidance Systems (RGS) has been the topic of extensive research for the last two decades. Many solution algorithms and implementation efforts have been well documented. Past research on RGS suggests that the information to drivers on prevalent traffic conditions can impact their route choice, and it may benefit the traffic system in reducing traffic congestion.

This chapter evaluates the benefits of RGS in a traffic system using Combined Traffic Assignment and Control Framework (CTAC). Eleven scenarios were tested with different proportions of RGS-equipped demand under Dynamic Traffic Assignment (DTA) and vehicle-actuated traffic controls. The test results suggest that system-wide travel time improvements and delay reductions can be achieved through RGS. The travel

time improvement and delay reduction benefits were the minimum in the scenario with only 10% RGS-equipped demand, and the benefits were the maximum in the scenario with 100% RGS-equipped demand. Further studies are needed on drivers' response behavior to information through RGS, and to test the benefits of RGS in larger study area networks.

3.2 Introduction

Congestion management is one of the most pressing issues for research in transportation planning. Large metropolitan areas around the globe are facing congestion mitigation challenges, especially when infrastructure expansion is out of the question in those areas. Consequently, the transportation research is focusing on developing transportation systems that could efficiently use existing infrastructure. The recent advancements in computer technology have impacted the field of transportation in many folds. Especially, gadgets like in-vehicle navigation systems and global positioning systems-based Route Guidance Systems (RGS) are available for use by drivers and may help the drivers to find a cost efficient alternative route if available. RGS, if available to drivers, has the potential to inform the drivers of any changes in traffic conditions, and may impact their route choice behavior (1).

There are many algorithms that have been investigated for the development and implementation of RGS. Some of the initial algorithms on RGS originated from simple static algorithms that could calculate the path for the shortest distance (1). The static algorithms later evolved to robust algorithms that take travel times into account based on past travel experience of the drivers or historical data (2). Some of the latest RGS algorithms are capable of establishing real-time communication between the vehicle and the traffic operation centers for frequent updates on travel times, traffic congestion, and bottle neck conditions (3). In a typical traffic system, the drivers with little or no information regarding their travel route-choices and prevailing traffic conditions may make costly route choices with respect to traffic congestion and travel time. Traffic network information, if available to drivers before or during the trip, has the potential to eliminate poor route choices, and consequently improve the traffic system.

The solution algorithms and model formulations of the RGS have been the topic of academic research for the last two decades, yet very little has been done on quantifying the benefits of RGS in terms of system-wide travel time improvements and system-wide delay reductions. Lack of advanced computer technology until the late 1990s was a hindrance in modeling and simulating RGS-equipped demands on complex networks. With the availability of advanced computers and robust microsimulation software like VISSIM (4), DYNASMART (5), and CUBE-DYNASIM (6), it is now possible to test and implement RGS on complex traffic network simulations.

This chapter is an extension of Chapter 2 because this chapter presents research on the quantification of the benefits of additional traffic modeling features such as RGS when implemented on CTAC models, which according to the research presented in Chapter 1, could reduce the traffic delay and improve travel time in a traffic system.

The objective of this chapter is to quantify the benefits of RGS in terms of total travel time improvement and total delay reduction by providing the drivers with information on prevailing network traffic conditions while they are en-route, in addition to the information on network travel time based on previous day’s travel experience. A CTAC framework (7) built in VISSIM software was used with DTA and Vehicle

Actuated Controls. A section of a Salt Lake City, Utah street network was used in the tests. In addition to DTA, a RGS module of VISSIM was used. An overview of all the tools used in the microsimulation is presented at a later section in this chapter.

3.3 Literature Review

Some of the earliest efforts on evaluating the impacts of RGS on drivers' route choice behavior started in the mid-1980s. Streeter et al. (8) conducted experiments to test impacts of network information on driver's behavior. Jeffery (9), and Stergiou and Stathopoulos (10) investigated RGS in terms of road telematics. Dingus et al. (11) and Davis and Schmandt (12) in separate efforts investigated the impacts of network information on driver's route choice on theoretical scale. Most of the initial efforts to investigate the impacts of information on driver's route choice used the very basic concept of an in-vehicle navigation system in their investigations. Walker et al. (13) used the Federal Highway Administration's (FHWA) highway simulator (HYSIM) to investigate the driving performance associated with RGS. Green (14) also investigated the human factors on in-vehicle navigation system.

In the early 1990s, the theoretical and conceptual studies on RGS transitioned to computer simulation-based investigations. Arnott and Lindsey (15) investigated the impact of network travel time information to drivers on reduction of traffic congestion. The purpose of the study was to question the presumption that RGS and information systems necessarily reduce traffic congestion. The study suggested that the information on network can impact the drivers' route choice depending on how credible the information is to the drivers. Mahmassani and Chen (16) presented a comparative assessment of origin-based and en route real-time information under alternative-user behavior rules. The study suggested that real-time information to drivers could lead to system-wide benefits. Bonsall (17) investigated the influence of route guidance advice on drivers’ route choice in urban networks. Lam and Tong (18) investigated a dynamic route guidance system based on historical and current traffic patterns. Mahmassani and Peeta (19) investigated the implications by traveler information systems with network performance under system optimal and user equilibrium dynamic assignment. Walting and Van Vuren (20) investigated the modeling of dynamic route guidance systems. Yang et al. (21) investigated the application of fault tree analysis to route guidance systems. Emmerink et al. (22) investigated the potential of advanced traveler information systems (ATIS) in a road network in which incidents are generated in random fashion. Shimizu et al. (23) investigated a simplistic route guidance system based on an evaluation algorithm of mean travel time.

Wahle et al. (24) investigated a dynamic route guidance system based on real traffic data. The study proposed a two-step procedure. First, online simulations were performed with real-time traffic data. Afterwards, the data were processed in a route guidance system allowing optimization of drivers’ route choices. Khaled et al. (25) investigated the behavioral component of route guidance systems using neural networks. Park and Yoo (26) developed a location-based dynamic route guidance system of a Korea highway cooperation. Zhang and Xu (27) investigated dynamic route guidance using neuro-dynamic programming. Zou et al. (28) investigated an application of a genetic algorithm in dynamic route guidance systems. Park and Lee (29) investigated assessing sustainability impacts of route guidance systems under a cooperative vehicle infrastructure environment.

To summarize, the past research on RGS suggests that the network information provided to drivers may change their route choice behavior. While several investigations on development and implementation of RGS have been well documented, more studies are needed to quantify the benefits of RGS for system-wide travel time improvements and delay reductions.

3.4 Research Methodology

3.4.1 Description of Test Scenarios

Eleven scenarios were tested though simulations by VISSIM. DTA coupled with VISSIM-based RGS, and vehicle-actuated controls were used in simulations. The built in "base data traffic characteristics" menu in VISSIM allows the user to define vehicle types in the traffic demand by different vehicle characteristics like RGS, speed, or any other user-specified characteristics. For this chapter, the traffic demand was divided into "RGS-equipped" and "NO-RGS-equipped" types. The "traffic composition" tool in VISSIM allows the user to set proportion/share of RGS-equipped and nonequipped traffic demand. Using the traffic composition tool, the proportion of RGS-equipped peak period demand was changed in each scenario.

Starting from 0% RGS-equipped demand in Scenario 1, the percentage of RGS equipped demand was increased by 10% in each scenario until 100% RGS-equipped demand in Scenario 11. Consequently, each 10% increment in RGS-equipped demand was compensated by 10% reduction in Non-RGS-equipped demand in the scenarios to keep the sum of total demand in OD matrix to 100%. Table 3.1 describes the test

Table 3.1 Route Guidance System-Based Test Scenarios

Scenario	Scenario Traffic Demand Description	
No.	No RGS Equipped (%)	RGS Equipped (%)
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50
7	40	60
8	30	70
9	20	80
10	10	90
11	0	100

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scenarios. This research assumes that the selected proportion of RGS-equipped demand is fully cooperating.

The RGS algorithm in VISSIM software assumes that about 25% of the equipped demand will not comply to RGS information on prevailing network travel time information. The complying-behavior component of the drivers in equipped demand is another extension of this research work which is open for future research.

3.5 Overview of Traffic Analysis Tools

3.5.1 Modeling and Simulation Software

The PTV Vision software VISSIM was used to test the scenarios. OD matrix was calibrated using the OD Matrix calibration module of VISUM software, PTV Vision travel demand modeling software. The OD matrix correction module of VISUM has been proven reliable by a previous study (31). VISSIM 5.00-08 was used to mimic a realistic traffic system in the simulation. VISSIM has been proven as a reliable microsimulation tool (32).

3.5.2 Combined Traffic Assignment and Control Framework

The traffic engineering practice tends to keep traffic assignment and traffic control optimization strategies as two separate processes. The travel demand models do not include traffic controls in the assignment process due to their macroscopic nature. Similarly, the traffic flows are considered fixed input to the control optimization process and the impacts of postoptimization traffic flows are not considered. By keeping the two processes separate, the practice tends to ignore the interaction between the drivers' route choice and traffic controls.

CTAC framework-based models can capture the interaction between driver's route choice and traffic controls in a single modeling framework (7). Several solution algorithms, model formulations, and implementation efforts of CTAC-based models have been well documented (33) and past research emphasizes the use of CTAC models in practice. For this chapter, the CTAC framework in combination with DTA, vehicle-actuated controls, and RGS was used.

3.5.3 Dynamic Assignment

In VISSIM software, DTA is an iterative simulation process. The route choice made by the drivers in each run is based on their travel experience in the previous run. The best paths in each run of the DTA-based simulation is computed based on travel cost. The travel cost can be in terms of travel time, trip length, toll, or any other user-specified cost. Any change in traffic conditions during the simulation may impact the travel cost.

Thus, more choices of routes with better cost are available in the next run. For convergence, VISSIM requires that all paths must have a relative change lower than the defined threshold. Acceptable convergence criteria define indicators such as verifying that 95% of all paths are within 10 to 15% of travel time difference compared to the previous run. Other standard practices look at mean errors of the nonconverging paths.

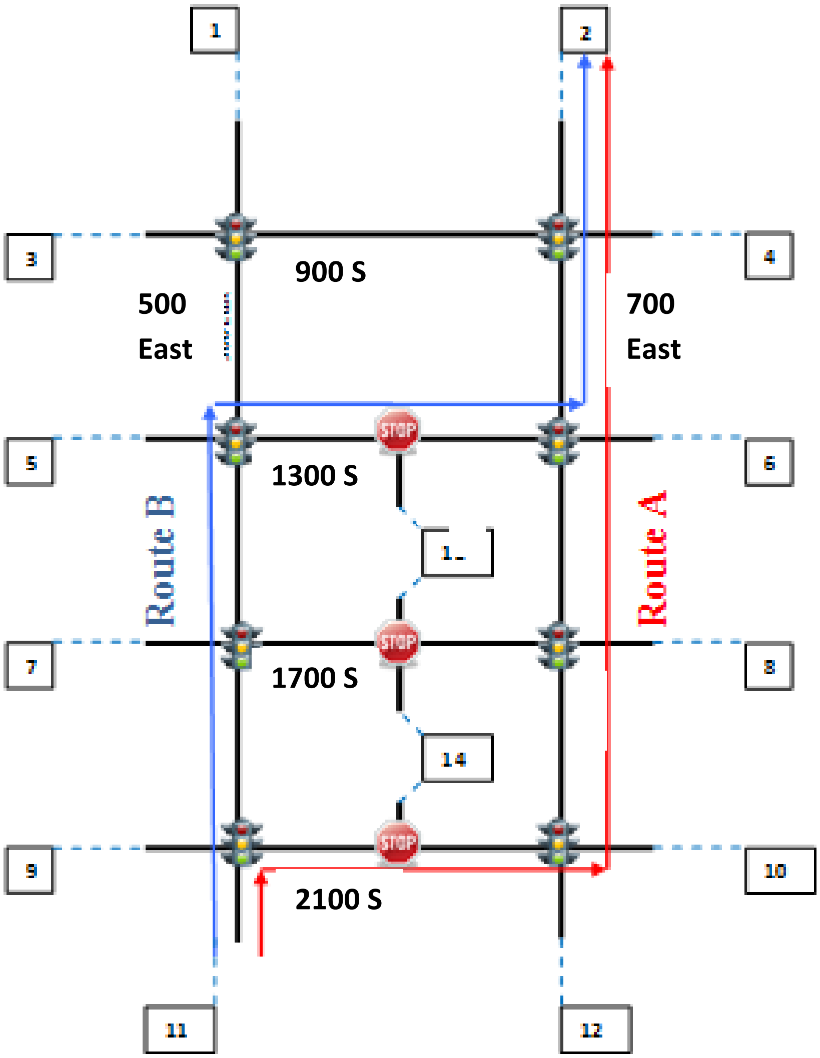
For this chapter, the travel time on paths was used as cost in DTA. A convergence criterion of 5 % travel time difference on paths was used. In the current state of implementation, for each run of DTA simulation, VISSIM compares the travel time on paths to the previous run. If the travel time difference on all paths is less than or equal to 5%, the convergence criteria is met. Otherwise, the simulation continues until it reaches the maximum number of runs specified by the user or the convergence criteria, whichever comes first. Travel time evaluation files containing travel time for each OD pair were written for every run of DTA simulation using the “Evaluation Files” feature of VISSIM.

3.5.4 Route Guidance System

In VISSIM-based DTA simulation, the drivers choose their routes from origin to destination based on general cost information collected in the preceding iterations of the simulations. In addition to DTA, VISSIM software, through the RGS module, offers an option of rerouting vehicles while en route based on prevailing traffic conditions in each simulated-iteration. The rerouting caused by the VISSIM-based RGS module is not restricted to fixed positions on the road network. Instead, the equipped vehicles are rerouted in the fixed time interval, a user-defined attribute. At the current state of the implementation in VISSIM 5.00-08, the action triggered by the system is always to search the “best” (best cost) route from the current vehicle position to the destination parking lot.

The criteria for the rerouting search are the general cost with travel times measured in the current simulation. The travel times taken into account for the re-routing are not necessarily the most recent travel times but travel times measured some time ago based on a user-defined offset. The offset is introduced to model the processing time of typical route guidance systems, i.e., the time from measurement on the road until the data are available to the route guidance equipment in the vehicles. Whether a vehicle type is equipped with RGS can be selected while defining the vehicle type characteristics. The traffic composition, with proportions on equipped and nonequipped vehicles in the traffic demand, can be defined using the traffic composition tool of VISSIM. For this paper, RGS was tested with 10% increments of equipped traffic demand starting from 0% equipped to 100% equipped over the course of eleven test scenarios. The offset was set to 30 minutes as per guidelines of the VISSIM Manual for a 3 hour peak period. In the base scenario, 0% of the demand was equipped with RGS.

Figure 3.1 part a) outlines an example of route choice under the DTA-based simulation with No-RGS-equipped demand as compared to part b) that shows an example of DTA-based simulations with RGS-equipped demand traveling from origin zone 11 to destination zone 2. Figure 3.1 part a) shows that in a DTA-based simulation without RGS-equipped demand, the drivers in simulation may choose Route A on day 1 based on shortest travel costs, and on the second day of travel the drivers may choose Route B based on the previous day’s travel costs experience. The offset and interval in the RGS module of VISSIM are explained in the next section.



(a)

Figure 3.1 Route Guidance System-Based Route Choice Example a) DTA Based Route Choice with NO-RGS Equipped Demand b) DTA Based Route Choice with RGS Equipped Demand

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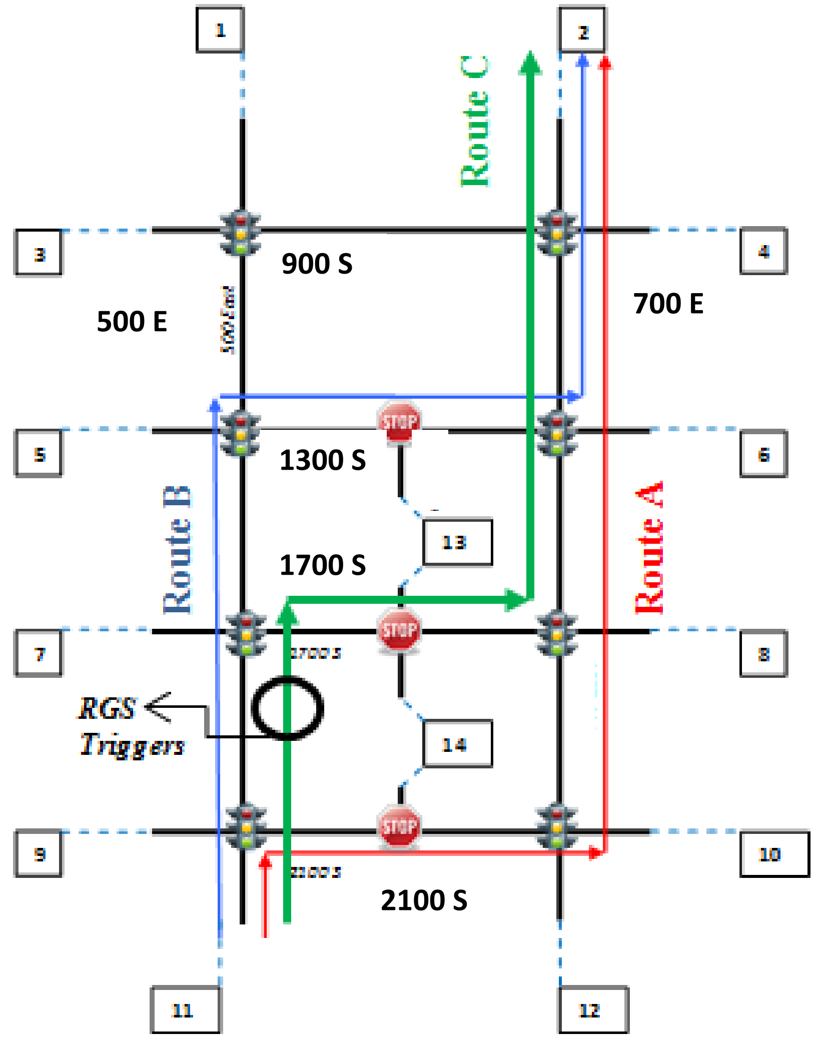

(b)

Figure 3.1 Continued

Figure 3.1 part b) shows that in a DTA-based simulation with RGS-equipped demand, the drivers on second day may choose route B based on the previous day’s cost experience, yet a portion of traffic demand equipped with RGS may opt to choose Route C based on prevalent network information available to them. This example reflects one of the possible route choice behaviors under RGS for one OD pair in a traffic system. This paper will evaluate the system-wide benefits of RGS in a traffic network shown in Figure 3.1.

The VISSIM-based route guidance system is triggered on user-defined intervals. The VISSIM manual suggests that the RGS interval duration depends on several factors, including type of network information, communication technology, and time period of simulation. For a typical 3 hour p.m. peak period time period, the VISSIM manual and the previous research suggests a 1 hour time interval and 30 minutes offset (29). For this paper, the RGS was evaluated for a time interval of 1 hour with 30 minutes offset.

Figure 3.2 outlines the example of 3 hours p.m. peak period RGS progression in a simulation with a 1 hour RGS interval. Due to the 1 hour RGS interval, the RGS system triggers after every hour during the 3 hour p.m. peak simulation, and the drivers had an opportunity to get information on prevalent network travel times after every hour. Due to the offset of 30 minutes, the information on prevalent travel times was collected, processed, and was available to the drivers in the same time frame at the trigger of each RGS interval.

3.5.5 Signal Control Emulator

A National Electrical Manufacturers Association (NEMA) Standard Signal Control Emulator was used for traffic controls in test scenarios. This controller is

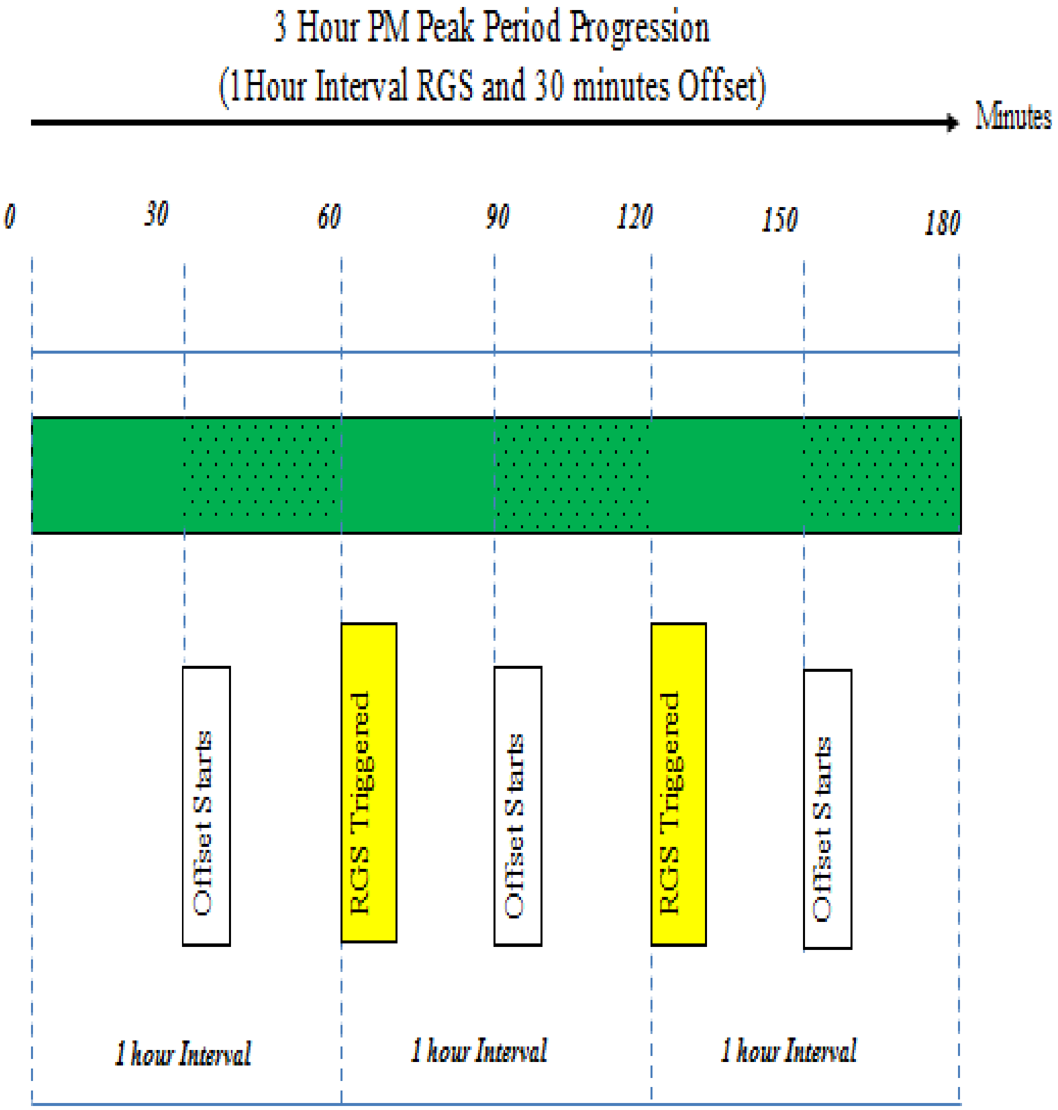

Figure 3.2 Peak-Period-Progression with Route Guidance System Interval and Offset

available in the North American releases of VISSIM and emulates common signal controllers used in North America. With this controller, VISSIM can simulate fully actuated signal control as well as coordinated and vehicle-actuated coordinated signal control.

The interface to the controller is accessed through VISSIM but saves its settings to an external data file with the extension (NSE). To use the NEMA standard emulator in VISSIM, traffic control programs for each intersection in the study area network were exported to NEMA format using VISUM software.

3.5.6 Traffic Controls

Vehicle-actuated controls were used in all the test scenarios. Vehicle-actuated controls differ from fixed-time control because they can respond to variations in traffic flow and are typically used is in situations with irregular traffic flow. The actuated controls can be grouped into two types: semi-actuated and fully actuated. Semi-actuated controls primarily apportion the green time to the major movement of the traffic and minor streets are served at vehicle detection. Fully actuated control systems detect vehicles on all approaches of the intersection and make adjustments according to the flow. The vehicle-actuated controls were used with the limitations that offsets and cycle lengths would not change, and only green splits within the given cycle length framework could be adjusted. The changes in green split could respond to the variation in traffic flow due to different route choices of drivers in DTA simulation. For this chapter, the traffic control program data for each intersection were collected from the Traffic Operation Center (TOC) of Utah Department of Transportation (UDOT) for the 3 hour P.m. peak period starting at 4 p.m. to 7 p.m.

3.5.7 Study Area

A portion of the Salt Lake City urban area was selected for testing. The area consists of sections of collector 500 East and principal arterial 700 East from 900 South to 2100 South with cross roads 1300 South and 1700 South in between.

The network consists of 25 nodes including 8 signalized intersections and 3 intersections with 2-way stop signs, and 14 zonal nodes. Turning movements and traffic control data were collected from UDOT. The turning movements' data were then assembled for 3 hour p.m. peak period starting at 4 p.m. to 7p.m. Figure 3.3 displays the study area network.

3.6 Model Calibration

This chapter is an extension of a previous study conducted by Farhan et al. (30) which investigated the benefits of CTAC with the possibility of improvements to traffic controls. The previous study implemented, calibrated, and validated a base-run on a CTAC-based scenario with STA and vehicle-actuated controls on two selected sections of Salt Lake City networks. This paper takes advantage of the already calibrated base-run on network 1 from the study to further investigate the benefits of RGS.

3.6.1 Origin-Destination Matrix Correction

The OD matrix for the study area was extracted from the regional travel demand model of Wasatch Front Regional Council (WFRC). Version 6.0 of the WFRC model was the source of the study area OD matrix. The WFRC regional travel demand model is a macroscopic model developed, calibrated, and validated for the regional transportation projects. Since the regional model is macroscopic in nature, the OD matrix extracted from the model may not be representative when used for travel demand in simulations for

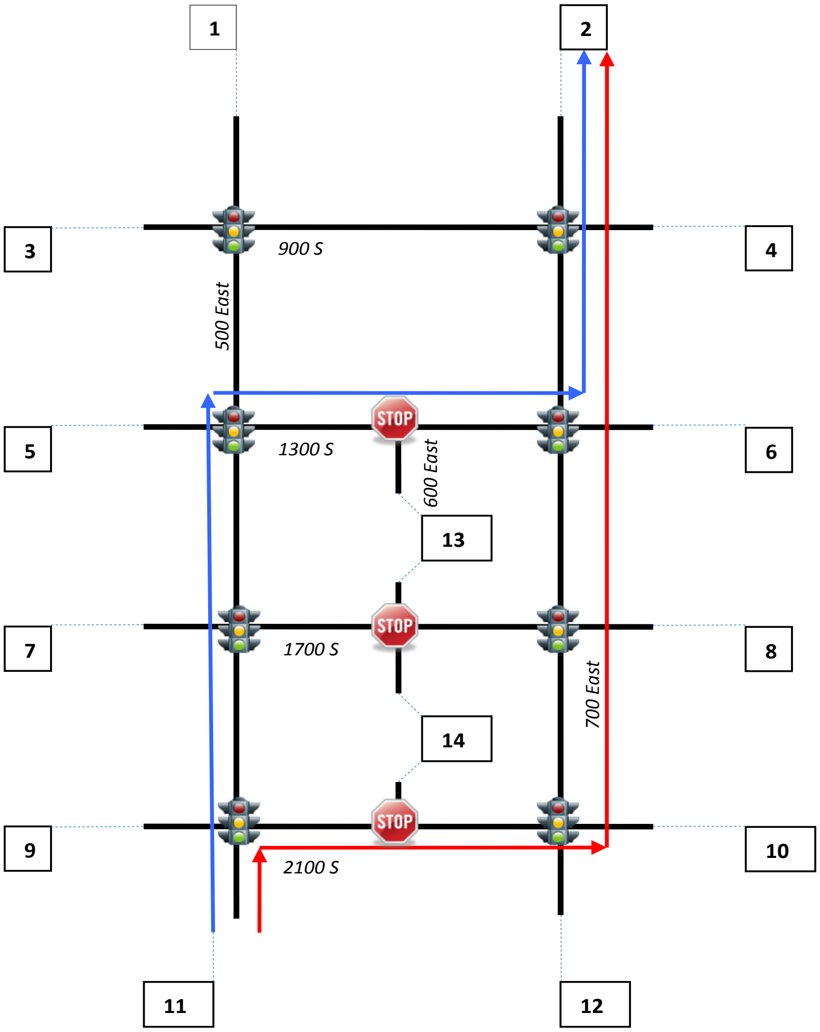

Figure 3.3 Study Area Network from Salt Lake City
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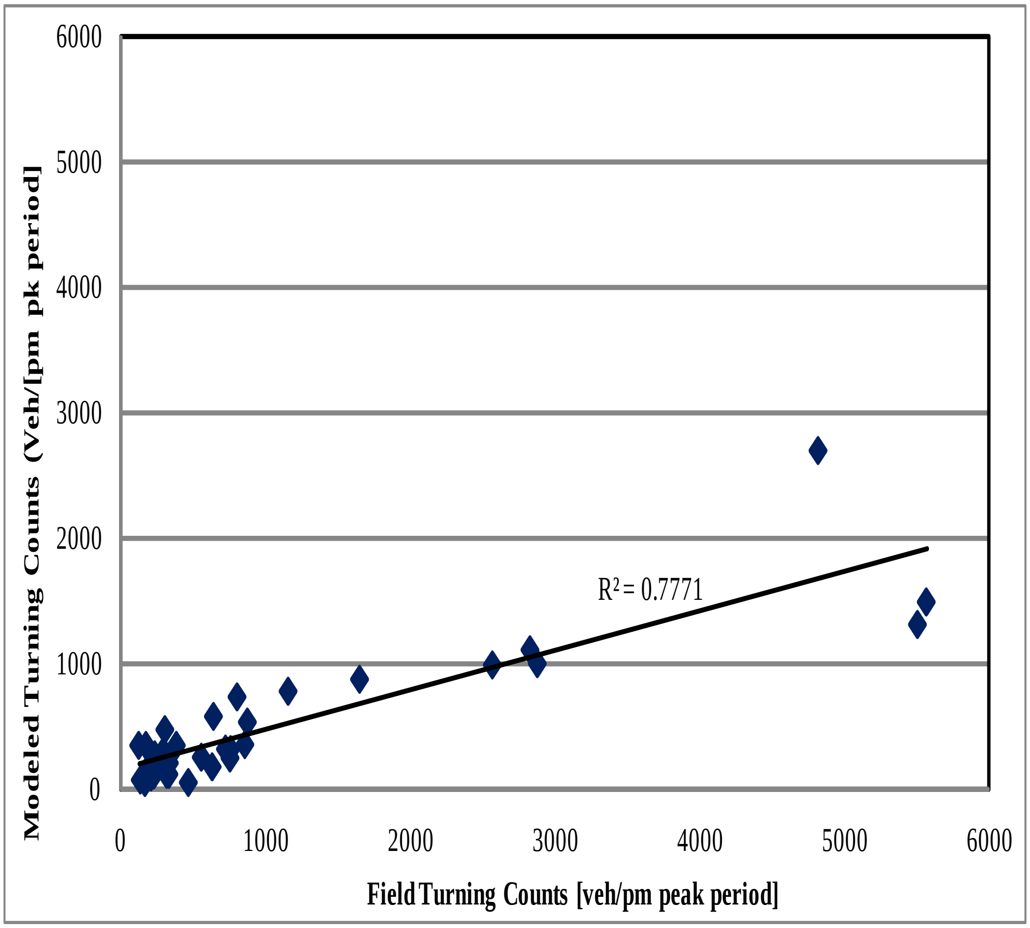
the study area. The comparison of modeled volume to the field counts was therefore necessary.

VISUM has several built-in traffic assignment algorithms to assign travel demand specified in an OD matrix (34). A multi-equilibrium assignment routine was used to assign demand in the extracted OD matrix. Volume-delay functions were specified as Bureau of Public Roads (BPR) curves. The assignment process did not give a close match to the field counts. The extracted OD matrix for the study area was therefore calibrated using the TFlowFuzzy matrix correction module of VISUM.

Matrix correction methods are used to adjust a given OD matrix in such a way that the result of the assignment closely matches the matrix correction criteria. The criteria for correction may include link volumes or OD travel demand in the form of traffic counts. The matrix correction module in VISUM software is based on a well-known entropy maximization algorithm (35). The user can specify several criteria that may weigh in the matrix correction process. Each run of the matrix correction process outputs a synthetic matrix, and the traffic assignment based on the synthetic matrix reduces the difference between the traffic counts and the modeled data.

For this paper, the matrix was calibrated for the turning movement counts. The counts included left-turns, right-turns, and through movements at the intersections in the study area. The process with 43 iterations gave an OD matrix with 100% match to the counts. The matrix calibration process for larger matrices, however, may not achieve the ideal (perfect match) results. Figure 3.4 parts a) and b) display the scattered plot for modeled versus count data for initial and calibrated OD matrices.



(a)

Figure 3.4 Calibration of Origin Destination Matrix: a) Modeled vs. Field counts from initial OD Matrix b) Modeled vs. Field counts from calibrated OD Matrix
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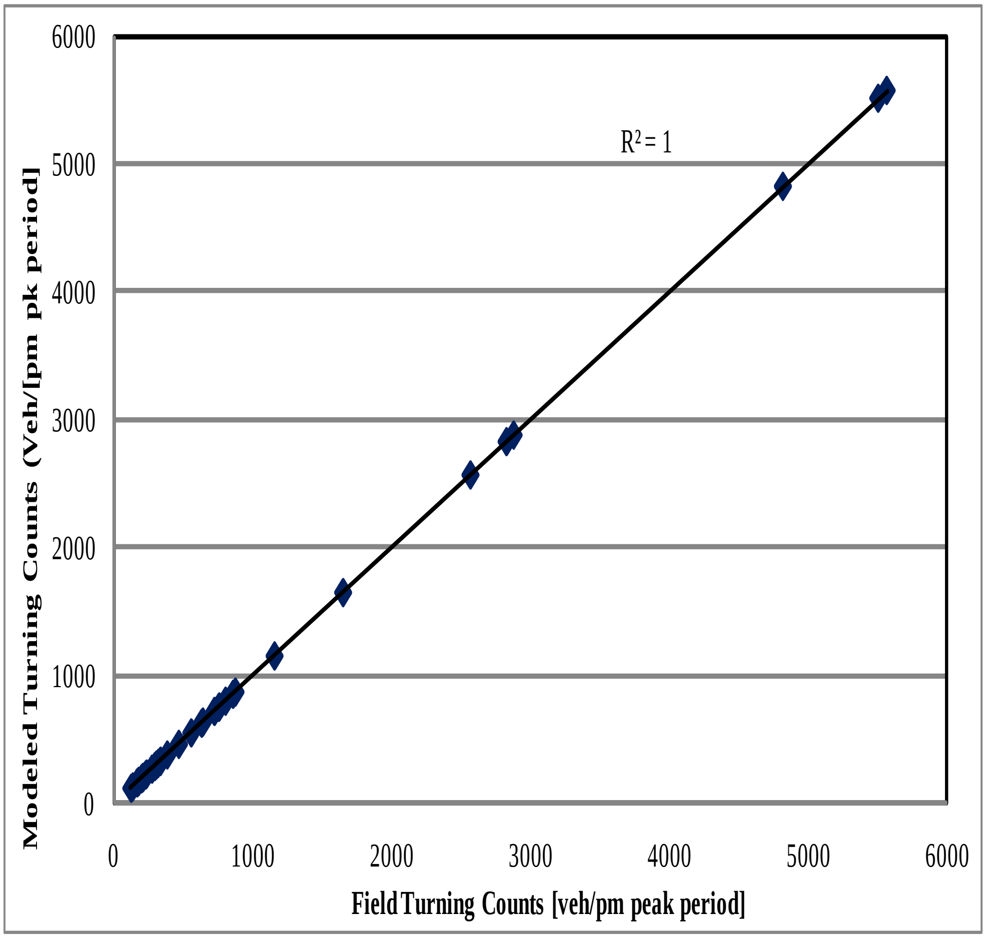

(b)

Figure 3.4 Continued

3.6.2 Model Calibration for Microsimulation

Microscopic simulation models have been widely used in both transportation operations and management analyses because simulation is safer, less expensive, and faster than field implementation and testing. While these simulation models can be advantageous to engineers, the models must be calibrated and validated before they can be used to provide meaningful results. Microscopic simulation models contain numerous independent parameters to describe traffic control operation, traffic flow characteristics, and drivers' behavior. These models contain default values for each variable, but they also allow users to input a range of values for the parameters. Changes to these parameters during calibration should be based on field-measured conditions and should be justified and defensible by the user. The chapter is an extension of a previous investigation by Farhan et al. (30). The study calibrated and validated base-runs on two portions of Salt Lake City networks using CTAC framework with Static Assignment and Vehicle Actuated controls. The calibration and validation process was performed to closely match a) travel times data, b) speed data, and c) validation to match traffic counts. The field data on counts, travel times, and speeds were collected from the UDOT and WFRC. The same base-run of network 1 from the previous study was used to further investigate the benefits of the RGS in CTAC-based microsimulation.

3.7 Results and Discussion

3.7.1 Evaluation of Results

Table 3.2 outlines the average total travel time and average total delay for all the simulation runs. Table 3.2 also describes the travel time improvements and delay reductions with respect to Scenario 1 (Scenario with No-RGS-equipped Demand), and

Table 3.2 Total Delays and Total Travel Time Comparison

Scenario	RGS Equipped Demand (%)	Average Total Travel Time (Hours)	Average Total Delay (Hours)	Average Total Travel Time Improvement (%)	Average Total Delay Reduction (%)	Std. Deviation Travel Time	Std. Deviation Delay
1	0	2125	895	n/a	n/a	372	797
2	10	2098	865	1.3	3.4	343	764
3	20	2068	843	2.7	5.8	327	753
4	30	2045	842	3.8	5.9	311	748
5	40	2027	835	4.6	6.7	302	729
6	50	1996	830	6.1	7.3	298	721
7	60	1976	829	7	7.4	281	715
8	70	1968	819	7.4	8.5	280	703
9	80	1913	803	10	10.2	262	691
10	90	1876	785	11.7	12.3	243	679
11	100	1828	754	14	15.8	238	665

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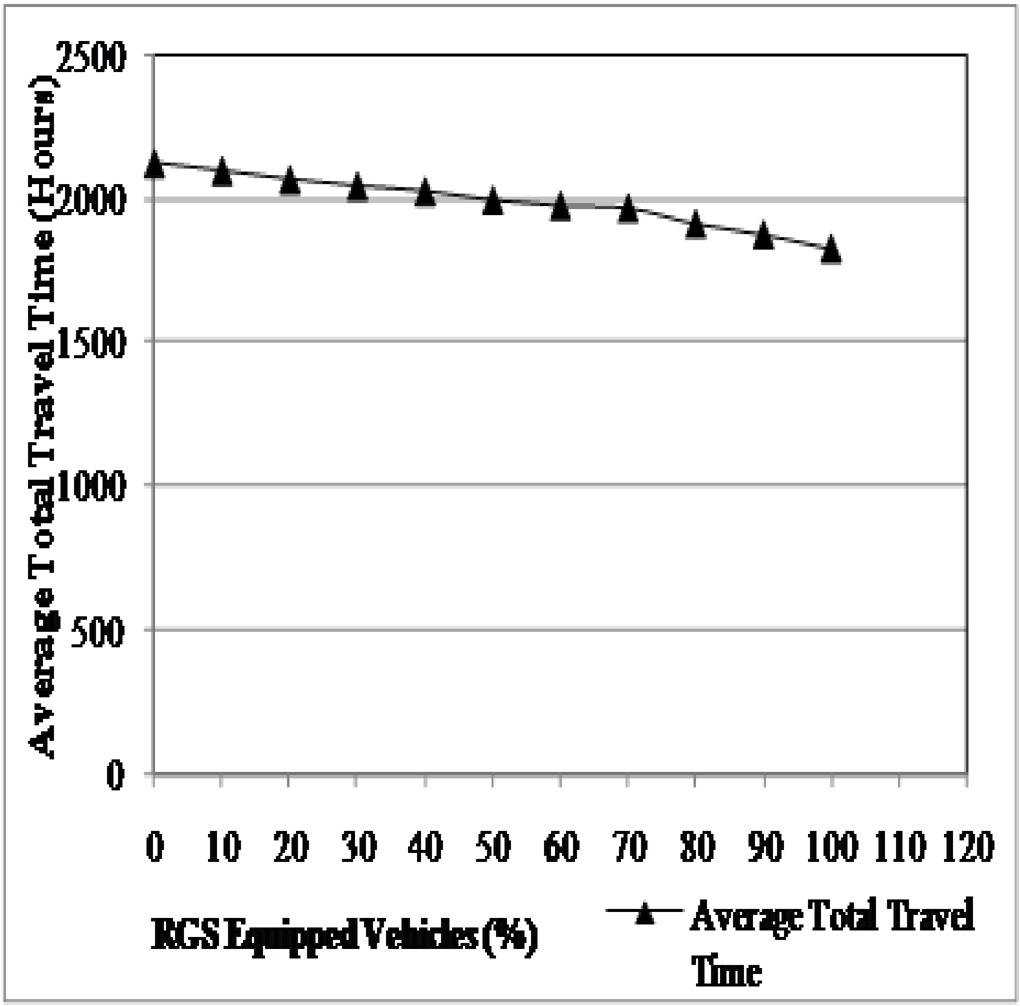
across other scenarios with increasing proportions of RGS. Scenario 1 did reach convergence after 16 iterations although it had the highest average travel time and highest mean total delay. On the other hand, the scenarios with RGS-equipped demand (Scenario 2 to Scenario 11) show improvements in average total travel time and average total delay but never converged, even after 100 iterations. Figure 3.5 part a) and part b) show the improvement in average total travel time and reduction in average total delay over the course of test scenarios starting from Scenario 1 with 0% RGS-equipped demand to Scenario 11 with 100% RGS-equipped demand. In scenarios with RGS-equipped traffic demand, on each day of travel, the drivers may choose to change their route choices while en route due to RGS information.



(a)

Figure 3.5 Total Travel Time Improvements and Total Delay Reductions a) Total Travel Time Improvements, b) Total Delay Reductions

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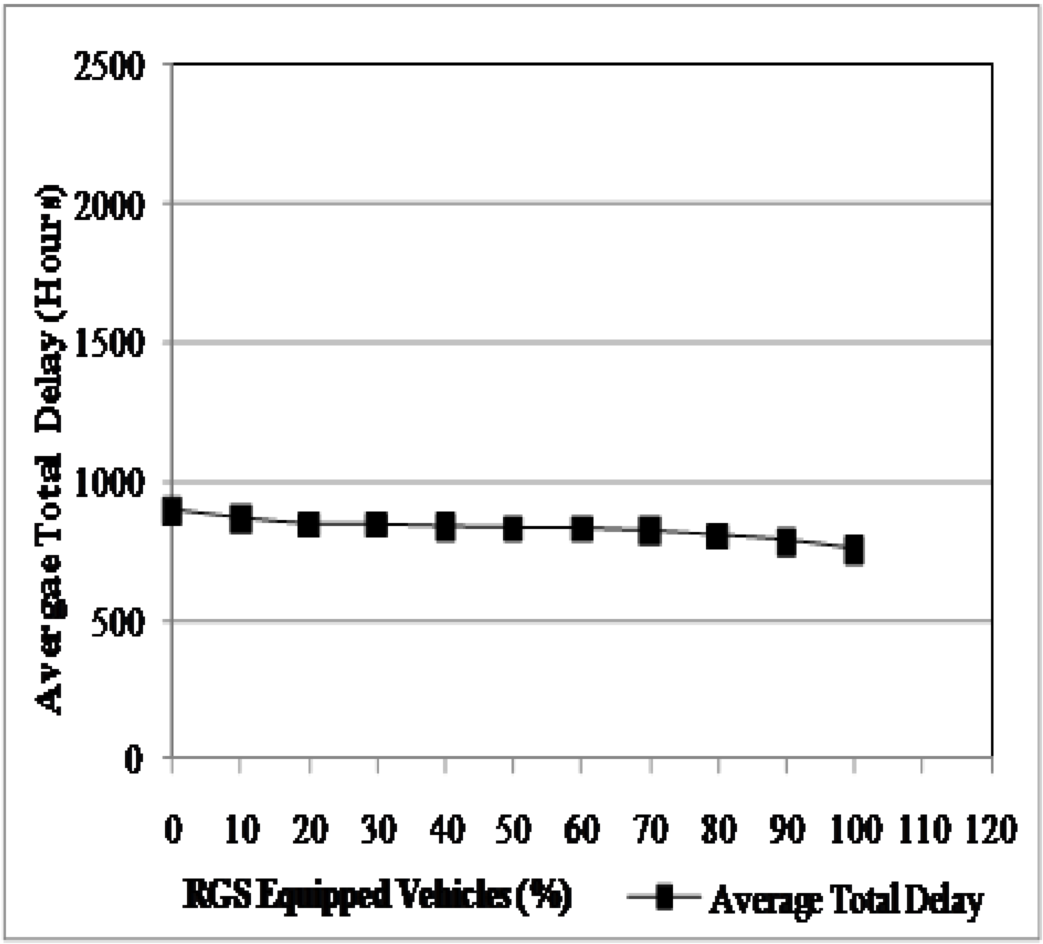


b)

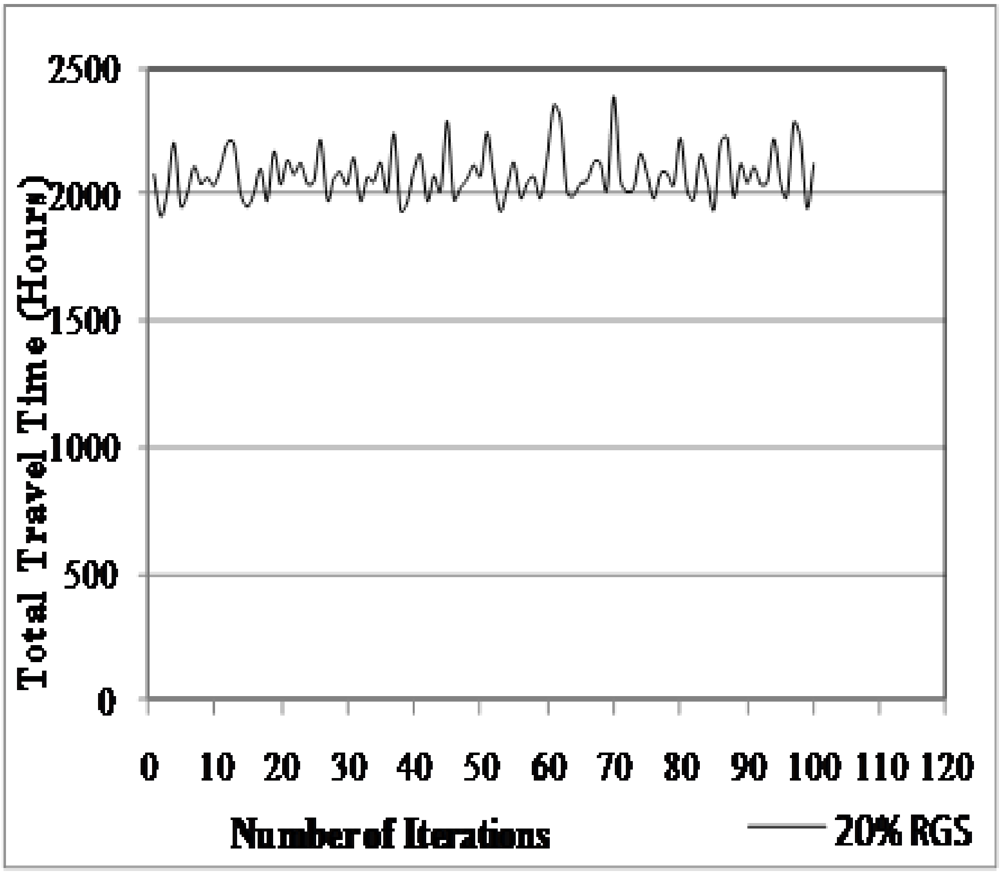
Figure 3.5 Continued

Figure 3.6 part a) – part d) show the total travel time for each run of the Scenario 3 (20 % RGS-equipped demand), Scenario 6 (50% RGS-equipped demand), Scenario 9 (80% RGS-equipped demand), and Scenario 11 (100% RGS-equipped demand), respectively. The scenarios were selected to evaluate the total travel time improvements with the increase in RGS-equipped demand.

While Figure 3.5 part a) shows improvement in average total travel time with increase in RGS-equipped demand, Figure 3.6 part a)-part d) suggest that with the increase in RGS-equipped demand, the traffic system stabilizes at lower congestion levels yet it may not converge in comparison to their "actual" route choice based on past travel experience. Thus with RGS-equipped demand, on each day (in each run), the drivers may find a new set of "best cost" route choices based on the information on prevalent traffic conditions through RGS.

While these best cost choices may help reduce the system-wide travel time in a congested traffic network, they may not be the most efficient route choices compared to previous day travel experience of the drivers. Figure 3.6 part a) - part d) explains this phenomenon where with the increase in RGS demand, the total travel time improved yet the total travel time in each run was not necessarily lower than the previous run. Further, Table 3.2 also shows that the travel time and delay benefits of RGS in traffic systems were the minimum when 10% of the demand was RGS-equipped and the benefits of RGS were the highest when 100% of the demand was RGS-equipped.

The maximum travel time improvement was up to 14%, and maximum delay reduction was about 16% with 100% RGS-equipped demand. This chapter assumes that all the equipped drivers would evaluate their route choice based on the RGS information



(a)

Figure 3.6 Total Travel Time in Selected Scenarios with Route Guidance System Equipped Demand a) Scenario 3 (20% RGS), b) Scenario 6 (50% RGS), c) Scenario 9 (80% RGS), and d) Scenario 11 (100% RGS)
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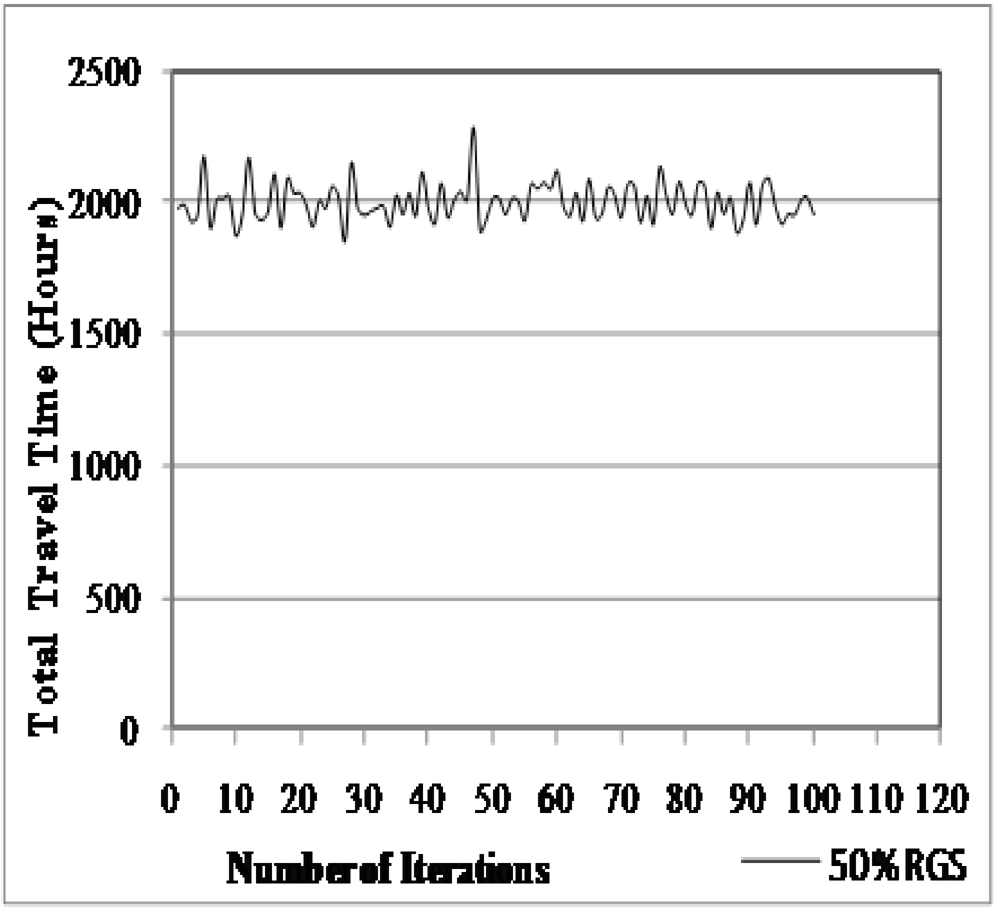
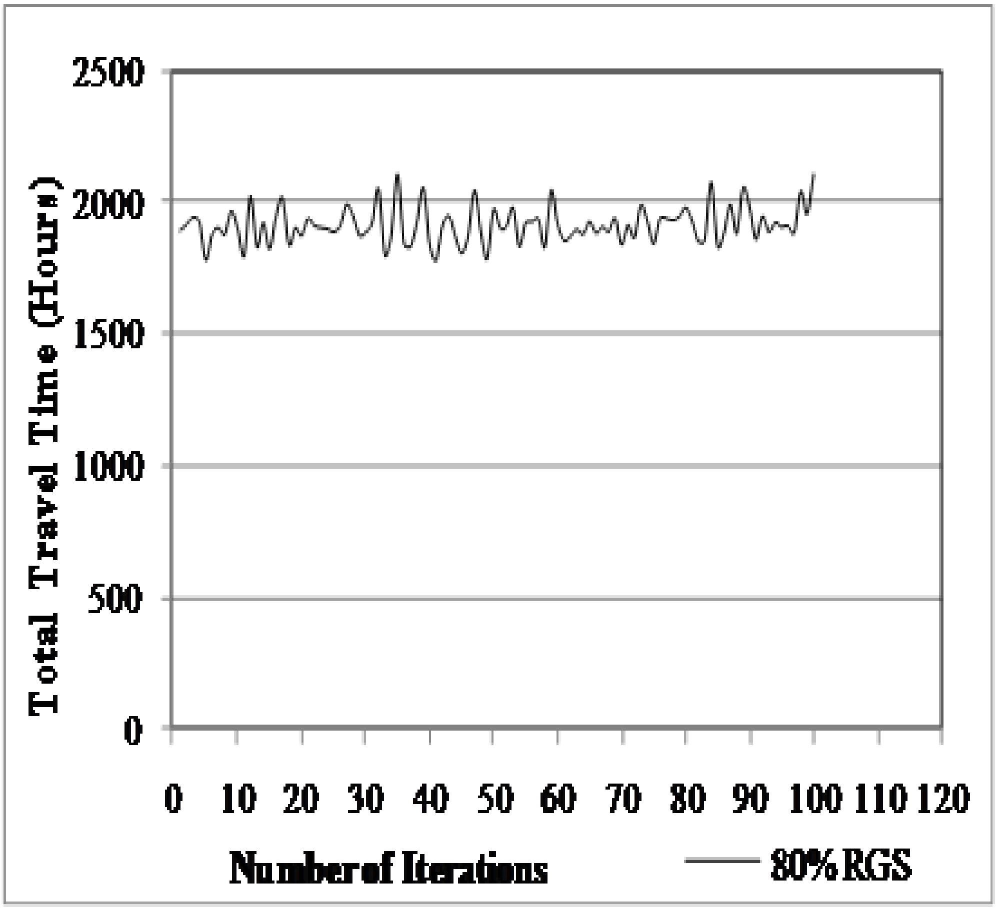


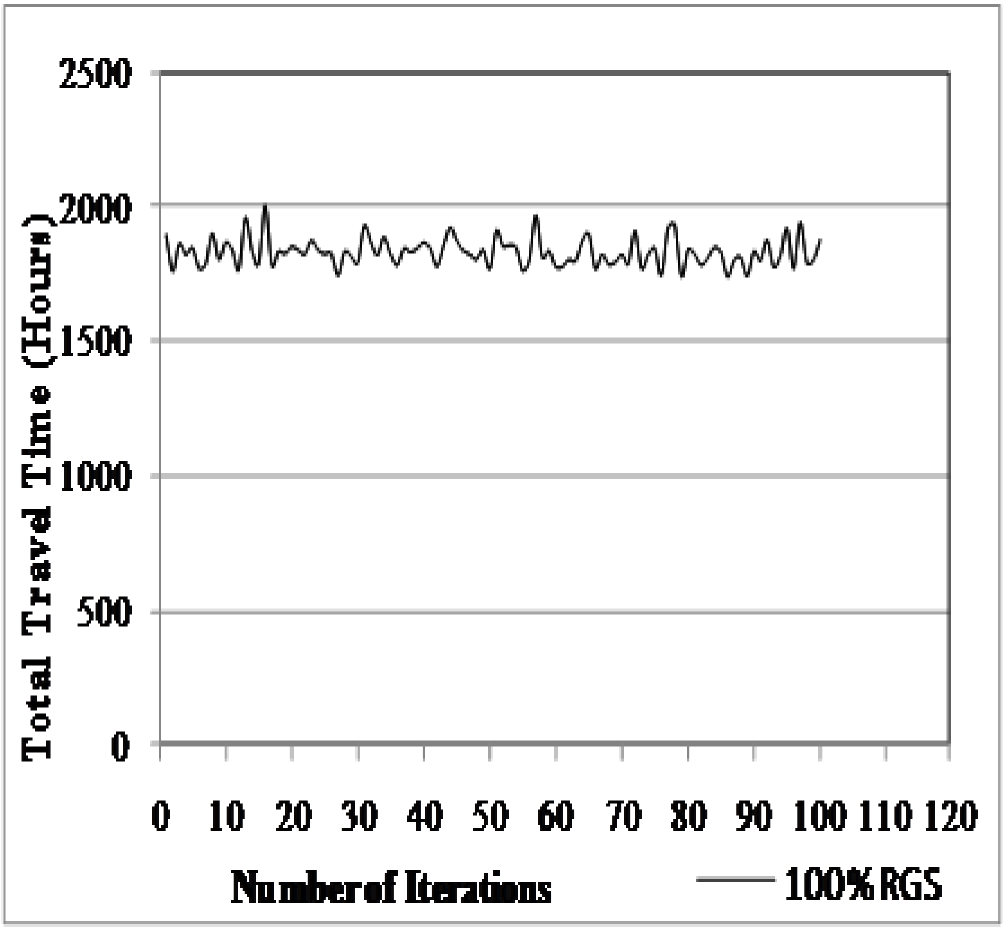
(b)

Figure 3.6 Continued



(c)

Figure 3.6 Continued



c) d)

(d)

Figure 3.6 Continued

on prevalent traffic conditions, and reroute on best cost paths with minimum travel time.

Several studies on RGS-equipped drivers' behavior suggest that not all the equipped drivers in the traffic system may respond to the information on prevalent traffic conditions. The paper does not explore the drivers' response behavior on RGS, which is the limitation of this paper.

3.8 Limitations and Future Research

The test network was a small portion of the Salt Lake City area. Larger study areas could be tested on the same test setup. More studies are needed on the benefits of RGS, especially on drivers response behavior to RGS using other software that can simulate traffic demand equipped with RGS. A computer with an Intel ® Core ™ 2 QUAD CPU with a 2.66 GHz processor and 3.24 GB of RAM was used to perform simulations. For the study area network, a test scenario simulation with 100 iterations took 36 hours to simulate. For larger networks, it may take more. However, should the development trends of computing technology continue, this may prove a smaller obstacle to researchers.

3.9 Conclusion

Past research suggests that information on prevalent traffic conditions, if available to the drivers by RGS, may impact their route choice. Many solution algorithms and model formulations on RGS are well documented, and the past research insists on the use of RGS applications in practice. This chapter evaluated the benefits of RGS on a traffic system using combined traffic assignment and control framework. The benefits were quantified in terms of travel time improvements and delay reductions by studying the impacts of providing information to drivers on prevailing traffic conditions. Eleven scenarios were tested using VISSIM simulations, starting from 0% RGS-equipped demand in Scenario 1 to 100% RGS-equipped demand in Scenario 11.

The test results suggest that providing drivers with information on prevailing traffic conditions may impact their route choice, and in turn help improve the system-wide total travel time and reduce total delay. The test results also suggest that the travel time and delay benefits were the minimum when the proportion of RGS-equipped demand was the minimum (10%), and the benefits were the maximum when 100% of the traffic demand was RGS-equipped. With growing use of RGS technology in advanced automobiles, the need for modeling methods that can quantify the benefits of RGS is growing. The traffic models that can capture the impacts of RGS on traffic systems, therefore, can play an important role in congestion mitigation projects in practice. Further studies are needed to investigate the impacts of RGS on traffic systems, especially with emphasis on drivers' response behavior to RGS-based information and on how accurately the prevalent traffic conditions information can be relayed to the drivers through RGS.

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CHAPTER 4

COMBINED TRAFFIC ASSIGNMENT AND CONTROL METHOD: BENEFITS OF CAPTURING INTERACTION BETWEEN DRIVERS' ROUTE CHOICES AND FLOW RESPONSIVE TRAFFIC CONTROLS

4.1 Abstract

This chapter presents the benefits of interaction between drivers' route choice and flow responsive traffic controls when simulated in a Combined Traffic Assignment and Control Framework (CTAC). The benefits were computed in terms of providing the drivers with network travel time information from their past travel experience with the possibility of improvements in traffic controls from fixed to adaptive control types. Six scenarios were tested on the Park City, Utah road network using static and dynamic assignments with fixed-time, vehicle-actuated, and adaptive traffic control types. The results show that in a CTAC-based simulation, the improvements in traffic controls to adaptive control type alone can substantially reduce total delays and improve total travel time. Across the six scenarios, the total delay reductions and total travel time improvements were the highest for the traffic system when the drivers had network travel time information from past travel experience with signal-controls improved to adaptive controls. In real life, this represents a situation where drivers have knowledge on network

travel time based on the previous trip. Further experiments are needed to compare the benefits for larger regional networks and other simulation software.

4.2 Introduction

The traffic system in the United States has over 350,000 traffic signals. According to the U.S. Department of Transportation, 75 percent could operate more efficiently if they are updated for improved timing plans, and better coordination with adjacent signals on a regular basis (1). Sometimes, better efficiency in traffic operations can be achieved by updating existing signal timing plans to reflect changes in traffic demand in the field. However, maintenance of the signal timing plans is often a challenge for operating agencies with limited staff resources. A survey of 417 operating agencies for the National Traffic Signal Report Card found that about 38 percent of agencies do not routinely review signal timings at least once every three years (2). Almost half (49 percent) of the interviewed agencies do not have staff or resources to monitor or manage traffic on a regularly scheduled basis (2).

Intelligent Transportation System (ITS) technology enables the practice of traffic signal timing to be performed more efficiently through enhancements in data collection, monitoring capabilities, and automation of processes. ITS tools such as automated traffic data collection, centrally controlled traffic signal systems, and Adaptive Traffic Control Systems (ATCS) help make the traffic signal timing process more efficient and cost effective. ATCS, also known as real-time traffic control systems, have been used broadly since the early 1980s. Although still not extensively used in American cities, these systems have been deployed in more than 30 locations in the US (3). The Split Cycle Offset Optimization Technique (SCOOT), developed by Transportation Research

Laboratory (TRL) of the U.K. and Sydney Coordinated Adaptive Traffic System (SCATS), developed by Road and Traffic Authority (RTA) from New South Wales, Australia, have been installed extensively worldwide (4).

ATCS in general have been evaluated many times (5). Previous field evaluations of ATCS in North America showed that most of these systems improve traffic performance on networks under their control. Adaptive controls are known for their capability to progress traffic through multiple-intersection networks using adaptive logics (6-8). This chapter was motivated by the writers' aspiration to further investigate the benefits of providing drivers network travel time information with the possibility of improvements to traffic controls from fixed-time to ATCS. Several experiments were performed on the study area using Static Traffic Assignment (STA) and Dynamic Traffic Assignment (DTA) with fixed-time controls, vehicle-actuated controls, and adaptive traffic controls.

The Combined Traffic Assignment and Control modeling framework was used. The CTAC framework-based models can simulate traffic systems under the combined effect of improvements to traffic controls and drivers' route choices, thus capturing control-driver interaction in a traffic system (9).

4.3 Research Methodology

4.3.1 Test Scenarios

Six scenarios were tested with STA and DTA, with improvements to traffic controls from fixed controls to vehicle-actuated, and finally to adaptive traffic controls.

SCENARIOS WITH DTA – The DTA-based scenarios represent a situation where drivers have network travel times information from past travel experience.

SCENARIO WITH STA – The STA-based scenarios represent a situation where drivers do not have network travel time information based on past travel experience.

The traffic controls in DTA and STA scenarios were changed as follows:

SCENARIO 1 and SCENARIO 4 – The scenarios represent a situation where the traffic controls have not been upgraded for a long time because better timings cannot be provided due to multimodal operation. Fixed-time traffic controls will not respond to changes in traffic flow.

SCENARIO 2 and SCENARIO 5 – The scenarios represent a situation where the traffic flows are unpredictable and congested. Vehicle actuated traffic controls may respond to changes in traffic flow.

SCENARIO 3 and SCENARIO 6 – Adaptive traffic controls continuously measure the traffic demand on all roads in a coordinated network and optimize signal timings for detected traffic. Figure 4.1 displays the sequence of scenario testing process with DTA-based Scenarios, STA-based Scenarios, and traffic control improvements. Table 4.1 briefly describes the test scenarios.

4.4 Overview of Traffic Analysis Tools

4.4.1 Study Area

The Park City road network described in Figure 4.2 was used as a test network. The network consists of principal arterials SR 224 and SR 248, and several intersections on them. The study area can be divided into three sections as described below:

1. Kimball Junction – Interchange at SR 224 and I-80 with close by signalized intersections at SR224 and Landmark Drive, and SR 224 and Olympic Park. The area generates work and retail trips due to commercial district in the vicinity.

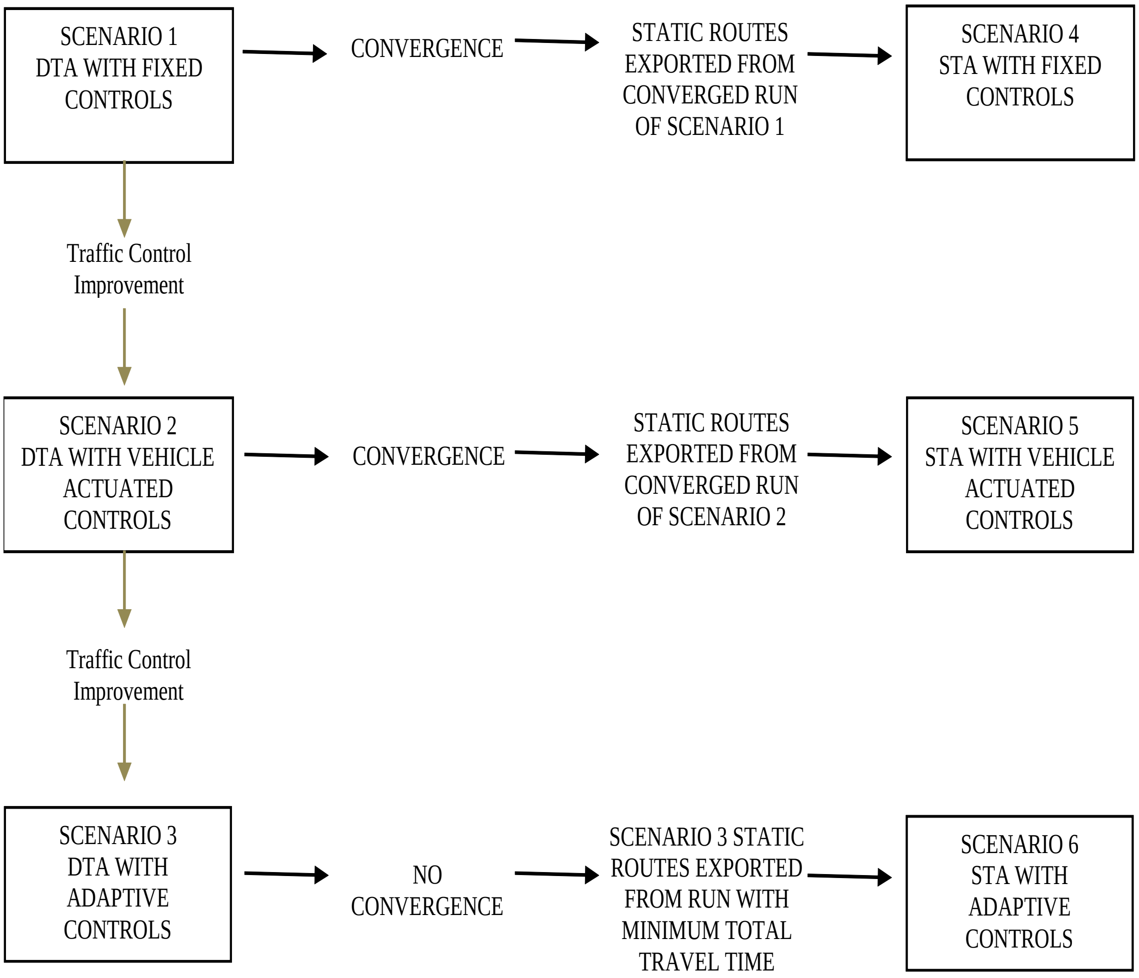

Figure 4.1 Sequence of Scenario Testing Process

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Table 4.1 Test Scenarios

Scenario Matrix	Dynamic Traffic Assignment	Static Traffic Assignment
Fixed Controls	Scenario 1	Scenario 4
Vehicle-Actuated Controls	Scenario 2	Scenario 5
Adaptive Controls	Scenario 3	Scenario 6

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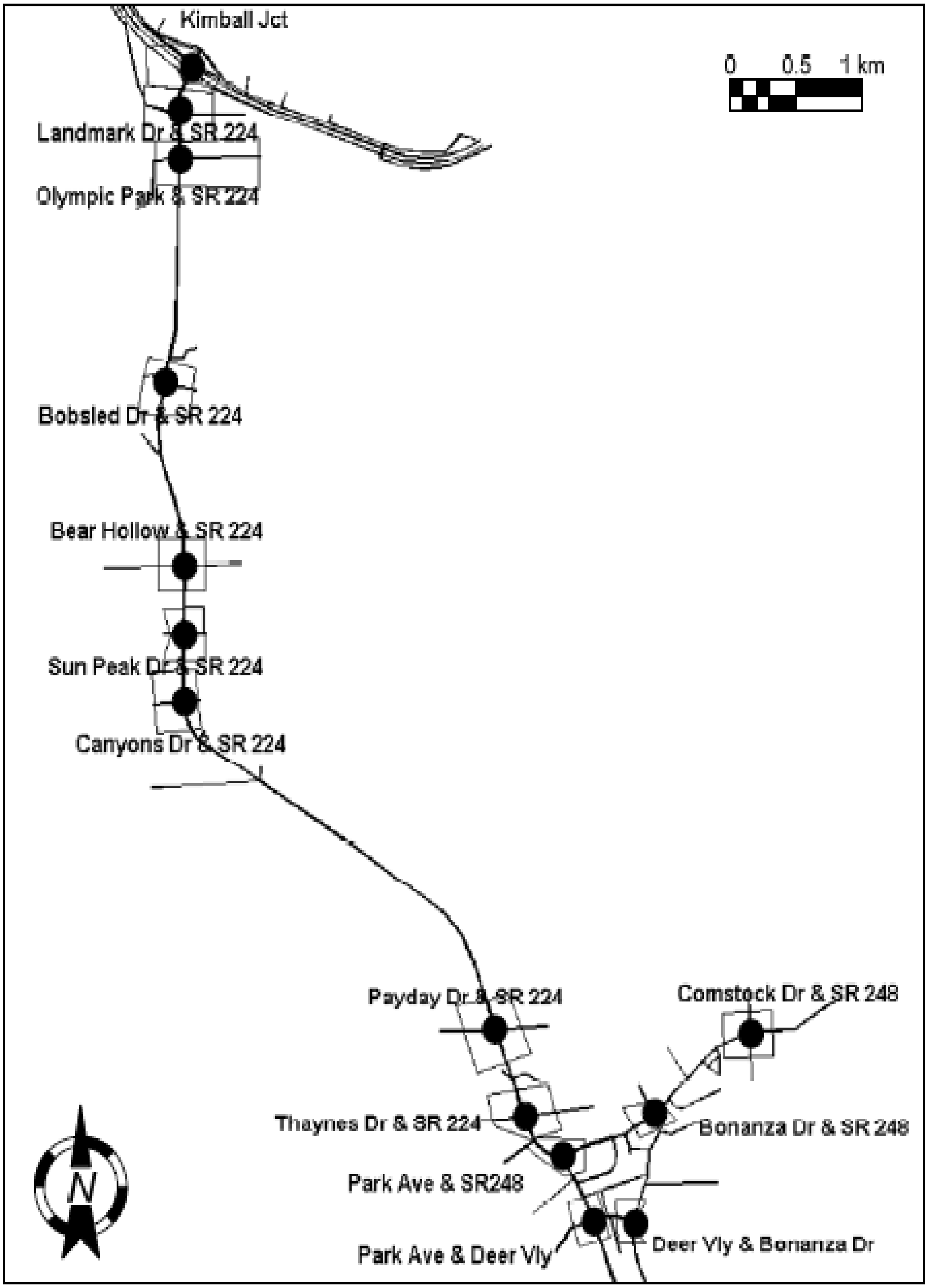

Figure 4.2 Study Area Park City Road Network

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1. Intersections of SR 224 at Bobsled Drive, Bear Hollow, Sun Peak, Canyons, Payday, and Thaynes Drive provide access to the downtown area, several residential developments, and Park City recreational facilities.
2. Intersections at Park Avenue and SR 248, Park Avenue and Deer Valley, Deer Valley and Bonanza Drive, Bonanza Drive and SR 248, and Comstock Drive and SR 248 form a number of traffic routes to the central business district.

4.4.2 Modeling and Simulation Software

The PTV Vision software VISUM - a travel demand modeling software, and VISSIM - a microscopic traffic simulator, were used to model the scenarios. VISUM 9.4 was used for Origin-Demand (OD) matrix correction. VISSIM 5.00-08 simulation software was used to emulate a realistic traffic system. VISSIM has been proven as a reliable microsimulation tool (10, 11).

4.4.3 Combined Traffic Assignment and Control Framework

The traffic assignment process in simulation models typically does not include traffic controls while the signal control optimization process in practice takes the traffic flows as known, and postoptimization flows are ignored. The two separate processes thus ignore the control-driver interaction. Combined Traffic Assignment and Control models can capture the control-driver interaction in a combined framework. Figure 4.3 describes the typical traffic analysis process with no traffic controls and no feedback on postassignment travel costs, and a CTAC modeling framework with flow responsive traffic controls and feedback on postassignment travel costs.

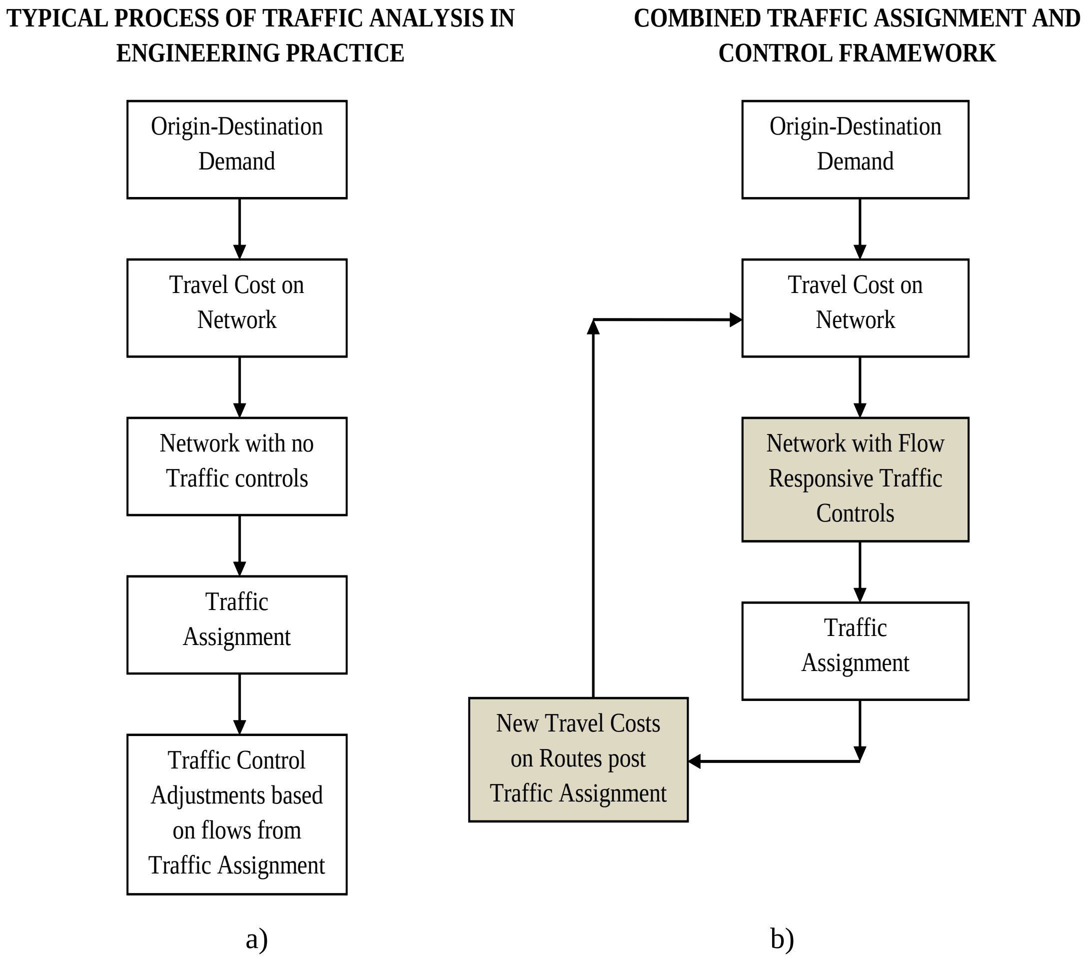

Figure 4.3 Typical Traffic Analyses vs. Combined Traffic Assignment and Control Framework a) Typical Traffic Analysis, b) Combined Traffic Assignment and Control Framework

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4.4.4 Dynamic Traffic Assignment in VISSIM

VISSIM applies DTA as an iterative simulation process. Drivers choose the routes based on travel experience (travel cost) in the previous run. VISSIM computes the best paths in each run based on travel cost. Travel cost can be travel time, trip length, toll, or any other general cost associated with trip making. The changing traffic conditions in each run may change the travel cost, leading to more routes with lower costs in subsequent runs.

For convergence, VISSIM requires that all paths must have a relative change lower than the defined threshold. Acceptable convergence criteria define indicators such as verifying that 95% of all paths are within 10 to 15% of travel time difference on path when compared to previous runs.

For this chapter, the travel time on paths was used as cost in DTA. A convergence criterion of 5% travel time difference on paths was used. Travel time evaluation files containing travel time for each OD pair were written for every run of DTA simulation using the “Evaluation Files” feature of VISSIM.

DTA-based Scenario 1 with fixed-time controls and Scenario 2 with vehicle-actuated controls met the set convergence criteria after 95 iterations, yet both scenarios were ran for 100 iterations after convergence for consistency in comparison with other scenarios. DTA-based Scenario 3 with adaptive traffic controls did not reach convergence even after 100 iterations.

4.4.5 Static Traffic Assignment in VISSIM

VISSIM provides an option to convert the current state of DTA into STA by static routes, volumes on the routes, and current state DTA data files. The data files with extensions WEG, BEW, and FMA contain the list of discovered paths, costs for paths, and OD information, respectively. The use of static routes-based assignment means the routes are frozen and vehicle inputs and routing decisions are created using the static data files. The static routes were exported from the converged runs of Scenario 1 and 2. Since Scenario 3 did not converge within 100 iterations, the run with minimum total travel time was used to export static routes. The static routes with the data files were then used by Scenario 4, 5, and 6 for 100 iterations of STA simulations for each scenario, respectively.

4.4.6 Fixed-Time and Vehicle-Actuated Controls

Fixed-time controls operate on a predetermined and repeated sequence of signal plans with fixed cycle length and splits. The signal timing plans are developed off-line and optimized based on historic data of traffic flow. A series of predetermined plans can accommodate variations in traffic volume during the day. Fixed-time controls are best with predictable traffic volumes.

Vehicle-actuated controls can respond to variations in traffic flow and are typically used for irregular traffic flow. The actuated controls can be grouped into two types: semi-actuated and fully-actuated. Semi-actuated controls primarily apportion the green time to the major movement of traffic and minor streets are accommodated at vehicle detection. Fully-actuated controls detect vehicles on all approaches of the intersection and make adjustments accordingly. The vehicle-actuated controls were used with the limitations that offsets and cycle-lengths would not change, and only green splits within the given cycle-length framework could be adjusted. The changes in green split could respond to the variation in traffic flow due to different route choices of drivers in DTA.

The vehicle-actuated controls in the simulations had the traffic control programs from the old field data prior to installation of SCATS on the Park City network shown in Figure 4.2. The field traffic control programs were collected from the Utah Department of Transportation (UDOT).

4.4.7 Adaptive Traffic Controls (SCOOT)

The Split Cycle Offset Optimization Technique (SCOOT) was used for adaptive traffic controls. SCOOT was developed by TRL of the U.K. in the early 1980s (12). The recent version of SCOOT is “Managing Congestion, Communications and Control” or MC3 (13). In one of the recent research efforts, Kergaye et al. (8) comparatively evaluated SCOOT and Sydney Coordinated SCATS with vehicle actuated-coordinated-traffic control in Park City, Utah. SCOOT and SCATS individually were found to reduce overall network delays and stops by at least 14% and 9%, respectively, when compared to the actuated-coordinated control taken from the field. For SCOOT’s principles, evaluations and features, the reader is referred to SCOOT User Guide Version 4.2 (14). For basic setup between SCOOT and micro simulation, we refer to previous studies done by Martin and Feng (15), and by Feng et al. (16).

4.4.8 Signal Control Emulator

A National Electrical Manufacturers Association (NEMA) Standard Signal Control Emulator was used for traffic controls. With this controller, VISSIM can simulate fully actuated signal control as well as coordinated and vehicle-actuated coordinated signal controls. The interface to the controller is accessed through VISSIM but saves its settings to an external data file with the extension (NSE). To use the NEMA standard emulator in VISSIM, traffic control programs for each intersection in the study area network were exported to NEMA format using VISUM software.

4.4.9 SCOOT Setup

VISSIM simulations with SCOOT need an interface between SCOOT and VISSIM. The SCOOT-VISSIM interface developed by previous studies conducted by Stevanovic and Martin (17), and Kergaye et al. (8) was used. The investigation by Kergaye et al. extensively built, calibrated, and fine-tuned the SCOOT-VISSIM system according to the processes established by Stevanovic and Martin (17). The process involved building network, coding the traffic control programs, and calibration and validation of the simulation process in VISSIM. The studies developed the SCOOT-VISSIM interface as a partial Hardware-In-the-Loop Simulation (HILS) and Emulation-In-the-Loop Simulation (EILS) setup (8). The central SCOOT kernel used for the study is based on an Alpha-DEC computer connected to an IBM compatible PC running VISSIM microsimulation. The interface between the two computers is through EILS, a module which is used to communicate between VISSIM's traffic model, SCOOT, and emulation of local intersection controllers in VISSIM.

4.4.10 Calibration of the Park City Model

Even though the calibrated and validated base-run was obtained from a previous study, the model output was revalidated to ensure consistency. The data, including turning movement counts, corridor travel-times, and speed, were assembled for three hour (4 PM to 7PM) and loaded to the network for use in re-validation of the base-run.

The VISSIM model calibration and validation was based on turning movement counts, speed comparisons, and travel time comparison.

4.5 Origin-Destination Matrix Correction Process

The Initial OD matrix for the selected p.m. peak period was obtained from the Wasatch County Regional Planning Organization/Summit County travel demand model. The travel demand model is calibrated and validated for the Park City/Heber Valley region and is used for regional transportation planning purposes. Due to the macroscopic nature of the RPO model, OD information extracted from the model was susceptible to some errors. The comparison of modeled volumes to field counts was therefore necessary. VISUM has several routines to assign travel demand specified in OD-matrix (18). A multi-equilibrium assignment routine was used to assign demand from the initial OD matrix. Bureau of Public Roads (BPR) curves were specified as volume-delay functions. The assignment process did not give a close match of modeled volume to the field counts.

In order to better fit the field-counts, the initial OD matrix was corrected using the VISUM-based TFlowFuzzy matrix correction module which is based on the well-known entropy maximization algorithm (19). The output from each run of OD matrix-correction is a synthetic matrix, which by assignment reduces the difference between the counts and modeled data. For this paper, the matrix was calibrated for the turning-movement counts only. The counts included left -turns, right-turns, and through movements at the intersections. The process with 77 iterations led to an OD matrix with R^2 of 0.98 for modeled vs. field counts, a decent match to the turning movement counts in the study area. Figure 4.4 parts a) and b) display the scattered plot for modeled versus count data for initial and calibrated OD matrices.

4.6 Results and Discussion

4.6.1 Evaluation of Results

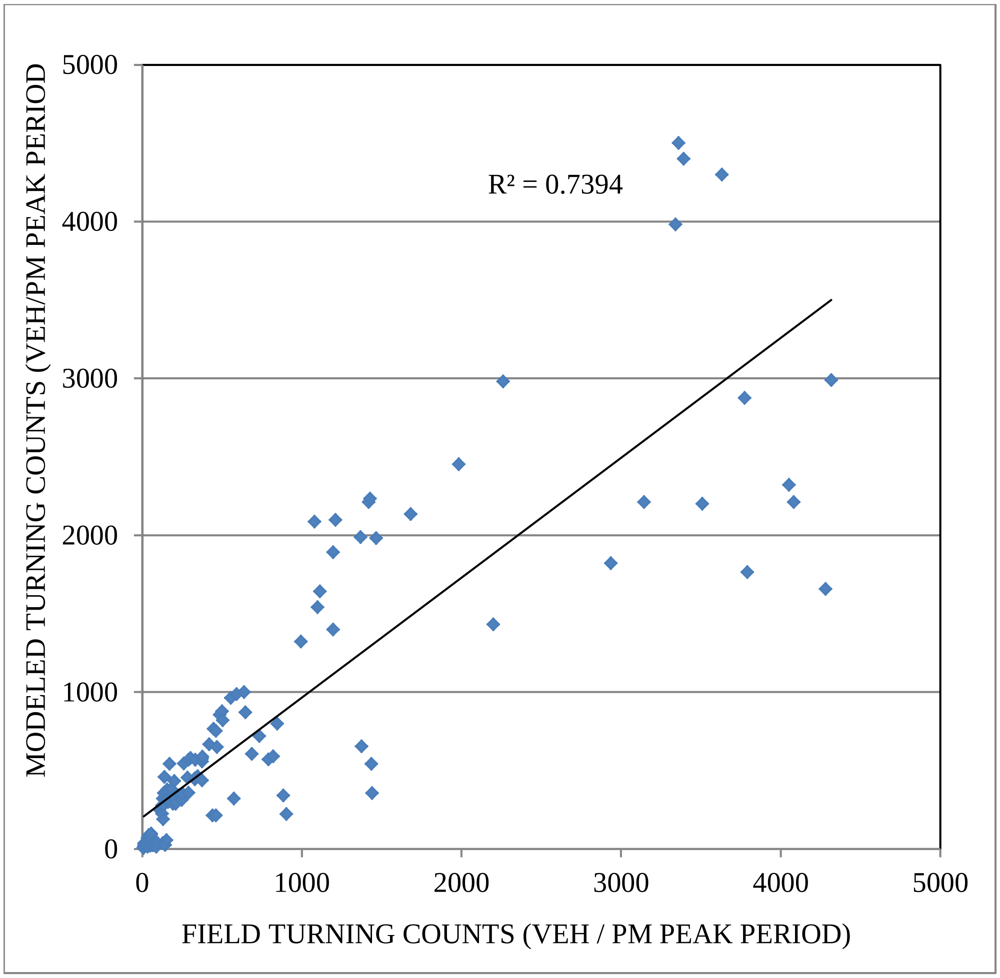
Table 4.2 displays the mean and standard deviation of total delay and total travel time from the simulation-runs in six test scenarios. For consistency in comparisons, 100 simulation-runs were applied in each scenario. Percentage changes in mean delay and mean travel time from Table 4.2 were compared across the scenarios to compute the relative delay reduction and travel time improvement benefits. Figure 4.5 part a) displays percent reduction in total delay and part b) displays percent improvement in total travel time. Figure 4.5 part a) and b) compares the delay reduction and travel time improvement benefits in terms of provision of network travel time information to drivers from past travel experience (STA vs. DTA) with the possibility of improvements in traffic controls.

4.6.2 Fixed-Time Controls to Vehicle-Actuated Controls Improvements

The description of various points shown in Figure 4.5 part a) and part b) are given below:

Pont O**:** It represents Scenario 4 with fixed traffic controls and static assignment.

Point A: If only the traffic controls are changed from fixed-time to vehicle-actuated while drivers do not have network travel time information, the total delay can be reduced by 6% and the total travel time can be improved by 4%.



(a)

Figure 4.4 Calibration of Origin Destination Matrix a) Modeled vs. Field counts from initial OD Matrix b) Modeled vs. Field counts from calibrated OD Matrix
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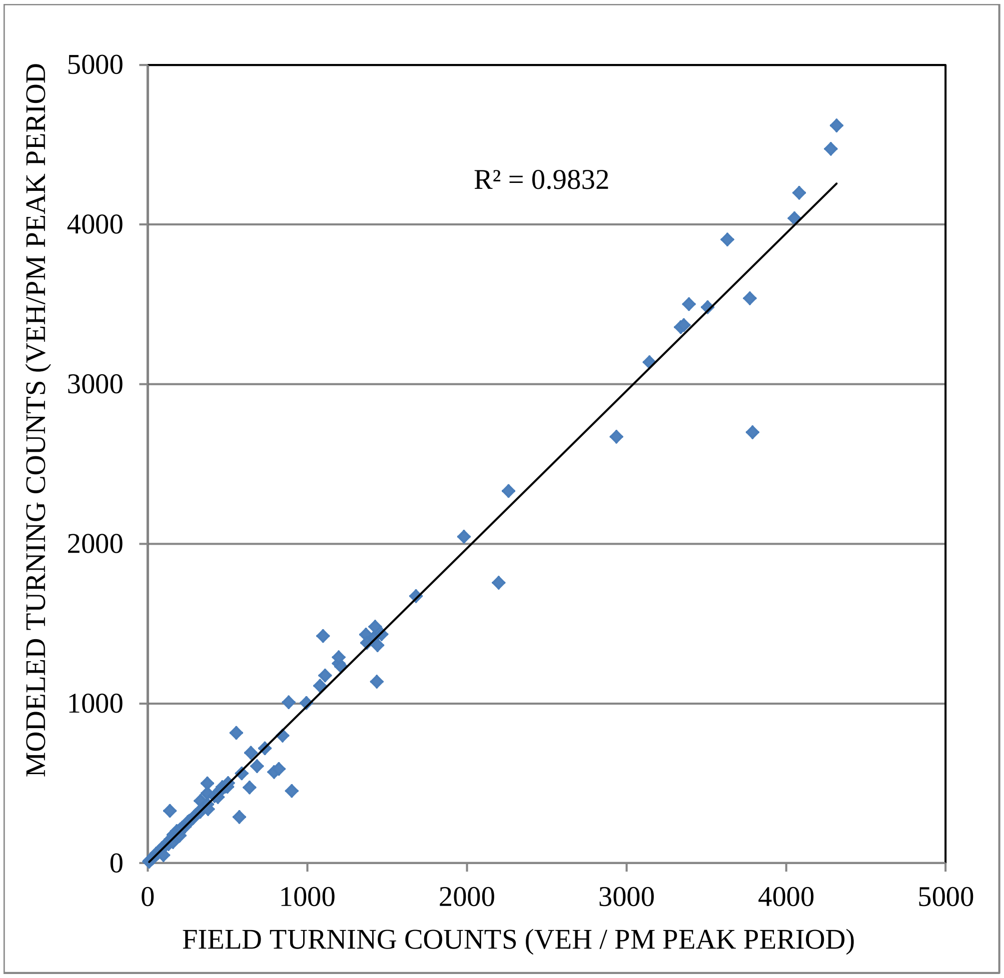

(b)

Figure 4.4 Continued

Table 4.2 Total Delays and Total Travel Time Comparison

Description	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Mean Total Delay (Hours)	18543	13785	10940	22987	21407	17018
Standard Deviation (Total Delay)	861	730	708	1934	1927	1684
Mean Total Travel Time (Hours)	23572	19636	17967	28117	26907	22926
Standard Deviation (Travel Time)	704	561	404	1897	1687	1340

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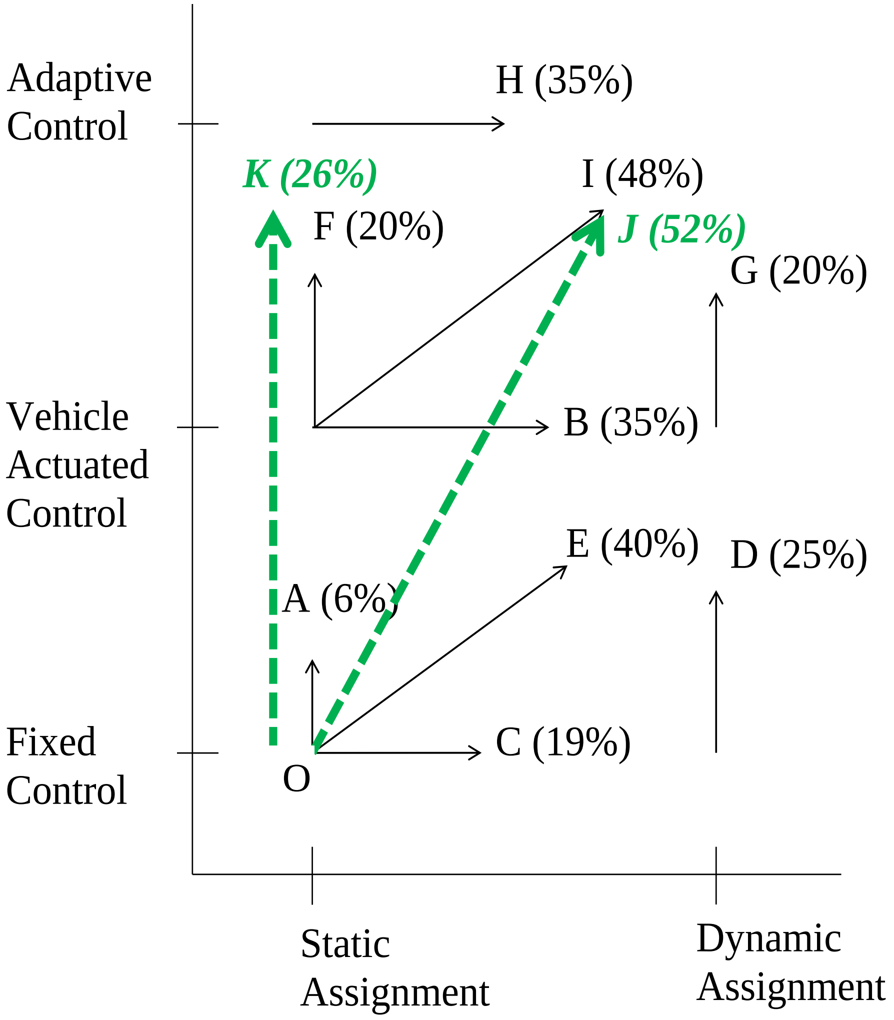

(a)

Figure 4.5 Total Delay Reductions and Total Travel Time Improvements a) Total Delay Reductions, b) Total Travel Time Improvements

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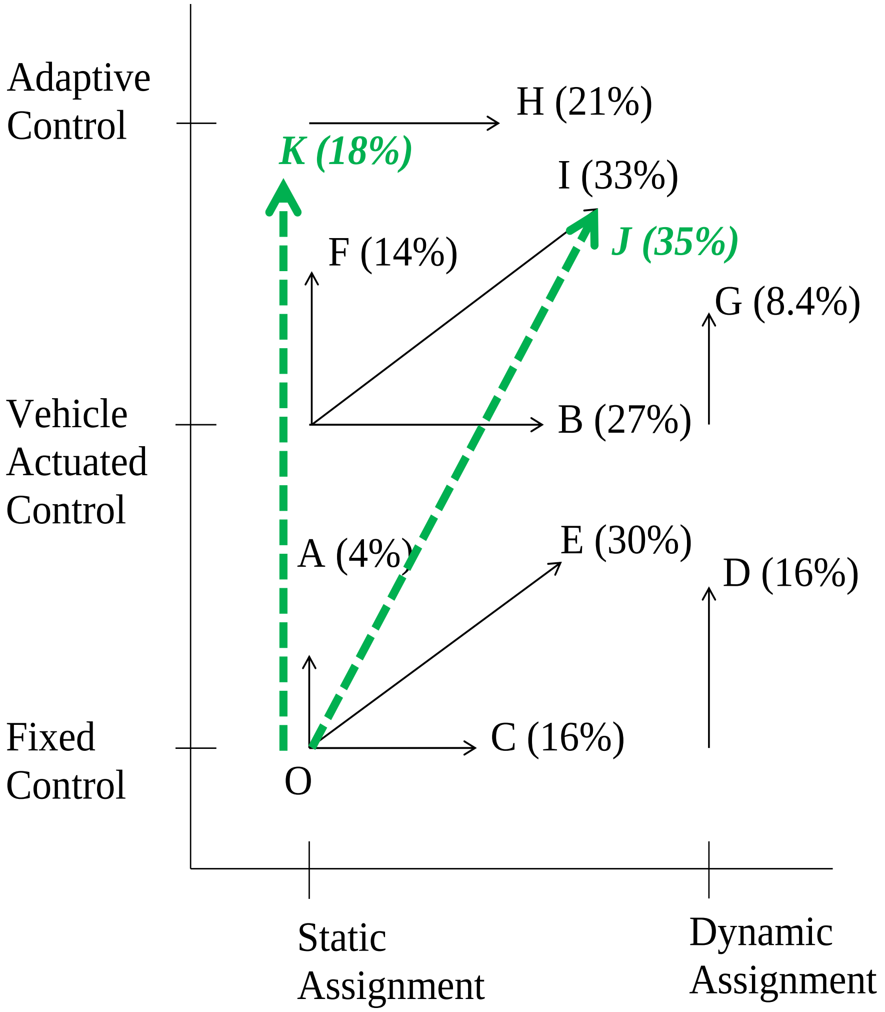


(b)

Figure 4.5 Continued

Point B: In addition to changing the controls from fixed-time controls to vehicle-actuated, if the drivers have information on network travel time, the total delay can be further reduced by 35% and the total travel time can be further improved by 27%.

Point C: If the traffic controls are kept fixed-time while the drivers have information on network travel times, the total delay can be reduced by 19% and the total travel time can be improved by 16%.

Point D: In addition to network travel time information to drivers, if the traffic controls are changed from fixed-time to vehicle-actuated, the total delay can be further reduced by 25% and the total travel time can be further improved by 16%.

Point E: If the traffic controls are changed from fixed-time to vehicle-actuated and at the same time drivers have network travel time information, the total delay can be reduced by 40% and the total travel time can be improved by 30%.

4.6.3 Vehicle-Actuated Control to Adaptive Control Improvements

Point F: If the traffic controls are further improved from vehicle-actuated to adaptive traffic controls while the drivers do not have network travel time information, the total delay can be further reduced by 20% and the total travel time can be further improved by 14 %.

These travel time and delay benefits will be in addition to the benefits already achieved at point A.

Point G: If the drivers have network travel time information, and traffic controls are further improved from vehicle-actuated controls to adaptive traffic controls, total delay can be further reduced by 20% and the total travel time can be further improved by 8%.These travel time and delay benefits will be in addition to the benefits already achieved at point D.

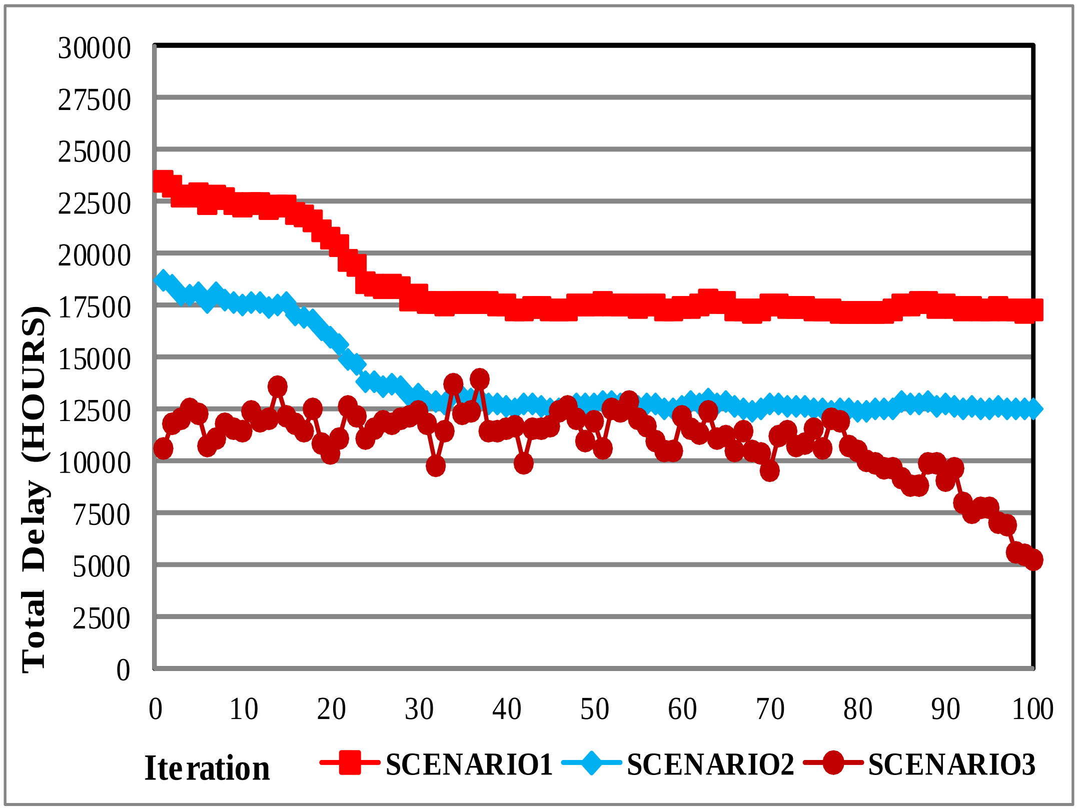
Point H: In addition to further improving the traffic controls from vehicle-actuated to adaptive traffic controls, if the drivers have network travel time information, the total delay can be further reduced by 35% and the total travel time can be further improved by 21%.

Point I: If the traffic controls are further improved from vehicle-actuated to adaptive controls and at the same time drivers have network travel time information, the total delay can be reduced by 48% and the total travel time can be improved by 33%.

4.6.4 Fixed Controls to Adaptive Control Improvements

Point J: If the traffic controls are changed from fixed controls to adaptive controls and at the same time drivers are provided network travel time information, the total delay can be reduced by 52% and the total travel time can be improved by 35%.

Point K: If the traffic controls are improved from fixed controls to adaptive traffic controls while the drivers do not have network travel time information, the total delay can be further reduced by 26%, and the travel time can be further improved by 18 %. Figure 4.6 parts a) through d) show that in Scenario 1-2 with DTA, the traffic flow converged and stabilized at lower congestion levels compared to Scenario 4-5 with STA, which stabilized at higher congestion levels. To evaluate the convergence and existence of system-level stable traffic flows, the total travel time and the total delay from all the runs were compared. In Scenario 3 with adaptive controls and DTA, the traffic flow stabilized at even lower congestion levels yet did not converge in 100 simulation-runs. In Scenario



(a)

Figure 4.6 Total Delay and Total Travel Time a) Total Delay in DTA Scenarios, b) Total Delay in STA Scenarios c) Total Travel Time in DTA Scenarios d) Total Travel Time in STA Scenarios

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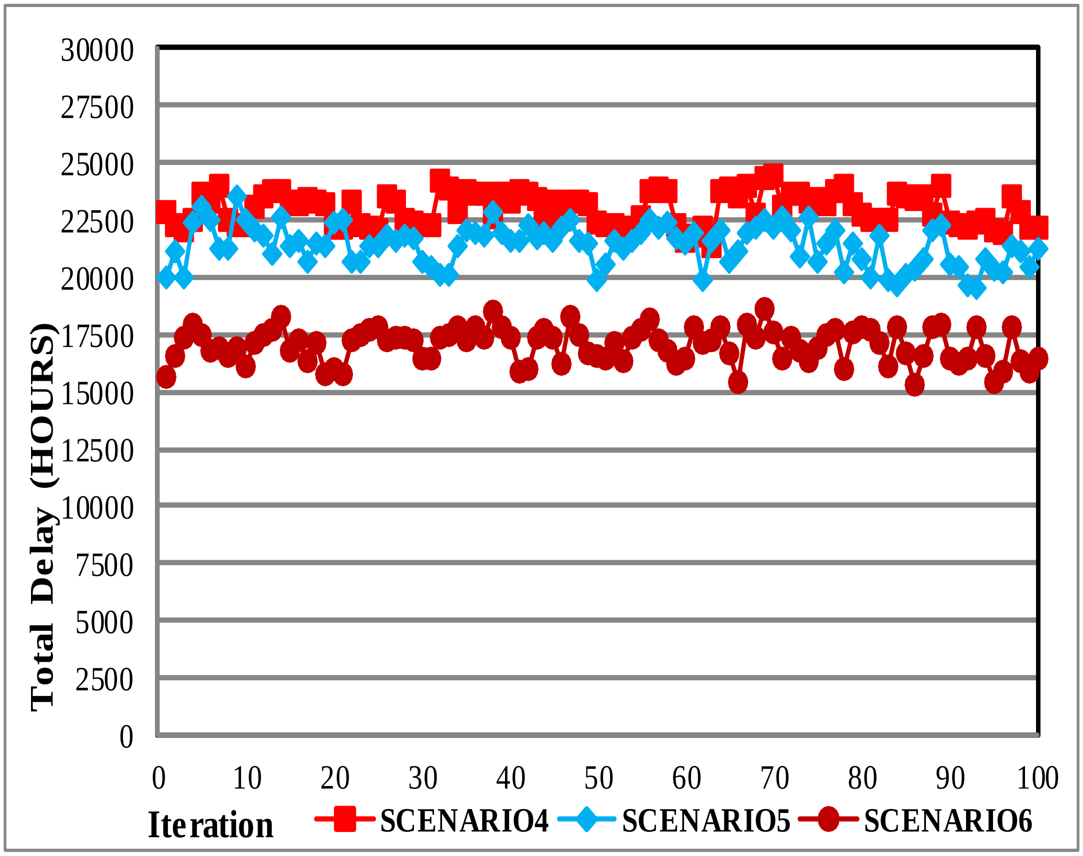
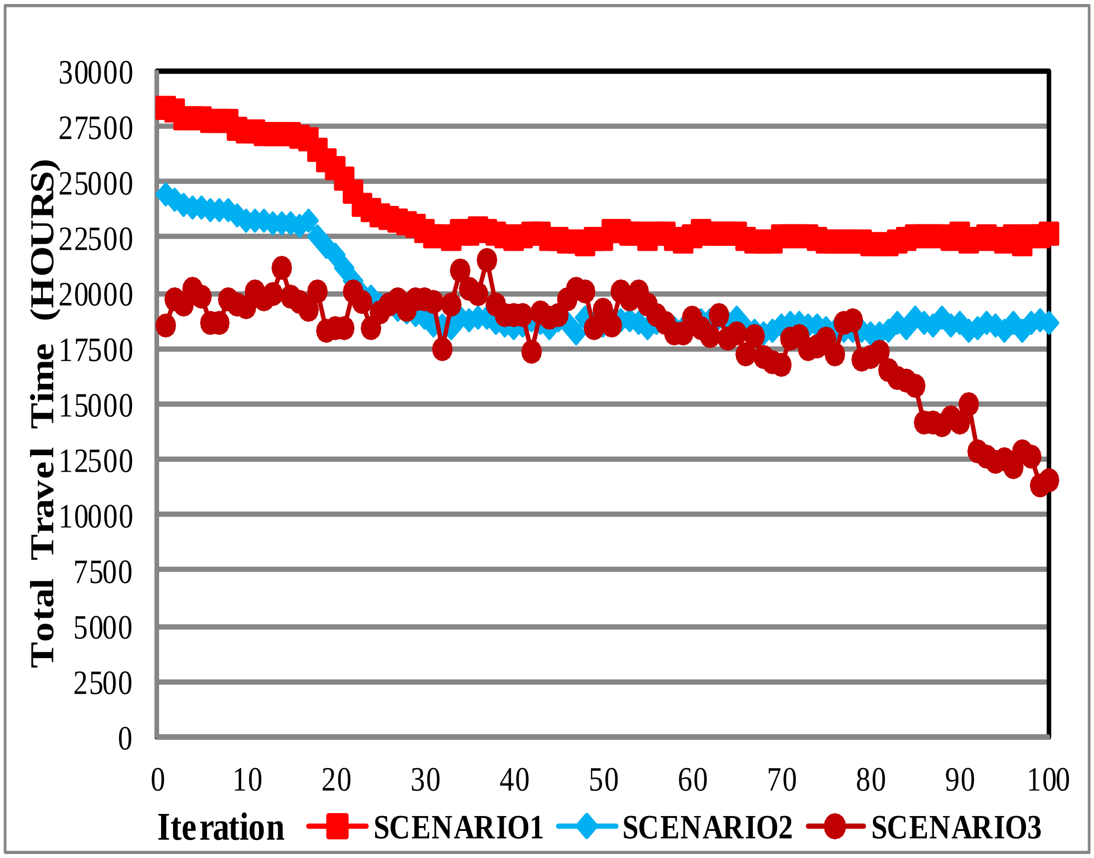


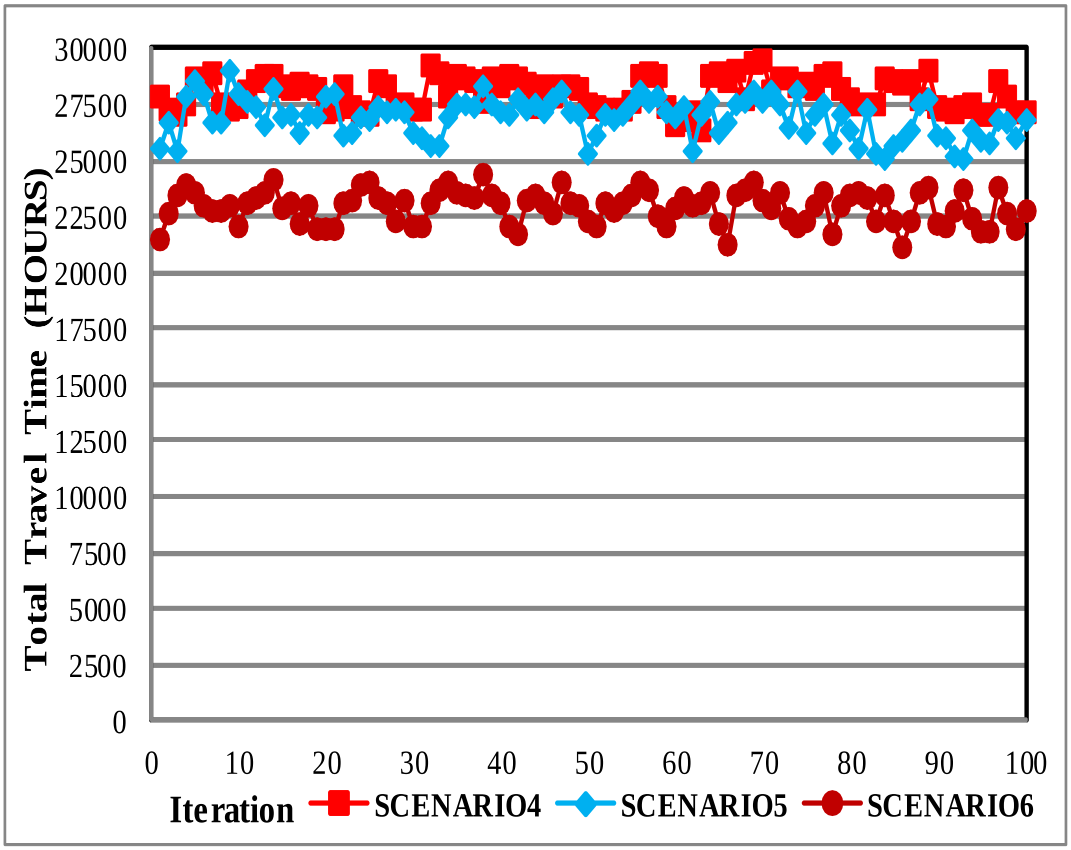
(b)

Figure 4.6 Continued



(c)

Figure 4.6 Continued



(d)

Figure 4.6 Continued

6 with adaptive controls and STA, the flow stabilized at relatively lower congestion levels compared to Scenario 4 and Scenario 5 yet at higher congestion levels compared to Scenario 3 with DTA and adaptive controls.

4.7 Limitations and Future Research

A computer with an Intel ® Core ™ 2 QUAD CPU with a 2.66 GHz processor and 3.24 GB of RAM was used. Achieving model convergence through DTA simulation process took over 65 hours for 100 iterations. However, should the development trends continue, this may prove a smaller obstacle to researchers. Another limitation of this research is that the research was implemented for P.m. peak period traffic only, the benefits on travel time improvement and delay reduction may quantify differently with a.m. peak traffic and Daily traffic.

4.8 Conclusion

The paper evaluated the benefits of providing network travel time information to drivers from their past travel experience with improvements in traffic controls. A network from Park City, Utah was used to test six scenarios using VISSIM.

The CTAC framework used in these tests was able to capture interaction between drivers' route choices and flow responsive traffic controls in a combined framework. The results suggest the following:

1. Provision of the near perfect network travel time information to drivers from previous day's travel alone can reduce the total delays by 19% and total travel time by 16%.

2. Traffic control improvements from fixed-time to adaptive controls alone can reduce the total delay by 26% and improve the total travel time by 18%.
3. Provision of network travel time information to drivers from past travel experience combined with improvements of fixed-time controls to adaptive controls can reduce total delay by 52% and improve total travel time by 35%.
4. With growing use of adaptive and vehicle actuated traffic controls to mitigate traffic congestion, the need for modeling methods that can capture control-driver interaction is growing. CTAC models, therefore, can play an important role in congestion mitigation projects in practice.

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CHAPTER 5

IMPLEMENTATION OF COMBINED TRAFFIC ASSIGNMENT AND CONTROL-BASED REGIONAL MODEL FOR THE WASATCH FRONT REGION

5.1 Abstract

The regional travel demand models are generally macroscopic in nature and do not include traffic controls in the traffic assignment process. In travel demand models, the road capacities are kept fixed within the functional classification of roadways and free-flow-speeds are adjusted to accommodate the impacts of traffic controls and traffic operations. Part of the reason this approach is adopted in travel demand models is their macroscopic application, where the focus is extensively on the region-wide results for transportation planning.

While there are advantages in using this approach, the cost is usually paid in “lost capacity on projects” due to the absence of traffic operations in modeling; more precisely, the absence of traffic controls tend to present partially skewed output from the travel models. CTAC models can address this issue by including the impacts of traffic controls in the modeling process.

5.2 Introduction

To study the benefits of the combined traffic assignment and control framework, researchers have been investigating the Combined Traffic Assignment and Control

(CTAC) *(1)* modeling framework for many years now. The framework allows a user to simulate a traffic system under the combined effect of traffic control and driver's route choice. CTAC has been the focus of research for solution algorithms and theoretical modeling formulations for the last three decades. One of the hurdles for implementation of the concept until the mid-1990s was lack of computer technology to perform complex calculations in relatively shorter time. Advanced computers, and software like VISSIM *(2)*, DYNASMART *(3)*, and CUBE-DYNASIM *(4)* can now simulate complex real-life networks. Due to the availability of advanced computer technology, implementation of CTAC has been the topic of extensive research in academia. However, from the perspective of practice, very little research has been done to implement the CTAC modeling framework on a large regional scale, especially to identify the benefits of providing network travel time information to drivers with the possibility of improvements in traffic control on the mesoscopic level for a region.

This paper evaluates the benefits of combined traffic assignment and control modeling framework implemented on a regional scale compared to a traditional four-step regional travel demand model. The study quantifies the benefits in terms of providing network travel time information to drivers to make route choice in comparison to improving the traffic controls on a large regional network (at a mesoscopic-simulation level). Several experiments were performed on a study area using Static Traffic Assignment (STA) and Dynamic Traffic Assignment (DTA) with fixed and vehicle-actuated controls. The study area network is a regional transportation network for the Wasatch Front Region in Utah.

5.3 Literature Review

Allsop conducted one of the first studies on the CTAC problem in the 1970s. Allsop *(5)* suggested that the traffic controls impact route choice. Maher and Akcelik (*6*), Gartner (*7*), and Allsop and Charlesworth (*8*) investigated CTAC on a conceptual level by studying the use of signal control to influence route choice. Smith (*9*, *10*) investigated the problem for the existence of equilibrium. Smith formulated conditions that guarantee the existence of equilibrium theoretically. Smith (*11,12*) introduced a control policy P_o that ensures the existences of traffic equilibrium. These theoretical approaches by Smith paved the way for one of the initial CTAC implementation efforts by Smith and Van Vuren (*13*). Meneguzzer (*1*) and Taale and Zuylen (*14*) presented an overview of 25 years of research on combined traffic assignment and control. Granato (*15*) suggested that the transportation planning agency in Iowa is using CTAC model for limited use to long-range planning only.

Early efforts on implementation of CTAC models began with a combined focus on solution algorithms and their implementation. Gartner and Al-Malik (*16*) derived an iterative approach for the combined traffic and control problem using a link performance function. Gartner and Stamatiadis (*17*) presented a theoretical framework for implementation of a joint control and dynamic traffic assignment. Meneguzzer (*18, 19*) solved a combined route choice control problem using a diagonal algorithm. Taale and van Zuylen (*20*) investigated CTAC with STA on fixed-time, fixed-time-optimized, vehicle-actuated, and vehicle-actuated-optimized control types. The study left other research options open, especially using adaptive controls and DTA on the latest simulation tools that are available now.

Mahmassani and Ta-YIN HU (*21*) presented a DTA simulation procedure to investigate day-to-day network flows in combination with offline and online traffic controls. The research concluded that real-time information and signal control strategies could reduce average delay system-wide. Abdelfatah and Mahmassani (*22*) presented a joint control and assignment problem to optimize the network performance with dynamic route guidance. The research concluded that joint routing and control optimization can lead to improved network performance.

To summarize, conventional traffic assignment and control optimization methods tend to ignore control-driver interaction. The CTAC method can capture control-driver interaction in a single framework. The investigations on solution algorithms, model formulations, and implementation of the method are well documented. However, there is no study to date that captures the benefits of provision of network travel time information to drivers to make route choice in comparison to the possibility of improving the traffic controls on a CTAC framework.

5.4 Research Methodology

5.4.1 Test Scenarios

Three scenarios were tested using Cube Voyager and Avenue-based mesoscopic simulation. A brief description of the test scenarios is given below. Table 5.1 displays the test scenarios.

5.4.2 Static Assignment Scenarios

The section below describes the STA-based scenario:

Scenario 1 – In the STA-based scenario the drivers will not have information on network travel times based on past travel experience to make better route choice.

Table 5.1 Test Scenarios

	Macroscopic	Mesoscopic	
Scenario Matrix	Scenario 1	Scenario 2	Scenario 3
Assignment Type	Static Assignment	Dynamic Assignment	Dynamic Assignment
Traffic Controls	No Traffic Controls	Fixed Controls	Vehicle Actuated Controls

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5.4.3 Dynamic Assignment Scenarios

The section below describes the DTA-based scenarios:

Scenario 2 - Signal timings are fixed and controls do not respond to changes in traffic flow. Since it is a DTA-based scenario, the drivers have network travel time information based on past travel experience and they are able to make better route choice.

Scenario 3 - Signal timings may respond to changes in traffic flow due to vehicle-actuated type traffic controls. Since it is a DTA-based scenario, the drivers have network travel time information based on past travel experience and they are able to make better route choice.

Figure 5.1 displays the sequence of the scenario application process, including the intermediate steps where origin destination data and network data is exported to Avenue software.

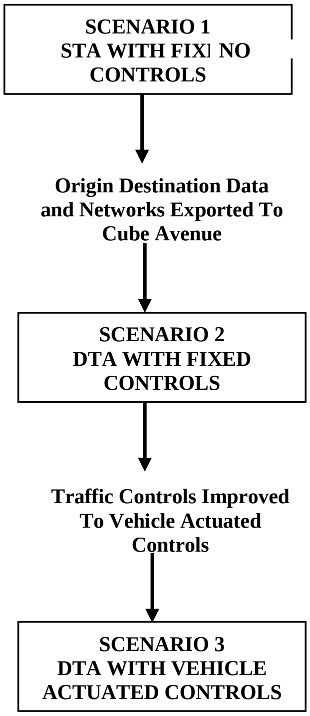

Figure 5.1 Sequence of Scenario Testing

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5.5 Overview of Traffic Analysis Tools and Data

5.5.1 Modeling and Simulation Software

A travel demand modeling software Cube version 5.1 with extensions Voyager- a travel demand simulator, and Avenue - a mesoscopic traffic simulator were used to model the test scenarios. Cube uses a modular and script-based structure, allowing the incorporation of any model methodology ranging from standard four-step models, activity-based models, and mesoscopic models. Cube Voyager includes highly flexible network and matrix calculators for the calculation of travel demand and for the detailed comparison of scenarios.

Cube Avenue has been proven as a reliable mesoscopic simulation tool that produces virtual traffic flows similar to real traffic flows (23-26). Cube Avenue, an extension to Cube software, offers transportation professionals an innovative tool for analyzing traffic. Cube Avenue is a mesoscopic modeling software. It models traffic at greater levels of detail than macroscopic models, like Cube Voyager’s Highway program, and at lesser levels of detail than microscopic models, like Cube DynaSim. With Cube Avenue, analysts can study problems for which traditional aggregate models do not provide enough data and for which microscopic models provide too much data. The mesoscopic modeling environment in Cube Avenue can be used for transportation planning studies, such as comparing policies for alleviating peak period congestion using the control-driver interaction in a traffic system, or examining the effectiveness of emergency evacuation plans.

5.5.2 Static Assignment

A static assignment model based on user equilibrium was used for Cube-Voyager-based Scenario 1. The model is the fourth step of the regional travel demand model (version 7) adopted by the Wasatch Front Regional Council (WFRC), and the Metropolitan Planning Organization responsible for Transportation Planning for Wasatch Front Region in Utah. The travel demand model is fully calibrated and validated for the regional forecasting, and has been used in several regional planning studies of regional significance by the MPO, ranging from studies for regional freeways, regional commuter transit projects, and light rail studies. The assignment model locates a specific route along the links and through intersections for every vehicle trip. The vehicle trips in the form of an origin-destination matrix are "assigned" to the network based on a user equilibrium model.

The STA model specifies the effect of road capacity on travel times by means of volume-delay functions (VDF) which is used to express the travel time (or cost) on a road link as a function of the traffic volume. The VDF based on the Bureau of Public Roads (BPR) function is used in the Static traffic assignment process of the Cube Voyager model in Scenario 1. The function is used to relate changes in travel speed to increases in travel volume. The equation for BPR function can be described as in equation 5.1.

$$Cs = FFS / [1+X*(V/C)\ {}^\wedge Y] \qquad (5.1)$$

where

Cs = Congested Speed
FFS = Free Flow Speed
X = Coefficient (often set at 0.15),
V = Assigned Traffic volume
C = the Link Capacity
Y = Exponent (often set at 4.0)

Figure 5.2 shows the volume-delay curves from Cube Voyager travel demand model (Scenario 1) for different functional classes. Figure 5.2 also describes the values of coefficient X and exponent Y for the calibrated model. The values of X and Y are the two critical parameters in the BPR function that vary by functional roadway classification, and are calibrated accordingly from the field data.

The assignment model uses an iterative process to achieve a best path solution in which travelers' travel costs are the best within the defined travel cost functions. The numbers of iterations for the traffic assignment runs were fixed at 100 for consistency on comparison with other scenarios, rather than allowing the assignment to stop at an arbitrary iteration. The rationale for fixing the number of iterations in STA is that the

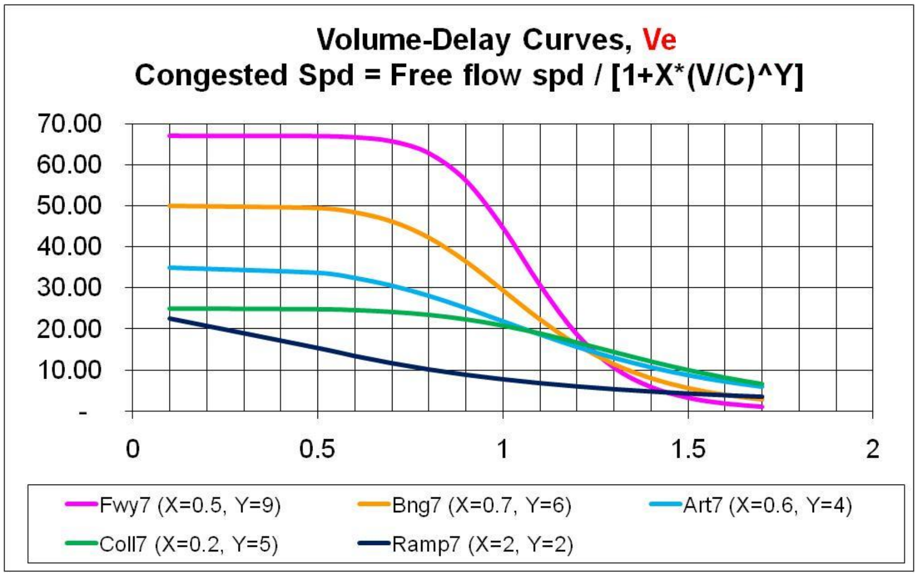

Figure 5.2 Volume Delay Curves from Scenario 1
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stability of traffic assignment is unique by iteration. The static traffic assignment results oscillate or flip-flop from one iteration to the next between alternating shortest paths.

This approach attempts to minimize differences between differently loaded networks due to oscillations by fixing the number of iterations, preventing different assignments from stopping at different iterations.

Once the STA scenario (Scenario 1) simulation was done on Cube Voyager, the regional loaded network was exported from Cube Voyager to Cube Avenue along with all the network attributes. The network with the attribute data files from Cube Voyager was then used by Scenario 2 and 3 for mesoscopic simulation in Cube Avenue.

5.5.3 Dynamic Assignment

Cube Avenue is a dynamic equilibrium assignment model. Cube Avenue loads and tracks the movement of vehicle platoons throughout the highway network. Vehicle packets can be any size ranging from an individual vehicle up to platoons of several vehicles. Cube Avenue explicitly simulates traffic flow and traffic control systems. It models traffic signals, roundabouts, stop-controlled intersections, and ramp merges.

Through an iterative process, Cube Avenue calculates optimal network conditions based on user-defined travel costs. Typically, the model converges in several iterations, an extremely fast process for smaller systems and quite feasible for large urban areas. According to the Cube Avenue Manual [34], the software is capable of applying DTA to regions with over 3000 zones and 30000 links. The dynamic assignment model is programmed using the Cube scripting language.

For this research, the DTA was applied as an iterative process where drivers made the route choice, based on their travel cost in the previous run (previous day travel cost experience in real life). The best path in each run of the simulation is based on defined travel cost which was the previous iteration’s travel times. Travel cost can also be in terms of distance, toll, or any other general cost associated with trip making. The changing traffic conditions in each run may change the travel cost, which leads to more routes with lower costs in subsequent runs. For convergence, Avenue requires that all paths must have a relative change lower than the defined threshold. Acceptable convergence criteria define indicators such as verifying that 95% of all paths are within 10 to 15% (25). Other standard practices look at mean errors.

The travel time on paths was used as cost in DTA. A convergence criterion of 5% travel time difference on paths was used. For each run of DTA simulation, Cube Avenue compares the travel time on paths to the previous run. Based on the threshold, if the difference in travel time on all paths is less than or equal to 10%, the convergence criteria is met. Otherwise, the simulation continues until it reaches the maximum number of runs specified by the user or the convergence criteria, whichever comes first. Travel time information files containing travel time for each OD pair were written for every run of DTA simulation using the output processing features of Cube Avenue. DTA-based Scenario 2 and 3 met the set convergence criteria after 95 iterations. The data from the 95th iteration of STA-based Scenario 1 were used in comparisons for consistency on comparisons.

5.5.4 Signal Control Emulator

A National Electrical Manufacturers Association (NEMA) Standard Signal Control Emulator was used for traffic controls in test scenarios. This controller is embedded in Cube Avenue and emulates common signal controllers used in North America. With this controller, Cube Avenue can simulate fully actuated signal control as well as coordinated and vehicle-actuated coordinated signal control. Traffic control programs for each intersection in the study area network were coded in Cube Avenue.

5.5.5 Traffic Controls

Scenario 1 was a traditional four-step travel demand model and due to the macroscopic nature of the model, no traffic controls were included in Scenario 1. Fixed Controls and Vehicle-Actuated Controls were used in the mesoscopic Scenario 2 and Scenario 3. Fixed controls usually operate on a predetermined and repeated sequence of signal plans with fixed cycle length and splits. The signal timing plans are developed off-line and optimized based on historic data of traffic flow. A series of predetermined plans can accommodate variations in traffic volume during the day. Fixed controls are best with predictable traffic volumes.

Vehicle-actuated controls differ from fixed control because they can respond to variations in traffic flow and are typically used in situations with irregular traffic flow. The actuated controls can be grouped into two types: semi-actuated and fully actuated. Semi-actuated systems primarily apportion the green time to the major movement of traffic and minor streets are accommodated at vehicle detection. Fully actuated control systems detect vehicles on all approaches of the intersection and make adjustments according to the flow. The vehicle-actuated controls were used with the limitations that offsets and cycle lengths would not change, and only green splits within the given cycle length framework could be adjusted. The changes in green split could respond to the variation in traffic flow due to different route choices of drivers in DTA simulation.

5.6 Study Area

The study area covered the entire Wasatch Front Region, including all of the developable areas of Utah, Salt Lake, Davis, and Weber counties, with the exception of the canyons and mountains to the east of the urbanized areas. Figure 5.3 shows the study area and the TAZ structure. TAZs were mutually exclusive (they do not overlap) and they cover the entire model region. The model is a zone-based forecasting tool, modeling travel between aggregate Transportation Analysis Zones (TAZ).

The 2007 road network used for the model included all facilities functionally designated as collector or higher functional class by the Utah Department of Transportation (UDOT). There are approximately 25,000 road links in the base year network and over 13000 nodes, and 2250 zonal nodes. For this research work, 60 signalized intersections and 60 intersections with 4-Way stop signs were selected from the areas with high traffic congestion. Out of the 60 signalized intersections, 30 were

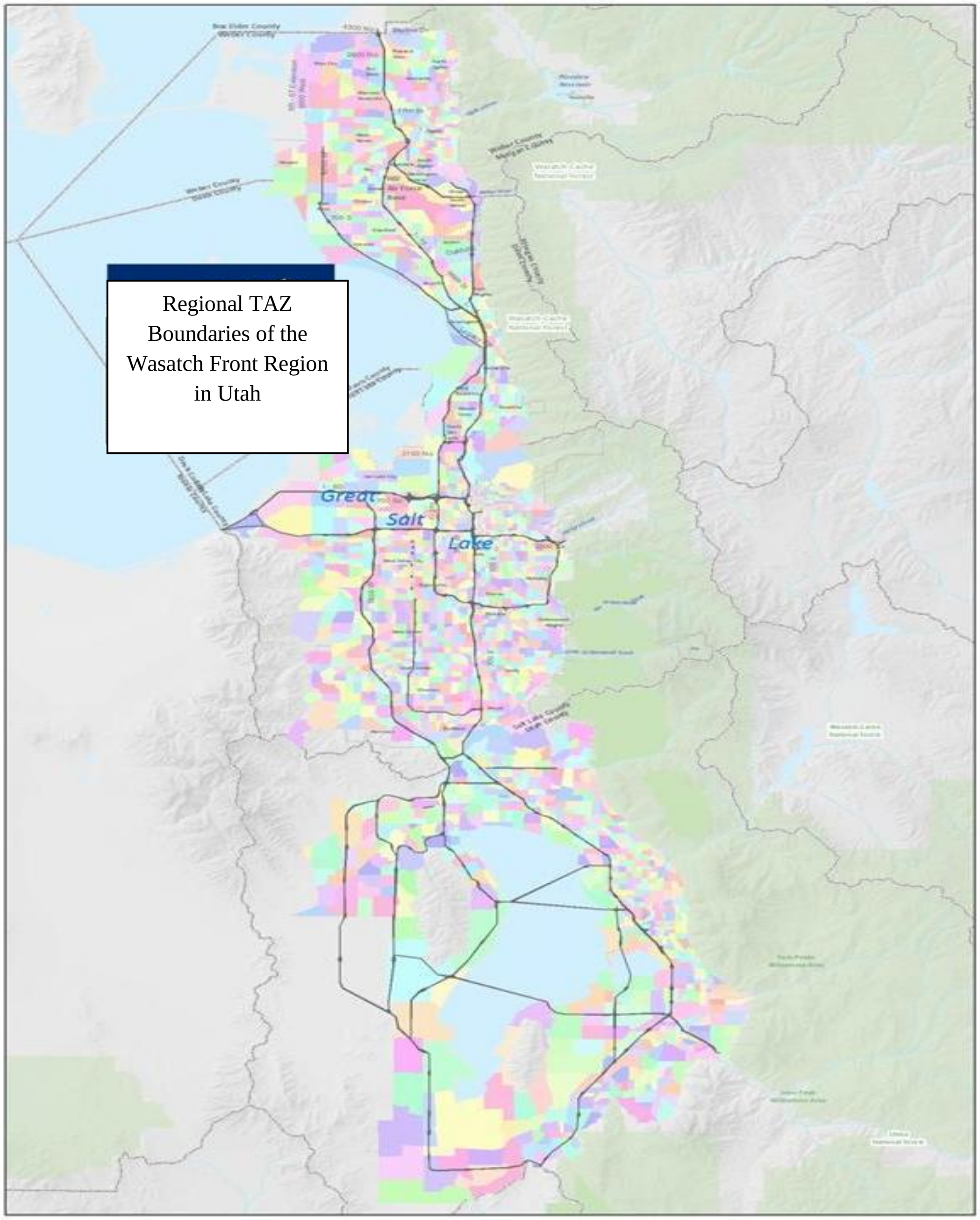

Figure 5.3 Wasatch Front Region Traffic Area Zones
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located in the urban core of Salt Lake County, 10 in the urbanized area of Weber County, 10 in the urbanized area of Davis County, and 10 in the urbanized area of Utah County. The same proportion was allocated to 4-Way stop signs among the four counties. Figure 5.4 shows a portion of the model's road network covering the Kaysville area.

5.7 Cube Voyager-Based Travel Demand Model

The model is based on a traditional four-step modeling process consisting of trip generation, trip distribution, mode split, and trip assignment steps. The model incorporates these steps and adds an auto ownership step that is sensitive to urban design variables and transit accessibility.

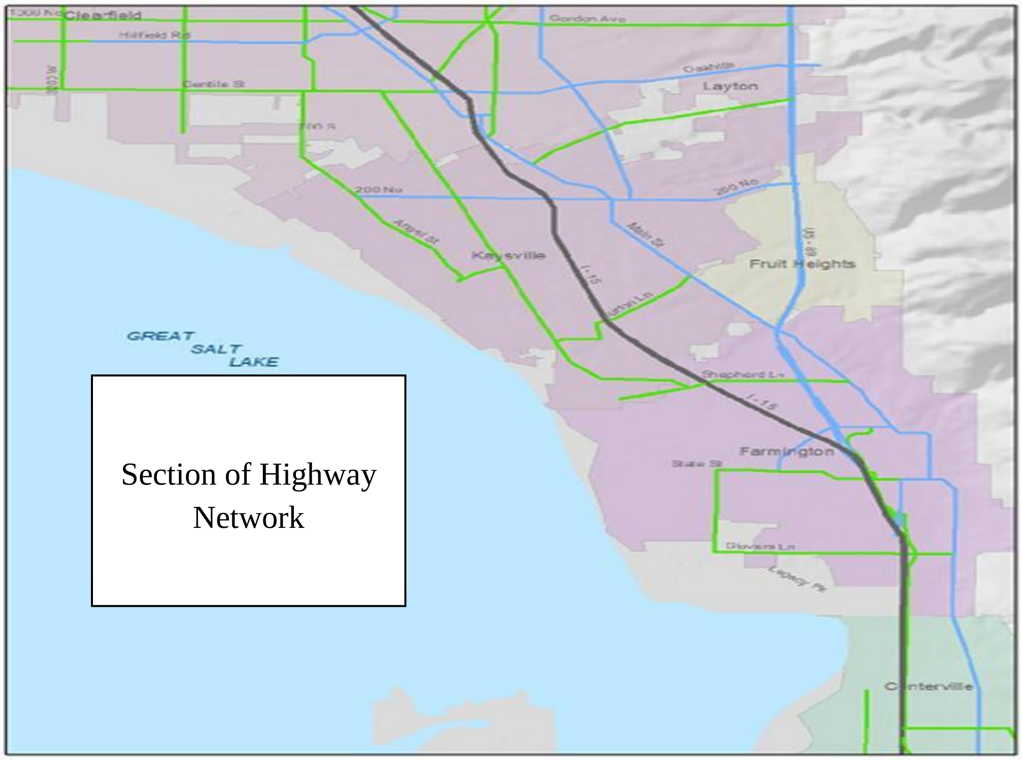

Figure 5.4 Snapshot of 2007 Street Network
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The model has a feedback loop between trip distribution and traffic assignment, which is a process that ensures consistency between travel congestion and times that influence trip distribution patterns and that are an outcome of trip assignment. Travel time is calculated based on outputs from the assignment step, but also is an important determinant of trip distribution and mode split.

Therefore, it is customary to iterate these steps in order to reach a convergent solution. Figure 5.5 outlines the various steps of the travel demand model used in Scenario 1. At the start of a model run, the auto ownership model estimates household auto ownership levels. The trip generation model then estimates trip-ends by TAZ based on household and employment characteristics. These trip-ends are then paired into trips in the trip distribution model.

In the mode choice model, a mode of travel is identified for each trip. Vehicle trips are assigned to the highway network in the trip assignment model, during which congestion levels on each road are estimated consistent with route choices. The travel time feedback loop in the model is run to a convergent solution prior to running mode choice. The origin-destination matrix postmode-choice step was exported to Cube Avenue in order to include the impact of all trips in the region.

5.8 Time Periods

The trip generation and trip distribution models are daily models, while the mode choice model distinguishes peak and off-peak periods, and the traffic assignment model estimates traffic flows for four periods of day:

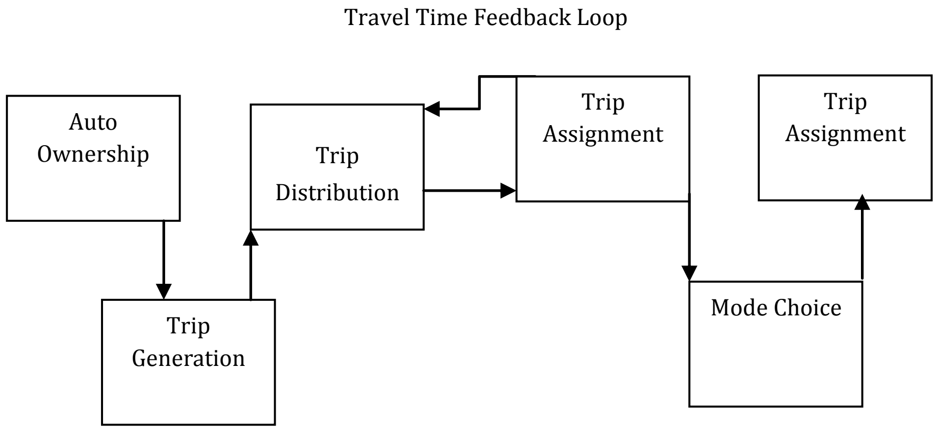

Figure 5.5 Different Steps of Cube-Based Model
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- a.m. Peak: 6-9 AM
- Midday: 9 AM – 3 PM
- p.m. peak: 3-6 PM
- Evening/Off-peak: 6 PM – 6 AM

At the end of the STA-based scenario, the OD matrix for each peak period was exported for use by Cube Avenue software in DTA-based scenarios.

5.9 Calibration and Validation of the Models

The regional travel demand model base-run in Cube Voyager with static assignment and no traffic controls (Scenario 1) has been calibrated and validated by WFRC to represent 2007 travel conditions and patterns by adjusting model input data, assumptions, and parameters so that the final outputs more closely match observed data.

The Cube Avenue base-run with DTA- and vehicle-actuated controls (Scenario 3) was calibrated for the mesoscopic traffic assignment simulation process. The mesoscopic assignment model was calibrated for speeds, and travel time data, and was also validated" against field counts data. Figure 5.6 part a) and part b) show the postvalidation comparison of field counts with modeled volume. In both cases of Scenario 1 and Scenario 3, the field counts closely matched with modeled volume with R^2 = 0.9444, and R^2=0.952, respectively.

In addition to field counts vs. modeled volume comparison in Scenario 1 and Scenario 3, the model output was compared with field counts aggregated by peak periods at selected locations. The 2007 base-run peak period count data were collected from WFRC's archived data inventory and was transferred to the Cube Voyager and Cube Avenue loaded networks. Table 5.2 part a) and part b) show the validation summary for Scenario 1 (Cube Voyager-based scenario) and Scenario 3 (Cube Avenue-based scenario with Vehicle-Actuated Controls). The table shows that in both Scenario 1 and Scenario 3, the percent error was consistent within peak periods. The percent error was 3% higher in case of arterials in a.m. Peak, and by 2% in p.m. peak.

The model output was also compared for Root Mean Square Error (RMSE), and Average Error. The RMSE is a measurement of error that weights the larger errors by more than they would be in an average error computation. The percent RMSE compares the RMSE statistic to the average observed value. The RMSE is always higher than the actual average network error because of the weighting. The percent RMSE should generally be less than 40%, overall, with higher values acceptable for low volume links and lower values expected for high volume links (37).

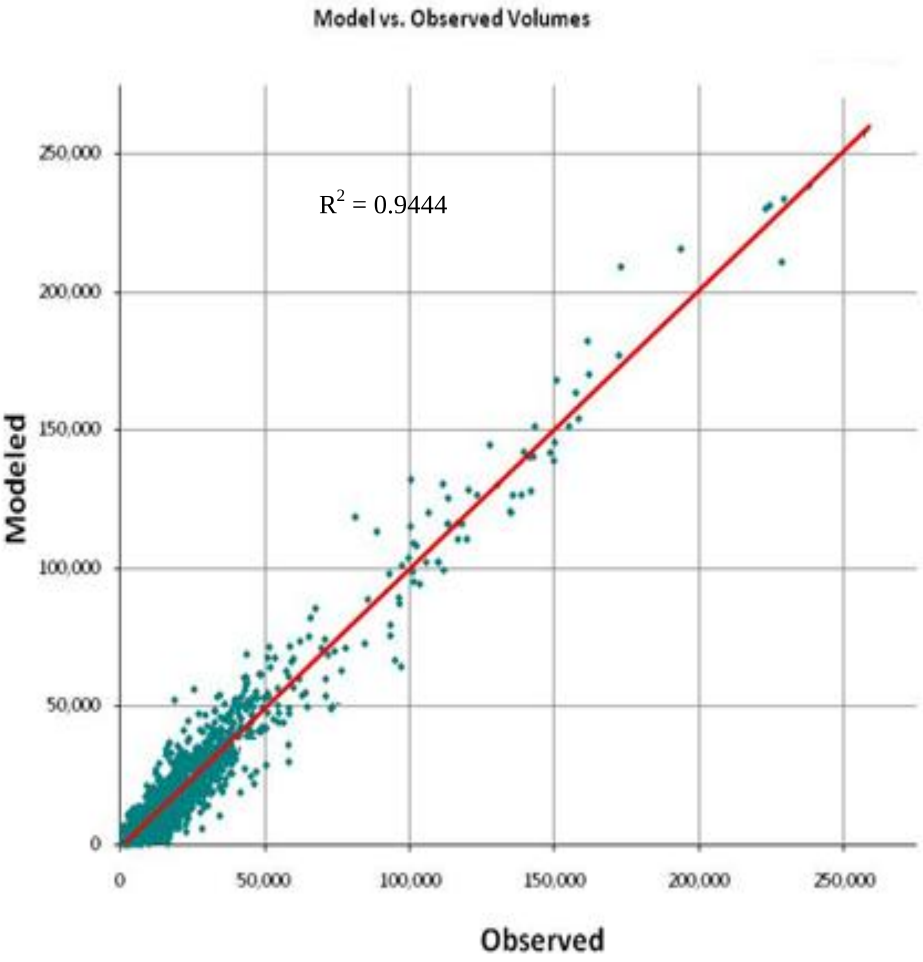

Figure 5.6 Correlation between Modeled Volume and Field Counts (a) Model vs. Counts from Scenario 1 (b) Model vs. 2007 Counts from Scenario 3

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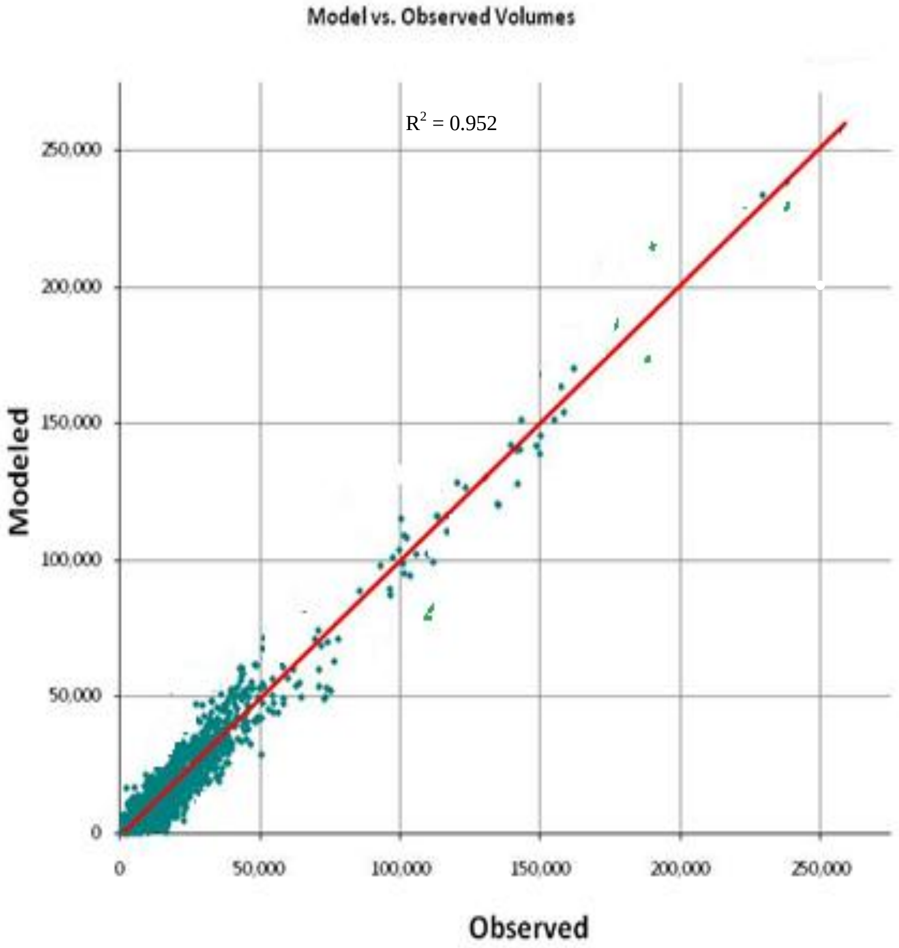

(b)

Figure 5.6 Continued

Table 5.2 Test Scenarios a) Scenario 1 Validation Summary b) Scenario 3 Validation Summary

a)

	Cube Voyager							
Period	Modeled	Counts	Vol Dif	Vol % Error	Model Pct	Count Pct	Pct Diff	Pct Error (%)
All Roadways								
AM	925,856	844,354	81,502	9.7%	18.8%	18.1%	0.74	4.09
PM	1,223,262	1,099,117	124,145	11%	24.8%	23.5%	1.33	5.65
Daily	4,926,848	4,676,910	249,938	5%				
Freeways								
AM	696,035	657,098	38,937	6%	19.1%	19.1%	-0.08	-0.40
PM	899,351	797,369	101,982	13%	24.6%	23.2%	1.41	6.05
Daily	3,650,577	3,432,506	218,071	6%				
Arterials								
AM	229,821	187,256	42,565	23%	18.0%	15.0%	2.96	19.67
PM	323,911	301,748	22,163	7%	25.4%	24.2%	1.13	4.66
Daily	1,276,271	1,244,404	31,867	3%				

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b)

	Cube Avenue							
Period	Modeled	Counts	Vol Dif	Vol % Error	Model Pct	Count Pct	Pct Diff	Pct Error (%)
All Roadways								
AM	957,792	844,354	113,438	13.4%	18.9%	18.1%	0.88	4.89
PM	1,292,118	1,099,117	193,001	18%	25.5%	23.5%	2.04	8.70
Daily	5,058,139	4,676,910	381,229	8%				
Freeways								
AM	703,249	657,098	46,151	7%	19.1%	19.1%	-0.04	-0.21
PM	890,082	797,369	92,713	12%	24.2%	23.2%	0.95	4.08
Daily	3,681,496	3,432,506	248,990	7%				
Arterials								
AM	239,334	187,256	52,078	28%	18.4%	15.0%	3.39	22.50
PM	334,446	301,748	32,698	11%	25.8%	24.2%	1.51	6.23
Daily	1,298,392	1,244,404	53,988	4%				

The sum of differences is the average error of the network. This measure is usually expressed as a percent error. Figure 5.7 shows the average percentage error across the three scenarios tested. The modeling literature on model calibration (37) recommend an average error for VMT and overall traffic volumes between +/-7% for freeways, +/-10% for major arterials, and +/-15% for minor arterials. It is common for regional travel models to perform relatively poorly on minor arterials, collector roads, and local roads, where the count data resolution is not better.

5.10 Analysis and Results

The simulated speed from mesoscopic Scenario 3 was also compared to field counts during the calibration process. In order to evaluate the benefits of implementing the combining traffic assignment and traffic controls framework on a regional scale, the system-wide delay among the three scenarios, and modeled vehicle miles traveled (VMT) were compared to VMT estimated by the highway performance monitoring system (HPMS). The HPMS is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the nation's highways. The HPMS contains administrative and extent of system information on all public roads, while information on other characteristics is represented in HPMS as a mix of universe and sample data for arterial and collector functional systems. HPMS was developed in 1978 as a continuing database, replacing the special biennial condition studies that had been conducted since 1965. The HPMS has been modified several times since its inception to reflect changes in the highway systems, legislation, and national priorities, to reflect new technology, and to consolidate or stream line reporting requirements. The HPMS Data on VMT was collected from UDOT by Geography.

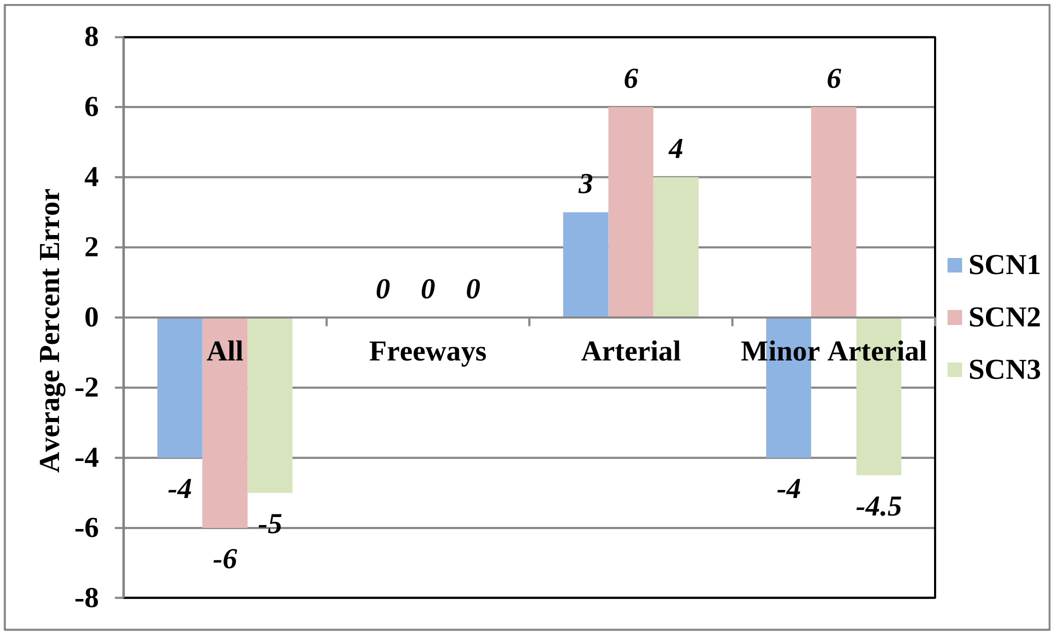

Figure 5.7 Average Percentage Error from Scenarios

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5.10.1 <u>VMT Comparison by Geography</u>

One of the key measures used in scenario analysis of regional travel models is vehicle miles traveled. According to the U.S. Bureau of Transportation Statistics, VMT is a good indicator of roadway use, and traffic congestion in a traffic system. VMT is the total number of miles driven by all vehicles within a given time period and geographic area. It is used by regional transportation and environmental agencies for planning purposes.

Average weekday vehicle miles traveled were reported as postprocessed data in all three scenarios through a postprocessing script written in Cube scripting language. Table 5.3 shows the comparison of VMT by functional type of highway, and by regional geography. The comparison shows that the combined traffic assignment and control

Table 5.3 Vehicle Miles Traveled Comparison by Geography

Geography	Source	SCN1		SCN2		SCN3	
		Freeway	Arterial	Freeway	Arterial	Freeway	Arterial
Weber County	Modeled	1,132,965	2,399,978	1,126,369	2,491,156	1,088,952	2,555,718
	UDOT	1,105,608	2,638,403	1,105,608	2,638,403	1,105,608	2,638,403
	% Diff	2.50%	-9.00%	1.88%	-5.58%	-1.51%	-3.13%
Davis County	Modeled	3,491,514	2,451,049	3,521,564	2,266,917	3,411,790	2,317,712
	UDOT	3,508,552	2,436,777	3,508,552	2,436,777	3,508,552	2,436,777
	% Diff	-0.50%	0.60%	0.37%	-6.97%	-2.76%	-4.89%
Salt Lake County	Modeled	10,142,361	11,763,713	9,839,453	10,409,147	9,603,245	10,779,213
	UDOT	9,730,230	11,321,725	9,730,230	11,321,725	9,730,230	11,321,725
	% Diff	4.20%	3.90%	1.12%	-8.06%	-1.31%	-4.79%
Utah County	Modeled	4,025,398	4,949,700	4,122,798	4,553,908	3,986,721	4,511,609
	UDOT	4,072,782	4,637,565	4,072,782	4,637,565	4,072,782	4,637,565
	% Diff	-1.20%	6.70%	1.23%	-1.80%	-2.11%	-2.72%
Region	Modeled	18,792,237	21,564,440	18,610,184	19,721,128	18,090,708	20,164,252
	UDOT	18,417,172	21,034,470	18,417,172	21,034,470	18,417,172	21,034,470
	% Diff	2.00%	2.50%	1.05%	-6.24%	-1.77%	-4.14%

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framework implemented for this paper lowered the regional VMT by up to 7% on Davis County arterials. On a regional scale, the CTAC framework lowered the VMT by 2% in Freeways, and by 4% on arterials.

5.10.2 Delay Reduction by Functional Type

In addition to the VMT, the daily delay statistics from the three scenarios were compared on the county level as well on a regional scale. Table 5.4 outlines the daily delay in hours by geography. The output data on delays in Table 5.4 shows that the mesoscopic traffic assignment based on the CTAC framework with DTA simulations and vehicle actuated controls (Scenario 3) reduced the delay up to 6.97% in subregions like Davis County, and reduce the overall regional delays by 5.3%.

Both Table 5.3 and Table 5.4 show that the Combined Traffic Assignment and Control Framework-based simulation help reduced the regional VMT and regional delays compared to traditional travel demand models without traffic controls and combined framework.

Table 5.4 Delay by Geography (Hours)

Scenario	WE	% Diff	DA	% Diff	SL	% Diff	UT	% Diff	RE	% Diff
SCN 1	4,797		7,280		39,956		12,454		64,483	
SCN 2	4,602	-4.1	7,119	-2.2	38,401	-3.9	12263	-1.5	62,385	-3.3
SCN 3	4,234	-12	6,791	-6.7	38,131	-4.6	11897	-4.5	61,053	-5.3

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5.11 Limitations and Future Research

The test network had only 60 signalized intersections region-wide selected from high congestion urbanized areas. The study can be expanded by adding more signalized intersections on the same set up. Only fixed controls and vehicle-actuated controls were used in this study. More tests can be done with adaptive traffic controls. Similar tests can be done using other software capable of simulating DTA and mesoscopic simulations. A computer with an Intel ® Core ™ 2 QUAD CPU with a 2.66 GHz processor and 3.24 GB of RAM was used to perform simulations. For larger networks from other regions, it may take more time for convergence on the same computer. However, should the development trends continue, this may prove a smaller obstacle to researchers.

5.12 Conclusion

The chapter evaluated the benefits of the CTAC framework implemented regionally in comparison to the regional travel demand model without traffic controls. A regional network covering the Wasatch Front Region of Utah was used to test three scenarios. The CTAC framework-based mesoscopic simulations used in the tests were able to capture interaction between drivers' route choices and flow responsive traffic controls.

The regional VMT and regional delays reduced in CTAC-based scenarios. The results suggest that the CTAC framework can be implemented on the regional scale networks. If implemented on regional travel models, the CTAC framework can help reduce VMT and reduce regional delays by over 6%. With growing use of new methods to mitigate traffic congestion, the need for modeling methods that capture control-driver interaction is growing. CTAC models, therefore, can play an important role in regional congestion mitigation projects in practice.

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CHAPTER 6

CONCLUSION

The need for more efficient traffic systems is commensurate with the demands of an increasing driving population. The last three decades have seen a dramatic increase in vehicle miles traveled, yet without the same accommodation in transportation infrastructure. Several metro areas around the globe have given up on the ideas of expanding existing transportation facilities as part of traffic congestion mitigation efforts just because there simply is no room for expansion, and the solutions proposing expansion in already built up areas are not cost effective and efficient anymore. The transportation planning agencies are looking into innovative ways to deal with the traffic congestion crisis. From the perspective of traffic simulation models, the CTAC-based modeling frameworks are a step in the right direction.

This chapter will summarize the conclusions of the research on the benefits of CTAC models. The chapter will look into the conclusions from each chapter as well as present an overall conclusion of the research in sections ahead.

6.1 Review of Research Goal and Objectives

The goal of this research was to show the benefits of the CTAC modeling framework using microscopic and mesoscopic simulations-based evaluations. The CTAC models are a class of models that combine traffic assignment and intersection signal control into a single analysis framework under the assumption of flow-responsive signal settings.

The most significant feature of these models is their capacity to take into account explicitly the mutual interactions between signal control policies and user route choices; such interactions are usually disregarded both in ordinary traffic assignment models and in traditional traffic engineering practice. The objectives of this research involved evaluating different CTAC-based scenarios with STA and DTA with the possibility of improvements in traffic signal controls across several scenarios, and different geographic resolutions. The following section summarizes previous chapters' conclusions within the overall context of the research goal.

6.2 Summary of Research Conclusions

The CTAC models have been the topic of extensive research for last three decades. Several solution algorithms, modeling formulations, and implementation efforts are well documented. The previous research emphasizes the use of the CTAC models for real-life projects yet very little is done in engineering practice when it comes to the implementation of this modeling technique. This research work evaluated the CTAC modeling framework for total travel time benefits and total delay reductions in traffic systems of different sizes. Finally, the CTAC modeling framework was also developed on a regional network (mesoscopic) and was evaluated in comparison to a traditional travel demand model. For mesoscopic evaluations, the system-wide delays and VMT were compared.

Chapter 2 presented a practical perspective on the benefits from the CTAC models by studying the impacts of providing network travel time information to drivers for route choice in comparison to improvements in traffic controls. Two portions of the network from Salt Lake City, Utah were used. The test results suggest that providing drivers with network travel time information for route choice alone can substantially reduce the total delays in a traffic system. While the traffic assignment and traffic control improvements are typically taken as two separate processes in practice, the CTAC framework used in these tests was able to combine the two processes in a single framework for the study area tested.

Chapter 3 explored the benefits of providing the drivers information on prevailing travel times in a traffic system while en-route. The chapter outlines the research which evaluated the benefits of RGS using a VISSIM-based RGS system in a CTAC model. The benefits were quantified in terms of travel time improvements and delay reductions. Eleven scenarios were tested, starting from 0% RGS-equipped demand in Scenario 1 to 100% RGS-equipped demand in Scenario 11. The test results suggest that providing drivers with the information on prevailing traffic conditions may impact their route choice, and in turn help improve the system-wide total travel time and reduce total delay. The test results also suggest that the travel time and delay benefits were the minimum when the proportion of RGS-equipped demand was the minimum (10%), and the benefits were the maximum when 100% of the traffic demand was RGS-equipped. The chapter also emphasized that further studies were needed to investigate the RGS for drivers' response behavior to RGS-based information and on how accurately the prevalent traffic conditions information could be relayed to the drivers through RGS.

Chapter 4 evaluated the benefits of providing network travel time information to drivers from their past travel experience in comparison to improving traffic controls from fixed controls to ATCS. A network in Park City, Utah was used to test six scenarios using the VISSIM microsimulator. The results suggest that the provision of network travel time information to drivers from their past travel experience alone reduced the total system wide delays by 19% and improved the system-wide total travel time by 16%. In addition, the traffic control improvements from Fixed-Time to Adaptive Controls alone reduced the total system-wide delay by 26% and improve the system-wide total travel time by 18%. Also, the provision of network travel time information to drivers from past travel experience combined with improvements of fixed-time controls to adaptive controls reduced the total delay by 52% and improve total travel time by 35%.

Chapter 5 evaluated the benefits of the CTAC framework implemented regionally in comparison to the regional travel demand model without traffic controls. A regional network covering the Wasatch Front Region of Utah was used to test three scenarios. The CTAC framework-based mesoscopic simulations used in the tests were able to capture interaction between drivers' route choices and flow responsive traffic controls. The results showed that the region-wide vehicle miles traveled and region-wide delays reduced in CTAC-based scenarios. The results suggest that the CTAC framework, if implemented on regional travel demand models, can help reduce the VMT and reduce regional delays by over 6%. The chapter concluded that with growing use of new methods to mitigate traffic congestion, the need for modeling methods that capture control-driver interaction is growing. CTAC models, therefore, can play an important role in regional congestion mitigation projects in practice.

6.3 Contributions of the Research

The contribution of this research on the benefits of CTAC models shows that CTAC models offer superior modeling framework for micro- and mesoscopic simulations in comparison to conventional modeling techniques in practice. The CTAC evaluations in both micro- and mesoscopic levels confirm the similar performance advantage in terms of travel time improvements, and delay reductions benefits. The results show that the CTAC models are a viable alternative to traditional modeling techniques, and have benefits over conventional modeling methods being used in practice. Therefore, the research goal was achieved: the CTAC modeling framework, if implemented in practice, can help traffic systems improve their travel times, and reduce delays.

6.4 Recommended Future Research

Microsimulation modeling has reached a new level of sophistication and realism. Its advances make possible additional investigations into related research areas. One such area that could benefit from continued research is integration of traditional travel demand models with the CTAC modeling framework. CTAC models, if implemented on regional four-step travel demand models, could add a fifth step to the modeling sequence, where the final assignment step (4th step) can be integrated with the CTAC model (5th step) or it can also be part of the final assignment if necessary. The integration will provide the modelers results that can be used for regional transportation planning as well as for traffic congestion mitigation efforts in a single framework. Once integrated to travel models, the CTAC framework can also be used to evaluate the future projections. Implementation of CTAC framework in a multimodal environment is another open avenue for research. Additional mesoscopic evaluations using other available simulation software for different performance measures can be performed. For example, impacts of CTAC models on air quality, impacts on use of public transportation, and the impacts on CTAC evaluations by changes in land-use patterns can be explored.

APPENDIX

REGIONAL MODEL CALIBRATION IN CUBE AVENUE (SCENARIO 3)

A.1 Regional Screen Line Calibration (Part of Mesoscopic Calibration)

The traffic assignment-based modeled volumes from Scenario 1 (Voyager Base Scenario) and Scenario 3 (Avenue Base Scenario), were compared across the modeling region. Figure A.1 outlines the large screen lines for the Wasatch Front Region.

Figure A.1 Large Screen Lines for Wasatch Front Region

Screen lines are sections of parallel roads identified in a user-specified area with unique identification numbers. In regional models, the aggregated screen line volumes help reasonableness of aggregated flows. Screen lines are often associated with physical barriers such as rivers or rail- roads; however, jurisdictional boundaries such as county lines that extend through the study area make excellent screen lines.

The large screen line network attributes from Scenario 1 (Cube Voyager travel model) were transferred to the Cube Avenue loaded network, and the screen line modeled volumes were compared to screen line field counts across the screen lines. Figure A.1 shows the Selected Screen Lines across the region. A total of 16 large screen lines were used across the region. Table A.1 shows the comparison of aggregate screen line volumes to aggregate screen line field counts (week day traffic).

Table A.1 Large Screen Line Comparison – Modeled vs. Field Count Comparison

Screen	Field Counts	Modeled Volume		Difference		Percent Difference	
Line	Field Counts	SCN1	SCN 3	SCN1	SCN3	SCN1	SCN 3
1	131103	116652	121221	-14451	-9882	-11%	-8%
2	233831	243351	221971	9520	-11860	4%	-5%
3	216583	208590	222963	-7993	6380	-4%	3%
4	149637	151088	143521	1451	-6116	1%	-4%
5	214584	198053	191429	-16531	-23155	-8%	-11%
6	711333	682452	669982	-28881	-41351	-4%	-6%
7	181952	208640	172214	26688	-9738	15%	-5%
8	679653	719947	621381	40294	-58272	6%	-9%
9	154515	161472	167523	6957	13008	5%	8%
10	20831	17965	23259	-2866	2428	-14%	12%
11	192658	217371	212654	24713	19996	13%	10%
12	168887	190707	182541	21820	13654	13%	8%
13	197884	206654	185224	8770	-12660	4%	-6%
14	112972	104342	118341	-8630	5369	-8%	5%
15	145745	123177	139788	-22568	-5957	-15%	-4%
16	146167	112839	127791	-33328	-18376	-23%	-13%

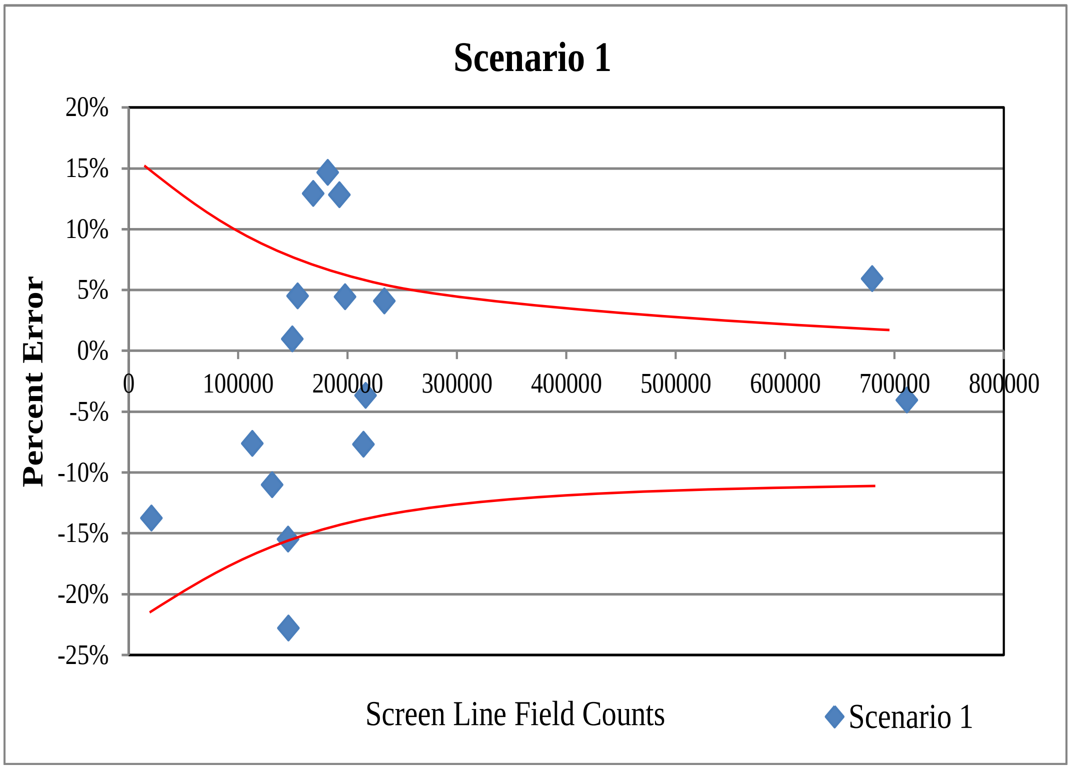
The table shows that the percent error for screen lines with large volumes was lower for screen lines with larger volumes. In regional models, screen line based comparisons help evaluate the reasonableness of aggregate traffic flows on selected sections of roads in the modeled region that intersect with screen lines. Screen lines are useful to evaluate relatively large flows moving across multiple roads and indicate in general whether the model is moving enough traffic across a certain line in the region.

Figure A.2 parts a) and b) show the percent error comparison to field counts for Scenario 1 and Scenario 3, respectively. In both Scenario 1 (travel demand model on Cube-Voyager), and Scenario 3 (CTAC-based model on Cube Avenue), as the observed traffic count across a screen line goes up, the acceptable error goes down as recommended and referenced in the National Cooperative Highway Research Program (NCHRP) Report 25.

In case of Scenario 3, all but one regional screen line comparison with -23% stood out. Overall in both scenarios, models did well with this calibration measure. The regional screen line comparison was within +/- 15% for most of the screen lines, with several within +/-8%.

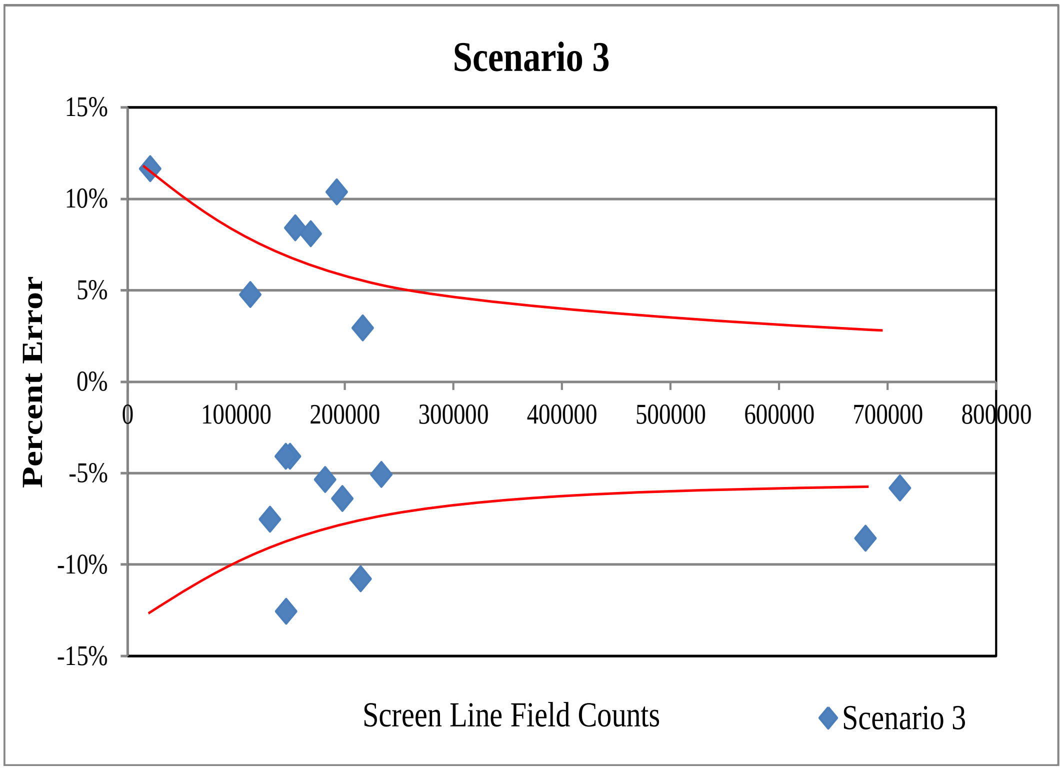
A.2 Notes on Microsimulation Model Calibration

Model calibration is defined as the process by which the parameters in the simulation model are adjusted so the model may represent field traffic conditions. The parameters of a simulation model requiring calibration include traffic control operations, traffic flow characteristics, and the behavior of drivers.



(a)

Figure A2 Large Screen Line Calibration a) Percent Error (Modeled vs. Field counts) Compared to Field Counts in Scenario 1 b) Percent Error (Modeled vs. Field counts) Compared to Field Counts in Scenario 3



(b)

Figure A2 Continued

Model calibration should not be confused with model validation. Model validation tests the accuracy of the model by comparing the modeled flow with field counts. Validation is directly related to the calibration process because adjustments in calibration are necessary to improve the model's ability to closely match field conditions.

Microscopic simulation models contain numerous independent parameters to describe traffic control operation, traffic flow characteristics, and drivers' behavior. These models contain default values for each variable, but they also allow users to input a range of values for the parameters. Changes to these parameters during calibration should be based on field-measured conditions and should be justified by the user. Unfortunately, many of the parameters used in microsimulation models are difficult to measure in the field, yet they can have a substantial impact on the model's performance.

Examples of some of these variables in microscopic simulation models could include start-up lost time, car-following sensitivity factors, time to complete a lane change, acceptable gaps and familiarity of the drivers with the network, desired speeds, and observed travel times. While transportation planning agencies collect different types of data, the ones that are readily available in the industry are observed travel times on selected routes and observed speed data. If simulation models are not calibrated and validated before the testing, the simulation results may output unrealistic estimates of the impacts on the study area. Thus, calibration and validation of simulation models are crucial steps in assessing their value in transportation policy, planning, and operations.

A.3 Evolution of CTAC Models

As the nation's traffic system becomes more congested for various periods of the day, more research in the area of intelligent transportation system and traffic assignment is needed. Traditional solutions of adding more highways to the system and widening the existing system are infeasible due to rapidly increasing demand and lack of room for expansion. For this reason, the national interest is focused on congestion mitigation methods that tend to make efficient use of existing infrastructure. Some of the key aspects of congestion management techniques include Intelligent Transportation Systems (ITS) elements that can be used by the travelers for pretrip planning and route selection. These elements include traffic control systems that can adapt to changing conditions in the traffic system in real time and play a role in driver's route choice process. This interaction between driver and traffic control can be used to improve the traffic system performance, thus reducing congestion. Combined Traffic Assignment and Control (CTAC) framework-based models can capture this control-driver interaction in traffic systems.

The Combined Traffic Assignment and Control method has been the topic of academic research for the last three decades. Several solution algorithms, model formulations, and implementation efforts have been well documented. Although proven in academic research, the use of the combined traffic assignment and control modeling framework is rare in engineering practice. Typically, the practice tends to keep Traffic Assignment and Control Optimization processes separate. By doing so, the control-driver interaction in the traffic system is ignored. Previous research found that CTAC models could capture the control-driver interaction well and the combined modeling framework should be used in practice.

This research evaluates the benefits of CTAC models. Several models were developed and tested employing different route choice and control strategies. Benefits of CTAC models were evaluated in terms of conveying near-perfect network travel time information to drivers based on their past travel experience with the possibility of improvements in traffic controls carried out. In selected experiments, various proportions of the route guidance system features were added to the combined modeling framework to evaluate the system-wide benefits of providing drivers with network travel time information under prevailing traffic conditions.

CTAC models have been continuously evolving for the last three decades. With all the complexity they carry in the model implementation process, the models can be further investigated in three basic avenues described as follows:

1. Integration with traditional four-step travel demand models as a fifth step to the modeling process.
2. Integration of the models with real-world signal controls instead of hand-coding the control programs to the modeling software.
3. Implementation of the CTAC models to evaluate the benefits of different traffic operations features. For example:
    a. Benefits of dynamic message signs to the congested urbanized are in a traffic system.
    b. Capacity improvements to bottle necks in traffic systems
    c. Integrated traffic signal optimization for future year model runs during the model stream to account for growth in traffic flows of future years.

CTAC models, though they show benefits in terms of travel time improvements and delay reductions, demand more time for the input development process. Without automation of the data coding process, these models can be very tedious to develop in the modeling practice.

More scientific research is therefore needed in integration and automation of the model development process of CTAC method of modeling.

A.4 References

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