A MODELING APPROACH FOR EVALUATING NETWORK IMPACTS OF OPERATIONAL-LEVEL TRANSPORTATION PROJECTS

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Thesis submitted to the Faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil and Environmental Engineering

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May 9, 2000
Blacksburg, Virginia

Keywords: Intelligent Transportation Systems (ITS), INTEGRATION, Microscopic Simulation, Metropolitan Model Deployment Initiative (MMDI), Signal Coordination, Simulation Modeling

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(Abstract)

This thesis presents the use of microscopic traffic simulation models to evaluate the effects of operational-level transportation projects such as ITS. A detailed framework outlining the construction and calibration of microscopic simulation models is provided, as well as the considerations that must be made when analyzing the outputs from these models. Two case studies are used to reinforce the concepts presented. In addition, these case studies give valuable insight for using the outlined approach under real-world conditions.

The study indicates a promising future for the use of microsimulation models for the purpose of evaluating operational-level projects, as the theoretical framework of the models is sound, and the computational strategies used are feasible. There are, however, instances where simulation models do not presently model certain phenomena, or where simulation models are too computationally intensive. Comprehensive models that integrate microscopic simulation with land use planning and realistic predictions of human behavior, for instance, cannot practically be modeled in contemporary simulation packages. Other than these instances, the largest obstacles to using simulation packages were found to be the manpower required and the complexity of constructing a model. Continuing research efforts and increasing computer speeds are expected to resolve the former issues. Both of the latter concerns are alleviated by the approach presented herein. Within the approach framework detailed in this thesis, particular emphasis is given to the calibration aspects of constructing a microscopic simulation model. Like the simulation process as a whole, calibration is both an art and a science, and relies on sound engineering judgement rather than indiscriminate, formulaic processes.

Acknowledgements

I would like to express my sincere gratitude to Hesham Rakha, Alejandra Medina, and Françios Dion for their helpful and caring tutelage. They were all wonderful mentors, and an invaluable asset to my education. I would also like to thank Dr. Rakha for providing me the opportunity to work with him and the other great researchers at the Virginia Tech Transportation Institute.

My fellow transportation students, too, were an inspiration to me. Each provided me with new ideas, both about my work and about life. Working closely with them as their research progressed complemented my work and my personality. I am grateful for the time we had together.

I would also like to thank all of my friends, both those whom supported me through the years, and those whom I have met during the past two years. My time in Blacksburg has been truly memorable and enjoyable; I treasure the friendships that have made this possible.

Finally, I would like to thank my family for their unending love and encouragement.

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CHAPTER 1: INTRODUCTION

1.1 Overview

Traffic simulation is a powerful tool for determining the benefits and impacts of transportation projects. Simulation is less expensive and safer than on-line tests, and not only provides transportation engineers with the ability test the feasibility and performance of a system before it is implemented, but also to optimize the proposed system.

As in all fields that use computers as a tool, traffic simulation will become easier, more powerful, and more comprehensive as computing power increases. This does not mean simulation will become any less complex. In fact, special care should be taken so that the underlying structure of the model—the most important part—is not being neglected for the sake of scale, detail, or extraneous information. Simply put, simulation is useless without sound techniques and common sense.

1.2 Problem Definition

Given the ever-increasing computing power available to the general public, the increasing ease of using computer programs, and the fact that a microscopic simulation tool provides a model that is both more precise and readily adapted to special cases, it seems a forgone conclusion that microscopic simulation be used in favor of other, more approximate, techniques. The increasing detail in these simulation models, however, means that these models are less forgiving of modeler errors and more difficult to calibrate.

For these reasons, and because of unforeseen complications, simulation projects invariably are more complex and require more man-hours than anticipated. Therefore, all simulation projects should begin with thorough and exhaustive planning, so that the manpower committed to the projects is used in the most productive and efficient manner. Also, every effort should be made to compile and present the outputs of this effort in a well-organized, logical way, so that they can be used for future projects.

1.3 Thesis Objective

The objective of this thesis is to provide a well-founded, comprehensive, and universal description of the progressive steps of using microscopic simulation to evaluate operational-level transportation projects. This approach is intended to provide a timeless framework for this process, one unchanged by changing technology and theory.

1.4 Thesis Contributions

This thesis presents an approach for evaluating the network impacts of operational-level transportation projects. Although future modeling efforts will incorporate land use and other planning issues, they are not addressed in this document, as the techniques required to do so have not been developed adequately. Indeed, modelers still find many refinements to the independent operational and planning models are necessary. In pursuing these refinements, however, transportation professionals can attempt to make the inevitable transition as seamless as possible.

1.5 Thesis Layout

The following chapters will present a literature review, outline an approach, review two case studies employing the approach, and discuss the implications of the findings as well as likely areas of future interest. The literature review contains insights gleaned from much of the current literature, particularly the literature that discusses microscopic simulation considerations, because a microscopic level of detail is needed to accurately capture the sometimes subtle impacts of intelligent transportation systems. Following the literature review, a thorough discussion of the ideal approach and framework for microscopic simulation on a network scale. Two case studies using the approach are then presented, with particular attention paid to the impacts of the ITS and signal timing strategies applied. Finally, a brief summary and discussion of the findings is presented.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review is a survey of material addressing the use of simulation to evaluate operational-level transportation projects. The generally accepted requirements for successfully conducting a simulation are reviewed, with emphasis placed on documents addressing the construction and calibration of simulation models. The relative merits of different simulation strategies as they apply to evaluating operational-level transportation projects such as intelligent transportation systems (ITS) are discussed, as are commonly used simulation strategies and procedures. More time is devoted to the discussion of microscopic and mesoscopic simulation practices, as macroscopic simulation simply cannot capture the sometimes subtle impacts seen from operational-level deployments.

While microscopic simulation is needed to give the most complete description of the effects of an ITS project, there is a place for less detailed techniques.

> "[The]…needed complexity of the evaluation depends upon the intended end use of evaluation results…For example, one may need an extremely sophisticated evaluation framework if the true economic impact to society is to be determined. A less complex evaluation framework may suffice, however, if the results are used to prioritize ITS projects or track annual results or progress toward goals. The cost of ITS evaluation may also be a limiting factor in terms of complexity and sophistication. In some cases, concerns about the cost of ITS evaluations have even prevented them from being conducted. Complex evaluation frameworks may appear conceptually sound on paper but be prohibitively expensive to perform, thus leading to little or no project evaluation." (Turner and Stockton, 1999)

The body of literature describing projects employing simulation is extensive, but very little literature is devoted exclusively to discussing the best practices for traffic simulation, especially a comprehensive description of the construction and calibration of microscopic simulation models. Due to the dearth of literature aimed at defining and presenting the best practices for approaching simulation, case studies were used to supplement the available information. These actual applications must, however, frequently deviate from the ideal approach. This document will only present the ideal approach. Any concessions to this approach or adaptations necessitated by real-world conditions must be reviewed for acceptability individually; as always, engineering judgement should supercede any prescribed procedures.

2.2 Why Simulate?

Field testing transportation projects is not always practical. Indeed, sometimes it is impossible. In these cases, numerical models must be constructed to assay the potential impacts from the proposed project. Simulation is less expensive, safer, and more flexible than field testing, and it “…allows the researcher a degree of experimental control that is not practical in actual traffic systems, as well as the ability to explore a wider range of situations than can be observed in field work" (Williams *et al*., 1987). In addition, it provides an objective framework in which to evaluate different alternatives.

The advancement of ITS technology has, in some cases, "…outpaced the planning and research to make the most effective use of them" (Thomas, 1999). In order to make good use of the available technology, the benefits of the technology need to be demonstrated, proven, and the benefits shown to justify the costs. Simulation is a good tool to do this.

Simulation shows particular promise for evaluating operational-level measures such as the implementation of Advanced Traffic Management Systems (ATMS). There is significant empirical data available for evaluating more traditional projects—like adding roadway capacity—but newer operational-level strategies such as ITS do not have this historical experience. In addition, deterministic solutions for ITS projects, if they are even solvable, cannot provide an accurate idea of the impacts of such projects. Finally, some system performance measures, such as accident rates, fuel consumption, and vehicle emissions, cannot reasonably be measured in the field.

Simulation models make it possible to quantify network performance indicators that are otherwise infeasible to measure. Air quality impacts of transportation projects have recently been the focus of much attention, particularly for those metropolitan areas that have not met the air quality standards mandated by the Clean Air Act Amendments of 1990 (CAAA) (US DOT JPO, 1999). While emissions cannot realistically be measured in the field, simulation models can predict what the emissions will be if the vehicle mix and the emissions patterns associated with each type of vehicle are known. Air quality and safety benefits are particularly important to quantify, because it has been estimated that most of the benefits from ITS implementation come in the form of increased safety rather than traditional measures such as travel time (Stewart, *et. al*., 1998).

2.3 Choosing the Type of Simulation to Use

The simulation model chosen should be appropriate for the intended application. Usually, this choice is a tradeoff between the accuracy and precision of the model and the development costs, data needs, and time required to execute the simulation. For example,

> "…practitioners would rarely use a stochastic, microscopic model to routinely assess basic intersection capacity. Neither would thoughtful practitioners use a macroscopic, deterministic model to assess reactions of the road-user population to very subtle changes in control. Going beyond this basic balance between model complexity and the required output detail is the application of one given model in situations requiring different levels of output detail. For example, some users will use microscopic models to measure subtle effects in a large network, where they are interested in the network-wide comparison of before and after performance. These same users might also use microscopic models in small networks to assess the effects of control changes on a particular traffic stream, or even on a particular class of users within that traffic stream (such as buses). Both applications may justify the use of a detailed microscopic simulation, either because of the subtlety of the effects being evaluated or because of the required output resolution." (Owen, et. al., 1996)

It may be wise to construct a more detailed model than needed, however, if there is a significant chance the model will be used for more in-depth analyses in the future.

Simulation models can be grouped into three general types: macroscopic models, mesoscopic models, and microscopic models. The following subsections discuss each of these options.

2.3.1 Macroscopic Models

Macroscopic traffic simulation models have been investigated more than microscopic and mesoscopic simulation models. They are based on aggregate descriptions of traffic flow rather than individual vehicle movements. For this reason, they require much less computing power, but are incapable of accurately predicting measures at the vehicular level, such as fuel consumption. Macroscopic models are capable, however, of measuring speed, flow, and density.

2.3.2 Microscopic Models

Microscopic models simulate vehicle-to-vehicle interactions, giving continuous or discrete speed and location data for each vehicle. This results in a more realistic representation of how vehicles actually move on a network, but requires significantly more data and computing time.

> "These models can be used to investigate a wide mix of traffic control and traffic management strategies, including pretimed or actuated signal control, sign control, special-use or general-use traffic lanes, and standard or channelized geometrics. Microscopic simulation models are designed to consider different statistical distributions for driver types, vehicle types, gap acceptance, vehicular speeds, and other factors. The ability to simulate vehicle movements in each lane and select different design and control alternatives makes them more attractive than macroscopic models. However, microscopic models require more input data than macroscopic models." (Radwan and Hatton, 1990)

One study, entitled Construction and Calibration of a Large-Scale Microsimulation Model of the Salt Lake Area, reported that data collection, network coding, and network calibration required approximately 4 person-years of effort (Rakha, *et. al.*, 1998).

2.3.3 Mesoscopic Models

Mesoscopic models incorporate aspects of both macroscopic and microscopic models, and are analogous to combined discrete and continuous (Owen, *et. al*., 1996). Usually, results from microscopic models are aggregated for use in mesoscopic models. This reduces the simulation time needed.

Mesoscopic models track individual vehicles at a level of resolution that is less than macroscopic models. For example, they do not model lane changing and car following behavior that microscopic models capture.

2.3.4 Selecting a Simulation Package

After the appropriate type of simulation package has been chosen, a simulation package needs to be selected. No single simulation package will always be the best for the task at hand. One study that made a redundant analysis of one network using VISSIM and CORSIM, for example, concluded that "although the parallel modeling effort added credibility to the analysis results, either model alone was adequate for the analysis. A specific model cannot be recommended based on this research – both were appropriate for this study. Each has specific strengths and limitations that should be evaluated on a case-by-case basis" (Bloomberg and Dale, 2000).

A discussion of the factors that must be considered when selecting a simulation package, including a brief comparison of some common simulation packages, is presented in Section 2-4.

2.4 Choosing A Simulation Package

As mentioned in the previous section, many existing simulation packages may be adequate for a given modeling project. Each of these packages, however, has advantages and limitations. Macroscopic models, for instance, do not adequately capture the level of detail needed for the evaluation of most ITS projects, as this usually requires modeling the interactions between individual vehicles and the transportation system (Lind, *et. al*., 1999). Microscopic simulation models provide this capability. For this reason, the remainder of this chapter will focus on literature regarding microscopic simulation packages. A brief synopsis of the capabilities of some of the more common microscopic simulation packages is presented below.

2.4.1 Comparison of Simulation Packages

Fifty-seven microscopic simulation models were identified by the SMARTEST project (Bernauer, *et. al.*, 1999). The intent and purpose of the most prevalent models is summarized in Table 2-1.

Table 2-1: General Purpose of Some Common Microsimulation Packages
(Bernauer, et. al., 1997)

Urban	Motorway	Combined	Other
CASIMIR	AUTOBAHN	AIMSUN2	ANATOLL
DRACULA	FREEVU	CORSIM	PHAROS
HUTSIM	FRESIM	FLEXSYT II	SHIVA
MICSTRAN	MIXIC	INTEGRATION	SIMDAC
NEMIS	SISTM	MELROSE	
NETSIM		MICROSIM	
PADSIM		MITSIM	
SIGSIM		PARAMICS	
SIMNET		PLANSIM-T	
SITRA-B+		TRANSIMS	
SITRAS		VISSIM	
THOREAU			

As is demonstrated by Table 2-1, few of the models are intended to model both freeway and arterial facilities. Network-level application of a simulation model, however, usually requires an integrated approach. It is of primary importance, therefore, to select a model that was developed using theory appropriate for modeling both arterial and limited access roadways. Other considerations that should be made when selecting a simulation model are discussed in Section 2-4.1.1.

2.4.1.1 Capabilities

This section will present the capabilities of various microscopic simulation packages, and a short discussion of why these capabilities are important. A summary of the capabilities available in current microscopic simulation tools is presented in Table 2-2, Table 2-3, Table 2-4, and Table 2-5.

Table 2-2: Transport Telematics Studied
(Bernauer, *et. al.*, 1997)

	Co-ordinated traffic signals	Adaptive traffic signals	Priority to public transport vehicles	Ramp metering	Motorway flow control	Incident management	Zone access control	Variable message signs	Regional traffic information	Static route guidance	Dynamic route guidance	Parking guidance	Public transport information	Automatic debiting and toll plazas	Congestion pricing	Adaptive cruise control	Automated highway system	Autonomous vehicles	Support for pedestrians and cyclists	Probe vehicles	Vehicle detectors
AIMSUN2	X	X	-	X	-	X	X	X	-	X	X	-	-	X	-	-	-	-	-	-	X
ANATOLL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
AUTOBAHN	X	X	-	X	X	X	X	X	X	X	X	X	-	X	X	X	X	X	-	X	X
CASIMIR	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
CORSIM	X	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DRACULA	X	X	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X
FLEXSYT II	X	X	X	X	X	X	X	-	-	-	-	-	-	X	-	-	-	-	X	-	X
FREEVU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X
FRESIM	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
HUTSIM	X	X	X	X	-	-	-	X	-	X	-	-	-	X	-	X	-	X	X	X	X
INTEGRATION	X	X	X	X	X	X	-	X	-	X	X	-	X	X	X	-	-	-	-	X	X
MELROSE	X	X	-	X	X	-	X	-	-	X	X	-	-	X	X	X	X	X	-	X	X
MICROSIM	-	X	-	X	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-
MICSTRAN	X	X	X	X	-	-	X	-	-	X	X	X	-	-	X	-	-	-	-	-	X
MITSIM	X	X	-	X	X	X	-	X	-	X	X	-	-	X	-	-	-	-	-	X	X
MIXIC	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-
NEMIS	X	X	X	-	-	X	X	X	-	X	X	-	-	-	-	X	-	-	-	X	X
NETSIM	X	X	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
PADSIM	X	X	-	-	-	-	X	-	-	-	X	-	-	-	-	X	-	-	-	-	X
PARAMICS	X	X	-	X	X	X	X	X	X	X	X	-	-	X	X	-	X	-	-	X	X
PHAROS	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PLANSIM-T	X	X	X	X	-	-	X	X	X	X	X	X	-	-	X	-	X	-	-	X	-
SHIVA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	X
SIGSIM	X	X	X	X	X	X	-	-	-	-	-	-	X	-	-	X	-	X	-	X	X
SIMDAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
SIMNET	X	X	X	X	-	X	-	X	-	X	X	X	-	-	-	X	-	-	-	-	X
SISTM	-	-	-	X	X	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	X
SITRA-B+	X	X	X	-	-	X	-	-	-	X	X	X	-	-	-	-	-	-	-	X	X
SITRAS	X	X	-	-	-	X	-	-	-	X	X	-	-	-	-	-	-	-	-	-	X
THOREAU	X	X	-	X	-	-	-	X	-	X	X	-	-	-	-	-	-	-	-	X	X
VISSIM	X	X	X	X	X	-	-	-	-	-	-	-	X	-	-	-	-	-	X	X	X

Table 2-3: Indicators Provided
(Bernauer, *et. al.*, 1997)

	Efficiency							Safety						Environment			Comfort		Technical	Performance
	Modal Split	Travel Time	Travel Time Variability	Speed	Congestion	Public Transport Regularity	Queue Length	Headway	Overtaking	Time-to-collision	Number of Accidents	Accident Speed / Severity	Interaction with Pedestrians	Exhaust Emissions	Roadside Pollution Level	Noise Level	Physical Comfort	Stress	Fuel Consumption	Vehicle Operating Costs
AIMSUN2	X	X	-	X	-	-	X	-	-	-	-	-	-	X	-	-	-	-	X	-
ANATOLL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AUTOBAHN	-	X	X	X	X	-	-	X	-	X	X	X	-	-	-	-	-	-	-	-
CASIMIR	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-
CORSIM	-	X	X	X	X	-	X	-	X	-	-	-	-	X	-	-	-	-	X	-
DRACULA	-	X	X	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X	-
FLEXSYT II	-	X	X	X	X	X	X	X	-	-	-	-	X	X	X	-	-	-	X	-
FREEVU	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FRESIM	-	X	X	X	-	-	-	-	X	-	-	-	-	X	-	-	-	-	X	-
HUTSIM	-	X	X	X	X	-	X	X	-	-	X	X	X	X	-	-	-	-	X	-
INTEGRATION	-	X	X	X	X	-	-	-	-	-	-	-	-	X	-	-	-	-	X	-
MELROSE	-	X	-	X	X	-	X	-	-	-	-	-	X	-	-	-	-	-	-	-
MICROSIM	-	-	X	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
MICSTRAN	-	X	X	X	X	X	X	X	-	-	-	-	X	-	X	X	-	-	-	-
MITSIM	X	X	X	X	X	-	X	X	X	-	-	X	-	-	-	-	-	-	-	-
MIXIC	-	X	X	X	X	-	-	X	-	X	X	X	-	X	X	X	-	-	X	-
NEMIS	-	X	X	X	X	X	X	X	-	X	-	-	-	X	-	-	X	-	-	-
NETSIM	-	X	X	X	X	-	X	-	-	-	-	-	-	X	-	-	-	-	X	-
PADSIM	-	-	-	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
PARAMICS	-	X	X	X	X	X	X	X	X	-	-	-	-	X	-	X	-	-	X	-
PHAROS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PLANSIM-T	X	X	X	X	X	X	X	-	-	-	-	-	-	X	-	-	-	-	X	-
SHIVA	-	X	-	X	X	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-
SIGSIM	-	X	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
SIMDAC	-	-	-	X	-	-	-	X	-	X	X	X	-	-	-	-	X	-	-	-
SIMNET	-	X	X	X	X	-	X	-	-	-	-	-	-	X	-	-	-	-	X	-
SISTM	-	X	X	X	X	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-
SITRA-B+	-	X	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-
SITRAS	-	X	-	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
THOREAU	-	X	X	X	X	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-
TRANSIMS	X	X	X	X	X	X	X	X	X	-	-	-	-	X	X	-	-	-	X	X
VISSIM	X	X	X	X	X	X	X	X	X	X	-	-	X	X	-	-	-	-	X	-

Table 2-4: Objects and Phenomena Modeled
(Bernauer, *et. al*., 1997)

	Weather conditions	Search for a parking space	Parked vehicles	Elaborate engine model	Commercial vehicles	Bicycles / motorbikes	Pedestrians	Incidents	Public transports	Traffic calming measures	Queue spill back	Weaving	Roundabouts
AIMSUN2	-	-	-	-	-	-	-	X	X	-	X	X	X
ANATOLL	-	-	-	-	-	-	-	-	-	-	X	-	-
AUTOBAHN	X	-	-	X	X	-	-	X	-	X	X	X	X
CASIMIR	-	-	-	-	-	-	-	-	-	-	-	-	-
CORSIM	-	X	X	-	X	-	X	X	X	-	X	X	X
DRACULA	X	-	-	-	X	-	-	X	X	-	X	X	X
FLEXSYT II	-	-	-	-	X	X	X	X	X	X	X	X	X
FREEVU	-	-	-	X	-	-	-	-	-	-	X	X	-
FRESIM	-	-	-	-	X	-	-	X	X	-	X	X	-
HUTSIM	-	-	-	-	-	X	X	X	X	X	X	X	X
INTEGRATION	-	-	-	-	X	-	-	X	X	X	X	X	X
MELROSE	-	-	X	-	X	-	X	-	-	-	X	X	-
MICROSIM	-	-	-	-	-	-	-	-	-	-	X	-	-
MICSTRAN	X	-	X	-	X	-	X	-	X	-	X	X	-
MITSIM	X	-	X	X	X	-	-	X	-	X	X	X	X
MIXIC	X	-	-	X	-	-	-	-	-	X	-	X	-
NEMIS	-	-	-	X	X	-	-	X	X	X	X	-	X
NETSIM	-	X	X	-	X	-	X	X	X	-	X	X	-
PADSIM	-	-	X	-	-	-	-	-	-	-	X	-	X
PARAMICS	X	X	-	-	X	-	-	X	X	X	X	X	X
PHAROS	-	-	-	-	-	-	-	-	-	-	X	X	X
PLANSIM-T	-	-	-	-	X	-	-	-	X	-	X	X	X
SHIVA	-	-	-	-	-	-	-	-	-	-	-	X	-
SIGSIM	-	-	X	-	X	X	-	X	X	-	X	X	-
SIMDAC	-	-	-	-	-	-	-	X	-	X	-	-	-
SIMNET	-	-	X	X	-	-	-	X	X	X	X	-	X
SISTM	X	-	-	-	X	-	-	X	-	-	X	X	-
SITRA-B+	-	X	X	-	X	-	-	X	X	-	X	X	X
SITRAS	-	-	-	-	X	-	-	X	-	-	X	X	-
THOREAU	X	-	X	-	-	-	X	X	-	X	X	X	X
VISSIM	-	-	X	X	X	-	X	X	X	X	X	X	X

Table 2-5: Other Model Properties
(Bernauer, *et. al.*, 1997)

	Sensible default values for key parameters are provided	Key parameters can be user-defined	Limited need for data acquisition	Easy integration with other models	Easy integration with other databases and Geographic Information System	Approved by local / national transportation body	Will run on a low cost non-specialist hardware, e.g. a PC rather than a UNIX box	Quantify the typical execution speed (symbols used are F for faster, S for slower and a number to quantify the speed e.g. F 1-3 means from 1 to 3 times faster than real-time)	Graphical Network Builder	Graphical Animation of Results
AIMSUN2	X	X	-	X	X	-	PC, UNIX	-	X	X
ANATOLL	X	X	-	-	-	ESCOTA	PC	F 100	-	-
AUTOBAHN	-	X	-	X	-	-	PC	real-time	-	-
CASIMIR	X	X	X	-	-	X	PC	-	X	-
CORSIM	X	X	X	X	-	FHWA	PC	-	-	X
DRACULA	X	X	X	X	-	-	PC	F 20	-	X
FLEXSYT II	X	X	-	X	-	-	PC	F 10	X	X
FREEVU	X	X	X	-	-	-	PC	S 50%	-	X
FRESIM	X	X	X	-	-	X	PC	-	-	X
HUTSIM	X	X	X	-	-	X	PC	F 1-5	X	X
INTEGRATION	X	X	X	-	-	-	PC, UNIX, VAX	F 1-5	-	X
MELROSE	X	X	-	X	X	-	UNIX, LINUX	F 14	X	X
MICSTRAN	X	X	X	-	-	NPA	UNIX	F 5	-	-
MITSIM	X	X	X	X	X	X	PC, UNIX	real-time	-	X
MIXIC	X	X	-	-	-	X	PC	F 3	-	X
NEMIS	X	X	X	-	X	X	PC	-	-	X
NETSIM	X	X	X	X	-	FHWA	PC	-	-	X
PADSIM	X	-	X	X	X	NTCC	PC, UNIX	F 3	-	X
PARAMICS	X	X	-	X	-	-	UNIX	F 2	X	X
PHAROS	X	X	-	-	-	-	UNIX	real-time	-	X
PLANSIM-T	X	X	X	X	-	-	UNIX	-	-	X
SHIVA	X	X	X	-	-	-	UNIX	real-time	-	X
SIGSIM	X	X	X	X	-	-	UNIX	-	-	X
SIMDAC	-	X	X	-	-	-	UNIX	F 5	-	X
SIMNET	X	X	-	-	-	-	UNIX, LINUX	F 6	-	-
SISTM	X	X	-	-	-	-	PC	F 5	-	X
SITRA-B+	-	X	-	-	-	-	PC, UNIX	F 1-5	-	X
SITRAS	X	X	-	-	X	-	PC	F 1-2	-	X
THOREAU	X	X	-	-	-	-	UNIX	F 2-3	-	X
TRANSIMS	X	X	-	-	-	-	UNIX	F	-	X
VISSIM	X	X	X	-	X	GMT	PC, UNIX	real-time	X	X

The fifty-one model users surveyed by the SMARTEST project considered the following capabilities a microscopic simulation model indispensable (Lind, et. al., 1999):

- traffic signal coordination
- adaptive signal control
- dynamic route guidance
- ramp metering
- variable message signs
- vehicle priority
- vehicle detection
- incident management

Additionally, a project that developed a large-scale microsimulation model of the Salt Lake area concluded that modeling large scale networks requires a model that is capable of modeling O-D demand tables, routing traffic dynamically, and modeling the dynamic interaction of freeway and arterial facilities (Rakha, *et. al.*, 1998). Brief discussions of some of the desired capabilities listed above are presented in the following sub-sections.

2.4.1.1.1 Signal Coordination and Adaptive Signal Control

Most of the network delays and increases in fuel costs can be attributed to delays at signalized intersections (Stewart, *et. al.*, 1998). Improving signal timings can result in a dramatic increase in safety and pronounced decreases in emissions and travel times. Changing a signal timing scheme from a time-of-day or fixed-time plan to an actuated plan may improve the performance of the control strategy, because an actuated plan allows phases to end early and start late, thereby accommodating short-term variations in traffic demand. Part the advantage of an adaptive strategy is the fact that time-of-day plans are typically generated from continuous average macroscopic measures of traffic demand, but actual traffic arrivals are discrete, with deviations in demand from one cycle to the next (Stewart, *et. al.*, 1998).

It is not clear, however, what magnitude of benefits can be expected from signal improvement projects. Stewart and Van Aerde (1998) found that studies presenting the benefits of signal improvement strategies do not always clarify to what the results are being compared. "For example, it is not known whether these studies used as their benchmarks optimized time-of-day plans, or simply used some other plans that were already in place. Therefore, it is possible that any improvements, gained through the implementation of adaptive control, might also have been achieved by simply updating the time-of-day plans that were already in effect" (Stewart, *et. al.*, 1998). In fact, they suggest that implementing adaptive traffic control may, in fact, do more harm than good: "…while the largest possible benefits (+10% improvement) could be achieved using the most traffic responsive type of control, the highest dis-benefits (-10% deterioration) were also associated with the most traffic responsive controls" (Stewart, *et. al.*, 1998). Most major microscopic simulation models are capable of optimizing signal timing, and of evaluating adaptive signal control.

2.4.1.1.2 Dynamic Route Guidance

The majority of microscopic models require link flows as input. Implicit in this is the assumption that vehicle routings remain constant. Alternatively, an assignment model uses O-D data as input, and computes the link flows based on vehicle routings. In order for vehicles to change their routes mid-trip, a dynamic route-choice model is needed; this model must be run in parallel (or integrally) with the simulation model. This is important because many of the most promising ITS technologies achieve benefits by allowing vehicles to respond to changing network conditions (Bernauer, *et. al.*, 1999). For example, the benefits of ramp metering will differ is vehicles are allowed to alter their routings as queues spill back onto upstream links. As shown in Table 2-2, however, many models do not provide dynamic route guidance.

2.4.1.1.3 Ramp Metering

Ramp metering is intended to improve traffic flow by stabilizing the freeway flow, thereby reducing overall delays and accidents. Hibbard *et. al.* (1990) suggest the following possible benefits of ramp metering:

- Increased freeway speeds
- Decreased travel time and delay
- Reduced accidents from localized congestion
- Improved merging safety
- Increased utilization of freeway capacity

Ramp metering has the added benefit of limiting access during an incident, thereby decreasing the number of vehicles impacted by the incident. "When an incident is detected at a given location, ramp metering rates upstream of the incident adjust to allow fewer vehicles to enter the freeway. This results in less time needed to disperse the congestion. Ramps downstream of the congestion, conversely, should typically be metered at less restrictive rates" (Hibbard *et. al.*, 1990).

Investigating the possibility of using ramp metering is generally desirable, as many "…systems which use ramp metering experience significant improvements ranging from 7.6% to 55% in speed and between 4% and 30% in accidents" (Hibbard *et. al.,* 1990). Over half of the microscopic simulation packages reviewed by the SMARTEST project are capable of modeling ramp metering to some extent. However, only those models that include dynamic traffic assignment can model all impacts of ramp metering.

2.4.1.1.4 Driver Information and Variable Message Signs

If information is provided to drivers during their journey (via such technologies as VMS or Highway Advisory Radio, HAR), this information may entice the driver to alter their route in favor of a route that, based on the information provided, appears faster. In order to model this behavior, a simulation model must be capable of performing dynamic re-routing, as discussed in Section 2-4.1.1.2.

Simulation projects intended to capture the effects of providing drivers with en-route information often begin by estimating the market penetration of the information technology, or the percentage of vehicles that have access to the information. This percentage is particularly important for in-vehicle technologies. Because the final percentage of vehicles with access to a particular technology is usually unknown, different levels of market penetration must be evaluated. An analysis of the Ali-Scout Route Guidance System, for instance, ran six scenarios: 0, 1, 5, 10, 15, and 20% market penetration (Hadj-Alouane, *et. al.*, 1996). Furthermore, the level of compliance must be determined. Even if a "better" route is advertised to the driver, the driver may decide to use the route they are already on, especially if the driver is not familiar with the area, or if he has little confidence in the information being provided.

The effects of the driver information are usually evaluated against the base case. Sometimes, however, the base case is not congested enough to cause drivers to change their routes. For this reason, additional scenarios are sometimes conducted, wherein traffic levels might be increased or incidents added.

In the case of Variable Message Signs (VMS), drivers must pass a sign before they have the information needed to make a decision. The Ali-Scout route guidance system presented above uses such a modeling technique, as it requires drivers to pass a beacon before the information can be downloaded to their vehicle. This study found that the benefits of a route guidance system were greatly dependent on the level of beacon coverage. In particular, travel time savings were only evident in those areas with dense beacon coverage, such as freeways. While travel time improvement on freeways was estimated to be approximately 30%, the network-wide travel times were only reduced by about 2% (Hadj-Alouane, *et. al.*, 1996). This may suggest that driver information provides little use if there is too much time between information updates. A possible explanation for this is that drivers are reluctant to change their behavior unless they have a high degree of confidence in the information that is provided to them, and infrequently updated information may be viewed as outdated.

The Ali-Scout study also found that the benefits for the route guidance system that was evaluated were greatest if the market penetration was limited to 10-15%. This is because the system-wide benefits decreased as more people chose different routes, resulting in congestion on the alternative routes (Hadj-Alouane, *et. al.*, 1996).

Although some studies have shown that driver information is useful for improving traffic flow, very few studies have attempted to investigate how information affects drivers. Because the whole objective of simulation is to objectively evaluate different technologies, more research needs to be done in this area. Furthermore, the types of information available and the means by which information is disseminated are not yet completely defined. In the future, both information and mechanical assistance (Automated Intelligent Cruise Control, etc.) may be available, and simulation software should include allowances for this (Reiter, 1991).

Approximately one-third of the simulation models reviewed by the SMARTEST project are capable of modeling VMS to some extent.

2.4.1.1.5 Vehicle Priority

Some have argued that incorporating public transit priority into signal optimization strategies is more equitable than giving public transit the same importance as passenger vehicles, because the movement of people is the objective of the transportation system—not the movement of vehicles (Lind, *et. al.*, 1999). In addition, emergency vehicles can be given priority, but the urgency associated with emergency vehicle trips usually means these vehicles command higher priority than public transportation vehicles.

Strategies for providing priority may be based solely on geometric considerations (e.g., bus lanes), or may use an altered signalization plan. For instance, fixed-time signal timing plans could be adjusted using predicted bus arrival times. In the case of adaptive traffic signal strategies, when a vehicle that is to be given priority is detected, the controller would either lengthen the green phase or decrease the red phase. Under fifty percent of the microscopic simulation packages evaluated by the SMARTEST project include provisions to model vehicle priority.

2.4.1.1.6 On-line Signal Optimization

In addition to using simulation to evaluate signal optimization strategies before they are implemented in the field, it is becoming increasingly desirable to use simulation in conjunction with field controllers to provide on-line simulation of these optimization strategies. TRANSYT is, perhaps, the most used model for optimizing signals off-line, and has been quite successful in improving network performance when traffic demand is relatively constant (Stewart and Van Aerde, 1998).

TRANSYT spawned the development of SCOOT, an on-line signal optimization program. SCOOT has been commercially successful, but the "…resulting benefit streams of about 5 to 10% have… been found to fall short of some of the more optimistic projections for the potential benefits of adaptive signal control, which were by some projected to be in excess of 20%. SCATS [is] the main challenger to SCOOT, and across the world these two systems are dominating the commercial installation of adaptive traffic signal control systems” (Stewart and Van Aerde, 1998).

Those desiring to deploy an on-line optimization tool such as SCOOT or SCATS may want to determine what the impacts of the tool will be. It is unwise to estimate these benefits from empirical evidence, as the results greatly depend on local conditions. There are three other major considerations:

- How the on-line optimization tool changes the current signal timing plan, and how these changes will affect normal recurring traffic conditions.
- How the tool affects non-recurring traffic conditions.
- How the tool performs when integrated with other ITS strategies (ATMS and ATIS).

Addressing these concerns requires an evaluation tool that can realistically replicate the performance of the on-line tool “…for recurring and non-recurring congestion, relative to off-line signal control, and in a setting where these controls may be integrated with freeway traffic management or other ATMS/ATIS deployments” (Stewart and Van Aerde, 1998).

2.4.1.2 Model Logic and Outputs

Equally important to a model’s capabilities is the mathematical relations it uses to represent the chosen real-world phenomena, and the way the model calculates the fundamental model outputs such as delay. Each simulation package may operate on different basic assumptions, potentially altering the results. It is therefore important for the modeler to be cognizant of the way the chosen model represents real-world phenomena.

Some researchers have attempted to compare the relative accuracy of simulation packages, but there is not a large enough body of evidence to categorically define which model best fits a given situation. “For the most part, simulation model comparisons have been performed at a very high level where only the features among the models are compared. In some instances, professionals perform the comparisons with little knowledge or detailed experience with the simulation models being compared…The lack of detailed comparisons provides an opportunity for further research" (Bloomberg and Dale, 2000). Some research efforts that would be particularly helpful are:

- Comparisons of a more statistically rigorous nature
- Comparisons of more models
- Comparisons of more networks and more functional classifications of roadways
- Comparisons made against field data
- An analysis of the number of runs needed to achieve results for a given confidence interval
- Sensitivity analyses of performance measures, especially sensitivities with respect to varying demand and varying traffic composition
- A definitive document summarizing comparisons of the internal model logic (Bloomberg and Dale, 2000)

2.4.1.3 Model Advantages

The survey of model users conducted by the SMARTEST project also produced responses about the noteworthy advantages of the most popular models. These advantages are shown in Table 2-6.

Table 2-6: Advantages of Some Popular Microsimulation Models
(Bernauer, *et. al.*, 1999)

Model	**Advantage**
NEMIS	well validated, includes assignment access to source code route guidance/en route diversion/connects to SPOT/SCOOT
AIMSUN2	excellent, graphical interface
DRACULA	very good representation of real traffic through a wide range of parameters day-to-day variability access and ability to import SATURN files
SITRA B+	a wide range of vehicle types, urban network layouts and sensors is available, communication interfaces with control strategies and algorithms, user-friendly animated interface during the running phase
TRAF-NETSIM	large network available animation best tool to handle arterial street operations stochastic features, animation excellent simulation of traffic signal operation better replication of the variability of on-street traffic conditions, animated and static

Model	Advantage
	graphics invaluable for calibration and for presentation
HUTSIM	modern input and animation, good output files can be run in real time connected to an external control device. User friendly possible to model the interactions between vehicles and to calculate number of stops, time gaps, speed variance etc. detailed simulation, suitable for signal control evaluation
VTI (Swedish two-way model)	flexible, fairly good validation, estimation of many effects, travel time mutual dependence traffic, alignment, sight profile
TRARR	Flexibility better than stochastic models, can assess small variations
INTEGRATION	telematics included, large networks wideness of the functions provided, models are of a high scientific level uses OD matrix, not turning percentages
SIGSIM	impact of traffic control strategy specification and control of traffic demands and occurrence of incidents to test the dynamic response of control strategies
CORSIM	arterial and highways allows system wide analysis of freeway and arterial graphic animation, very flexible, problem size, price, supported by a solid organization
FLEXSYT	specification of all possible control strategies
TRANSYT	impact of co-ordination established software
VISSIM	efficient (easy calibration), can be connected to complex control rules
TOLLSIM	handles toll plazas
TRAFF	sole control of the model
SIMULATEUR	own development, based on own needs
SIMIR	simplicity
MITHRA-SIMRES	allows to evaluate a traffic plan assignment
MITSIM/ SIMLAB	supports integrated networks and integrated ATMS and ATIS operation, explicit modeling or driver behavior
SIM2	large networks possible to simulate, re-produces link travel times with accuracy (the model has been validated using actual arterial link travel time data collected by ADVANCE probe vehicles)
SISTM	able to test a wide range of strategies with different parameter settings, able to test sensitivity of results with respect to changes in traffic demand, HGV proportion, geometric factors.
STEP	intelligent use, but some conditions
WATSIM	integrated corridor (freeway + arterial + surface streets), good graphics, show signal phases, turn queues etc.
In general	detailed modeling of intersections, fluctuations in traffic, differences in drivers

Model	Advantage
	preferences and knowledge of the network To classify the links. (In order to find rapidly the generating link which will jam the other ones). detailed simulation of the field behavior, thus realistic (detection of vehicles by loops, blockage and spilling back of queues) → a priori reliable evaluation The microscopic simulation model can provide insight information and complicate interaction of vehicle, control, roadways, and drivers which can not be provided by analytical models

2.4.1.4 Model Disadvantages

The survey of model users conducted by the SMARTEST project found several recurrently mentioned disadvantages for the most popular models. These disadvantages are listed in Table 2-7.

Table 2-7: Disadvantages of Some Popular Microsimulation Models
(Bernauer, *et. al.*, 1999)

Model	Disadvantage
NEMIS	poor user interface, runs under OS/2 not user-friendly yet - had to write graphics lacking UK features (roundabouts + flared approaches)
AIMSUN2	difficult to specify exact measurements with interface needs a program to correct loop width or link length
DRACULA	lack of many forms of variability (parked cars, roadwork s etc.), lack of graphical representation not user-friendly yet
SITRA B+	no user-friendly interface for data input, extended validation needed, motorway traffic modeling to be improved
HUTSIM	small models limited in scope, route choice not included, global results questionable no dynamic route assignment
TRAF-NETSIM	traffic signals are not functioning the European way difficult to collect and enter data, no route choice behavior It is always a challenge to adjust model parameters to local/national driving habits/behavior, because of lack of research data and use of special made (and not universal) sub-models within the main model gives a lot of details which are critical for some applications lack of route choice modeling cannot simulate all-way stop control, modifying model to produce different alternatives is difficult no left-hand drive version, roundabouts difficult to code, incomplete simulation of interactions between turning vehicles at intersection more data intensive, more time required to learn to apply the models correctly
TRARR	hard to calibrate and validate

Model	Disadvantage
	need for large amounts of data which is not always readily available
INTEGRATION	calibration and validation lack of conviviality (!) and of users requirement consideration not extremely user friendly, non-windows environment
FLEXSYT	no assignment
SIGSIM	limits to capacity in order to achieve real-time operation
TRANSYT	complex coding
TRAFF	slow
SIMULATEUR	too limited
SIMIR	limited to 1 or 2 intersections
CORSIM	very limited graphical printout, no gateway to spreadsheets
MITSIM/ SIMLAB	currently the graphical version works on SGI workstations only
SISTM	Ideally needs to be calibrated for each motorway being studied. Large amount of data required (e.g. 5 minute O/D matrices). Needs thorough knowledge of software before being able to use it effectively
WATSIM	needs considerable CPU horsepower to do heavy traffic smoothly
In general	The results can change significantly when making small adjustments of the premises. The results can differ between two runs with the same premises unless large number of iterations/time-spans are used. The models usually need a lot of data, making their use expensive. a lot of input data, a lot of output data, needs expertise. Expensive not user-friendly design, lack of validation Detailed input data requirement, some data may be difficult to obtain, it may be difficult for the user to explain some of the simulation results (i.e. the model is a black box for the user), calibration is important but most of the users just do not do it because of many field data are not available

2.5 Outlook and Research Needs

The use of simulation for modeling transportation projects shows much promise. Currently, however, operational models are not sufficient for addressing planning issues, and visa versa.

> "For example, the assessment of the travel demand management strategies in the 1970s strongly suggested the need to merge or link the planning and operational simulation models. The new requirements from the 1990 Clean Air Act Amendment (CAAA) and ISTEA legislation broadened the analysis envelope further to include the energy, environmental, and safety modeling as an integral element of the impact assessments procedures. The emergence of ITS technologies and concepts have added a new

> dimension to the problem—modeling and assessment of impacts of dynamic traveler behavior in response to information." (Rathi, 1995)

As computing power becomes less of a factor, more and more simulation models will rely on microscopic approaches, eventually culminating in comprehensive, multimodal models that can be used for both transportation planning and traffic analysis. The TRANSIMS project is a contemporary simulation effort that comes close to this goal, but computer restrictions necessitate the use of a discrete, cell-based representation of traffic flow in this model (Rilett and Kim, 2000).

Increasing computer processing power will not only bring about the ability to model bigger and more complex networks in greater detail, but will also allow "…Urban-Interurban interactions…to be studied and whole regions…to be modelled" (Bernauer, *et. al*., 1997). Because the simulations will take less time to run, more random runs will be able to be conducted, thereby increasing the statistical accuracy of simulation analyses. Furthermore, improvements in computer processing power will bring opportunities to improve user interfaces, thereby making the simulation models easier and possibly less time consuming to use. Also, model developers will have the option to include multimedia capabilities to view the model results. Improvements in outputs will make the results easier to interpret.

Increased computing power may also expand the ways in which simulation is used. Real-time analyses and predictions will become a more realistic endeavor, thereby enabling the use of simulation for predictive traffic control.

The future will also provide opportunities for improved calibration and validation data collection. For instance, as GIS grows in popularity, the geometry of more and more networks will be readily available. Also, more and more vehicles are becoming equipped with GPS. Although there may be legal complications regarding the release GPS data on privately owned vehicles, many military, state government, and commercial vehicles may be willing to cooperate in this endeavor. Even without these two technologies, visual and mechanical detectors are being placed on many ITS projects. In fact, these detectors may provide more information than has traditionally been extracted from them:

> "As a vehicle passes over a loop detector in the road,…it produces a profile which varies according to the vehicle characteristics. It has been claimed…that different vehicles produce signatures which are sufficiently different from each other to be able to identify them as they pass from detector to detector. If this proves to be true then it should be possible to obtain O-D data very easily and cheaply." (Bernauer, et. al., 1997)

The ITS infrastructure needed for the operation of small, independent ITS components will eventually provide the data needed to coordinate the different components. Indeed, it will provide the necessary data to link jurisdictions. This, of course, only reinforces the importance of developing sound, comprehensive modeling techniques that can efficiently process this information.

As is shown above, many current models do not adequately model some of the phenomena that are an integral and important part of the transportation network. For instance, transit vehicles, pedestrian, and on-street parking can all have significant impacts on network flow patterns. Much more research and model development needs to be done in this arena in order to adequately incorporate these aspects. Some research is already underway. For instance, "systems have been proposed to…use pedestrian detectors to count the numbers waiting to cross the road and use these numbers when setting signal timings" (Bernauer, *et. al*., June 1997).

In summary, there are many research areas related to microscopic simulation that need immediate attention:

- More flexibility is needed in simulation models. Most models are incapable of adequately modeling the impacts of ITS measures. While it is possible to modify simulation models to do this, the technology used in ATIS and ATMS is constantly changing, making it extremely difficult to keep simulation models updated. As the technology for ITS systems becomes standardized, it will be possible to incorporate it into simulation models, but technology will always rewrite the standards. For this reason, the developers of simulation packages must find generalized ways to model these ITS systems.
- Better representations of driver behavior are needed.

- Models should be adapted to provide more variability to better simulate real-world conditions; e.g., driver behavior that changes in response to weather (this could be done with a global reduction in capacity, but this would eliminate the variability of driver behavior and increase in accidents seen during inclement weather).
- The ability to add more detail and variability in microscopic simulations would be useful.
- More realistic modeling of measures of effectiveness is needed; some of these measures, such as noise pollution and emissions migration, are totally neglected today.

2.6 Conclusions

While the existing microscopic simulation tools are not perfect, they do provide a unique simulation environment for the evaluation of operational-level transportation improvement projects. The unique capabilities and limitations of these models also pose unique challenges to users of the models. These challenges require the modeler to be aware of the assumptions used by the model, the model's data requirements, and the effects of limited data on model results.

This thesis presents a recipe intended to allay these challenges for microscopic simulation model users. This recipe includes a list of ingredients, or the required data inputs and potential means for deriving these inputs. The recipe does not, however, describe what will happen if the ingredients are not fulfilled. That is, the implications of limited input data on model results is beyond the scope of this thesis.

CHAPTER 3: APPROACH

3.1 Introduction

3.1.1 Overview

As described in the previous chapter, microsimulation provides a unique environment for the evaluation of operational-level traffic improvement projects. This chapter describes a systematic methodology for the effective execution of a microsimulation tool.

In order to provide a context for the proposed methodology, the methodology is occasionally described using the INTEGRATION model. It should be noted, however, that the methodology can be adjusted to address the unique features of other microsimulation models. The methodology covers two potential applications: construction of a network from scratch, and deriving a network from a macroscopic model.

While the focus of this chapter is to develop a framework for model users to apply microsimulation tools, the first step in achieving this goal is to define the developer's and user's roles within the context of traffic modeling. Typically, model developers are responsible for the verification, validation, and documentation of the model. The model user, then, is responsible for network construction, calibration, model execution, and the interpretation of the results.

3.1.2 Layout

Verification, validation, and documentation of a simulation model are discussed in Section 3-2. These steps are important to model users because the model user cannot have confidence in the model's output unless the model has completed them satisfactorily.

The first step in constructing a model that successfully portrays real-world traffic systems is adequately defining the transportation network. Because checking the construction of the network is complex and time-consuming, it is important to be methodical and thorough in the initial network construction effort. This process is discussed in Section 3-3.

Once the physical representation of the network has been completed, the modeler must assess and adjust how well the model represents vehicle movements on the network. This is the first step of calibration, and is conducted to ensure that the vehicles move through the network in the same manner as observed in the field. This process is outlined in Section 3-4.2.

The second step of calibration is determining and refining the demand to be modeled. If the network has been well formed, any discrepancies between the model's results and field observations can be resolved with changes in the network demand. Methods of calculating Origin-Destination (O-D) matrices, and methods for evaluating how well they fabricate the demand observed in the field, are discussed in Section 3-4.3.

Model Execution is discussed in Section 3-5, as is the interpretation of the results obtained from the model. Research needs are discussed in section 3-6, followed by a summary of the chapter.

3.2 Verification and Validation

Verification is the process of checking the execution of the computer code used by the simulation model; validation is the process of checking the logic behind the computer code. Both are usually the responsibility of the vendor or developer of the simulation tool, but those using the tool should verify that these procedures have been done. Rakha *et. al.* (1996) define verification and validation as follows:

> "Model verification entails compiling the program successfully, running the model error-free and without excessive mathematical approximation. Model validation...is initiated once model verification [has] been successfully completed. Model validation entails comparing the model output to generated analytical solutions and to collected field data."

As shown in Figure 3-1, model developers iterate between verification and validation until the model performs as expected for all of the test scenarios. However, it is impossible to test the model for all scenarios. A model developer can only certify that the model is reliable for the conditions tested. If this is done, "…the model developer has fulfilled his/her obligations in providing a model that has been successfully verified and validated" (Rakha, *et. al*., 1996).

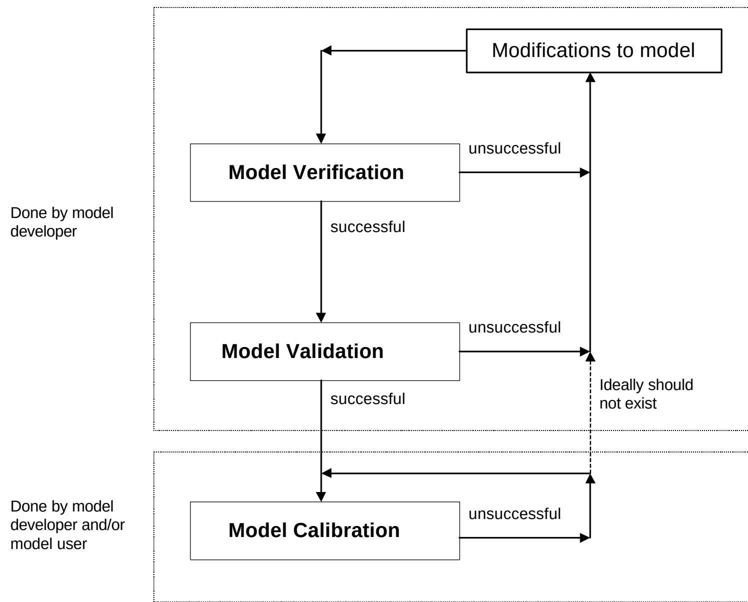

Figure 3-1: Model Verification, Validation, and Calibration Process
(Rakha, *et. al*., 1996)

As mentioned previously, those using the models cannot trust the data obtained from a simulation model unless they are confident the model will provide good results. While the task of ensuring a model operates correctly falls on the shoulders of the model developer, those using the model have a responsibility to review the model developer's assessment of the model. The model developer should provide documentation of the verification and validation procedures.

This chapter presents a framework for developing and calibrating a simulation model; verification and validation are discussed briefly in Sections 3-2.1 and 3-2.2 below.

3.2.1 Verification

Verification is done to ensure that the model is performing as intended; it is basically checking the execution of the computer code. As mentioned above, the user of the model typically need not be concerned with the verification process beyond ensuring that their model chosen has been thoroughly tested. Rakha *et. al.* (1996) emphasize that model developers should provide adequate documentation of the verification process, including typical values for input data, the magnitude of the error between the model's results and the selected benchmark, and the results of sensitivity analyses of the model about the default parameter values.

Although the validation and verification procedures are ideally not the concern of the model user, the model developer cannot ensure that the model will provide reasonable results for all scenarios. For this reason, it is the responsibility of the model user to address any unexplained discrepancies with the model developer.

3.2.2 Validation

Validation is the process of checking the logic behind the computer code used in the model. Validation is often more time-consuming than verification: "…having ascertained that the model is functioning in its intended manner, the analyst must determine whether or not the intended functioning of the model conforms to reality. If the simulation model is used to represent the behavior of an operational system, the results of the simulation model can often be compared with those realized from the real world systems where the exogenous conditions governing both are the same. However, even when this comparison is favorable there is no guarantee that the simulation model will function in a manner representative of the real world system under conditions which have not yet been experienced" (Schmidt, 1983).

> "It must be emphasized that it is impossible to conclusively demonstrate that a model is valid, since it is impossible to execute the model for every possible combination of input data. Instead the model developer demonstrates that the model is not invalid for the scenarios studied. Care must be taken to ensure that the scenarios that are studied are representative of typical scenarios for which model users are expected to encounter." (Rakha, et. al., 1996)

Validation is further complicated when the simulation model is to be used for a system that is not in existence, but planned for the future. In this case, there is no way to compare the results of the model with field-measured values, and it is not possible to complete validation. "In most instances all the analyst can do is experiment with the simulation model under a variety of conditions, past, present and expected in the future, and compare the results with historical data, where available, and with what one might expect from the system under study should those conditions expected in the future arise" (Schmidt, 1983).

Typical validation parameters are travel time, headway, speed, saturation flow, lane use, and emissions. The validation of each of these parameters usually requires collection of large amounts of data; this data should be different than the data used to calibrate a model. Fortunately, new technologies frequently track information that can be used in the validation procedures.

3.3 Network Construction

Building the geometric framework of a simulation model is one of the most time-consuming tasks in the modeling process. This section recommends a process for accomplishing this task.

The first step in constructing a network, after determining the study area, is to gather data that describes the physical attributes of the system being modeled. If the model is constructed from existing macroscopic model input data, it is likely that many refinements will be needed for the microscopic simulation to run correctly.

These refinements usually involve adding details such as speed limits, turning bays, lane striping, lane widths, and storage lengths. Refinement also includes specifying the control systems used within the network, including speed limits, loop detector locations, signal splits, cycle lengths, and cycle offsets.

The case studies presented in Chapter 4 and Chapter 5 of this thesis use, to the extent possible, the network creation process outlined in this section. These case studies used the INTEGRATION microsimulation model.

3.3.1 Data Collection

The first step when constructing a simulation model is gathering data. The data representing the system's physical characteristics can be obtained using surveying or digital maps, but the data collection process can be accelerated by using existing GIS databases or a municipality's planning model. Whichever method is used, the data will often need to be checked and refined. As an example, most planning models used by municipalities do not contain a level of detail appropriate for high-fidelity microsimulations. Consequently, additional data must be collected to achieve a network with the desired level of detail.

An example of the data required for construction and calibration of a simulation model, in this case, the INTEGRATION microscopic simulation model, is shown in Figure 3-2, below.

		Network	Link/Node	Vehicle
Input	*Descriptive data (non-calibratable)*	#of nodes Scale of coordinates and node coordinates Node ID and type Macro-zone cluster number # of links # of signals and signal plans # of OD pairs	Link scale factors Link and adjacent nodes ID Link length Number of lanes Initial cycle length Cycle length range for internal optimization for each intersection Phase splits and sequence OD scaling factors OD departure rate Lanes blocked by incident Incident duration Rate of internal optimization	N/A
	Modifiable data (Calibratable)	N/A	Free speed and speed at capacity in links Link saturation flow rate Link jam density Signal offset Effective lost time Passenger car equivalency Vehicle departure headways	Link vehicle speed variability Traffic stream composition
	Advanced Calibration data	N / A	Free speed and speed at capacity in links Link jam density	Link vehicle speed variability Traffic stream composition
output		Total link travel time Total network travel Average network speed Total network stops Avg. network stops Incident duration Fuel consumption Emissions - HC, CO, NO	Signal timing optimization results Min., avg., and max. trip times for all vehicles	Min., avg., and max. trip times by vehicle type Min., avg., and max. trip times by OD pair

Figure 3-2: Simulation Input Data
(Rakha, *et. al.*, 1998)

One report made the following suggestions for data collection:

- Do not underestimate the time and resources needed to collect data
- Develop a data collection plan and corresponding resource requirements
- Factor weather into the data collection plan
- Produce a database at the end of the project that can be distributed to other agencies and contractors
- Give responsibility for collecting data on a facility to the jurisdiction that owns that facility (Rakha, et. al., 1998)

If the network structure is obtained by converting planning model data, the resulting structure may be much larger than the study area. In order to effectively model the study area, the planning model must then be reduced to a size that is manageable, while still being large enough to allow the modeling of traffic diversion.

3.3.2 Defining Links and Nodes

If a planning model such as MINUTP or EMME/2 is used for the basis of a simulation network, the links and nodes from the planning model need to be converted into a format useable by the simulation model. This process is summarized in Figure 3-3.

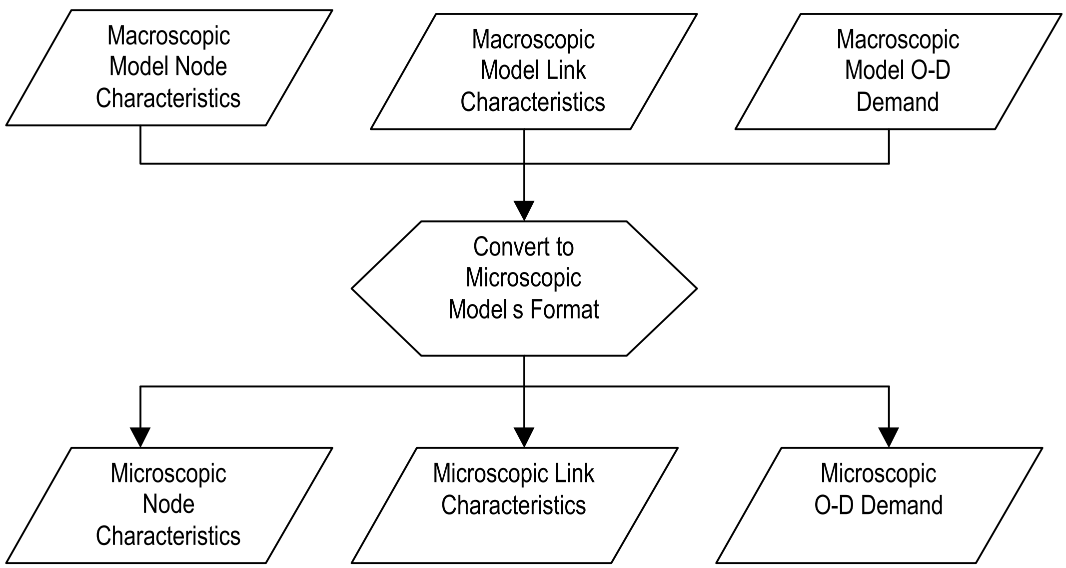

Figure 3-3: Macroscopic Model Conversion

Furthermore, if the data is obtained from a macroscopic model, it most likely needs to be pared down to fit the study area. This step is outlined in the flowchart shown in Figure 3-4.

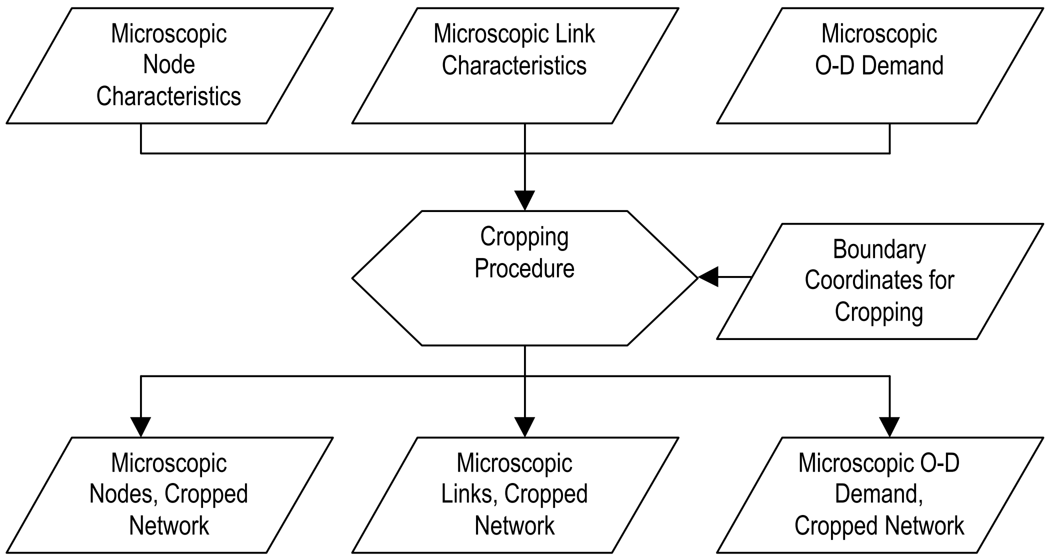

Figure 3-4: Network Cropping

This cropping procedure can be done manually, or with a feature designed to work with the model being used. For example, INTCROP is a program written to do this cropping for the INTEGRATION model. Such cropping programs remove the links and nodes outside of the coordinates specified by the modeler, and clip the links at the new boundaries. Usually, new O-D nodes are constructed at the clipping points. The O-D demand matrix, then, is cropped so that only those trips passing through the study area, or those beginning or ending there, are used. Furthermore, the trips with at least one origin or destination outside of the study area must have the origin and/or destination nodes that are outside of the study area relocated to the closest boundary node. These considerations are described succinctly below:

Table 3-1: O-D Cropping Scenarios

Origin Node Inside Network?	Destination Node Inside Network?	Action
Yes	Yes	Keep O-D Pair
Yes	No	Move Destination Node to Boundary Node
No	Yes	Move Origin Node to Boundary Node
No	No	Build All-or-Nothing Tree to Determine Origin and Destination Nodes

More detail about working with O-D information is given in the Section 3-4.3.

During the cropping procedure, it is important to set the cropping limits far enough outside the boundaries of the study area to allow origin-destination nodes to be created, and to allow for routing changes/traffic diversions during the simulation.

After cropping, the network structure must be reviewed to ensure it is consistent with what is in the field, or what will be in the field. Link lengths in particular should be checked, as the coordinate base used to calculate them may not be consistent over the entire network. Furthermore, the model will, in most cases, not yet have enough detail for use in a microscopic simulation. This is definitely the case if the cropped network is converted from a macroscopic planning model, and probably also the case if the data is obtained from a GIS database, because neither has the high-fidelity detail needed for microscopic simulation. Even if new data is collected expressly for constructing the network, additional details will most likely need to be added. In particular, the lane striping, signal timings, and turning bay details must be refined. These network refinement steps are discussed in the following subsections, and summarized by Figure 3-5.

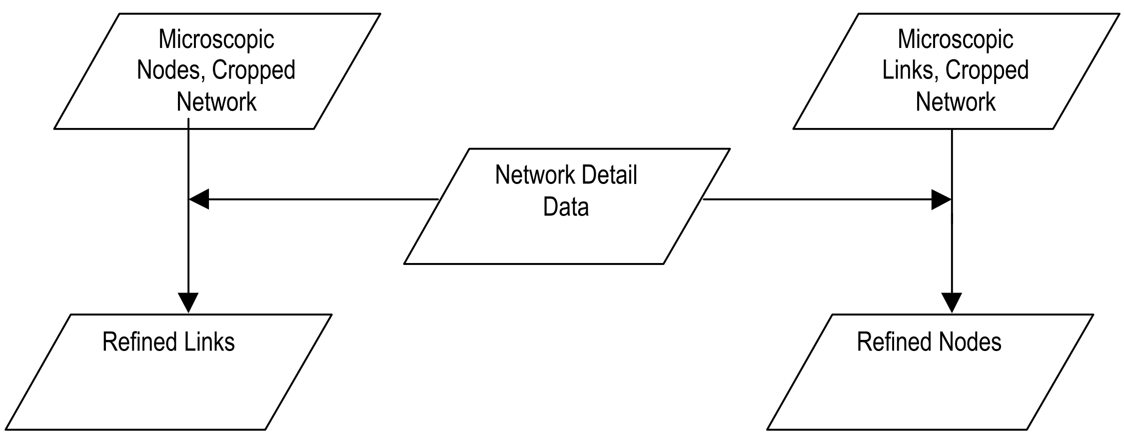

Figure 3-5: Network Refinement

3.3.2.1 Nodes

While most simulation packages will use nodes to represent some type of junction, the way in which these packages use nodes may differ. For example, some models will differentiate between intersection nodes, roadside parking nodes, off-road parking nodes, origin nodes, and destination nodes (Lind, *et. al.*, May 1999). For simplicity, only two primary types will be presented here--O-D nodes and intersection nodes. Intersection nodes are the points in space defining the endpoints of links; they represent all of the common intersections on the network. Each link has an upstream and a downstream intersection node; these nodes are just the transitions between one road to the next. O-D nodes are also the endpoints of links, but they serve as the origins and destinations for the network demand represented by the O-D matrix. The O-D matrix is discussed in Sections 3-4.2 and 3-4.3.

As noted previously, O-D nodes are usually placed at the boundaries of the network to provide the O-D points needed for those trips that either start outside of the study area, end outside of the study area, or both. External nodes may be added by the cropping tool. In addition to reviewing the location and number of the external nodes, the model user should investigate placing internal O-D nodes to provide the needed origins and destinations within the network. The level of detail here will depend on the scale of the network, but major generators and attractors of trips (e.g., colleges, shopping malls) should generally be represented with an O-D node.

3.3.2.2 Links

Links are the simulation model's representations of the streets on the network. While a link can have more than one lane, it is not usually bi-directional. A few microscopic simulation models allow for two-way traffic on one link, but most do not. Unfortunately, this precludes passing maneuvers conducted in oncoming traffic lanes.

Because the simulation model being used is unlikely to allow bi-directional traffic, most streets should be represented by two links, with the same upstream and downstream nodes, but in opposing directions. Some real-world links may change geometry mid-block, but some simulation models do not have the ability to represent this with just one link. In these models, the links must be split; that is, one link is required for each change in geometry between intersections. When links are split, care should be taken that links are not made too short to accurately model turning bays, or to allow for lane changing

(University of Leeds, *et. al.*, 2000). This and other issues are discussed below in Section 3.3.3.

3.3.2.3 Factors to Consider

During network construction, it is important to keep in mind the phenomena that the simulation will be expected to model, and the detail needed to accomplish this. The level of detail used is commensurate to the level of accuracy desired in the output. The network should be made small enough to be manageable, given constraints in computing power and manpower resources, but it should also be large enough and detailed enough to represent the situations being investigated. One of the most important aspects to consider is traffic re-routing—there should be enough detail and a sufficient area surrounding the study area to provide corridors for re-routed traffic.

It is also important to know the capabilities of the model being used. For instance, many simulation models cannot adequately model roundabouts and some types of interchanges. Or, some modification may be needed to properly model these components.

Further, it is important to note that some simulation programs assess a penalty for passing through O-D nodes. For instance, INTEGRATION levies a time penalty of one hour for vehicles attempting to travel through the O-D node. If this time penalty is too large, and is either not altered by the user or not programmable by the user, it effectively eliminates the node from consideration. Therefore, the node can only reasonably be used as an O-D node, and the network is constricted by what is in essence a dead-end street. It is important for modelers to review the network geometry near O-D nodes to ensure that the network is detailed and robust enough to allow traffic re-routing.

<u>3.3.3 Network Refinement</u>

3.3.3.1 Turning Bays

As discussed above in the Section 3-3.2.2, many simulation models assume constant geometry along links, thus requiring additional links to represent features such as turning bays. This process is often time-consuming and cumbersome, but is even more so after other network refinements (e.g., signalization) have been performed. For this reason, link splitting should be done before the other refinement procedures.

3.3.3.2 Lane Striping

Lane striping information is important to the simulation model because it governs the restrictions on vehicular movement. Some simulation models use independent links for each lane, particularly when lane changes are restricted. Providing multiple lanes, however, provides the opportunity for more realistic vehicle movement. Lane striping information is important to microscopic simulation models because these models attempt to simulate individual vehicles as they interact with the environment, and with other vehicles. Macroscopic models are not concerned with how the vehicles move once they are on the link (or the cell defined within the link), so lane striping is not as important. Some signal timing programs such as Synchro may contain lane striping information, or it may come from field surveys or aerial photos.

3.3.3.3 Signalization

Signal timing information is one of the most important variable aspects of the model. It may come from a municipality's signal timing plan, from field observations, or from a program used by a municipality for signal timing optimization. It may also come from other simulation models used for the study area. In the last case, the signal timing information obtained should be carefully reviewed to ensure it was not modified to be compatible with the other model's format restrictions. It is difficult and time-consuming to check these signal timings in the field, and the task is complicated if the signal timings are not fixed: e.g., if semi-actuated or fully actuated signal operation is being used and the network is not fully saturated, the green split will vary from phase to phase.

Stop signs and yield signs, should, of course, be placed at all of the positions in the network where they actually exist. While this information is not always available, common sense rules can be used in the placement of these signs. Additional stop and yield signs may be useful in defining the network flow. For instance, merging operations should sometimes be governed by yield signs, and stop signs may exist where a minor link intersects a major, unsignalized link, or another minor link.

3.4 Network Calibration

Calibration is the iterative process of adjusting a simulation model's input parameters to improve the match between the model outputs and field-measured data. After constructing a simulation network, the model’s inputs must be made suitable to the local conditions. For example, the vehicle mix and driver behaviors in Mexico City will be very different than they are in Great Falls, Montana. Some of these input parameters, however, are uncertain or unknown. For these uncertain parameters, the model developer’s recommendations can be used for guidance; the parameters can be adjusted if the data collected justifies such changes. Obviously, in order to do this, a significantly detailed data set is needed. Just as network construction requires more data for more detailed applications, calibrating detailed networks requires more data.

> “The technique needed to assure the model’s accuracy on an aggregate level will be much different than the technique required to assure accuracy at the detailed level. Likewise, the data required to support aggregate-level calibration will be very different from the data needed to support detailed-level calibration. From a practical standpoint, aggregate-level calibration will be most often applied in large network situations, where the resources required for detailed-level calibration are not usually available. Likewise, situations requiring highly detailed output will usually be formulated as small networks to control the cost of performing the simulation.” (Owen, et. al., 1996)

Calibration is conducted in two steps: Supply Calibration and Demand Calibration. Each is discussed in the remainder of this section.

3.4.1 Parameters Adjusted during Calibration

During calibration, only those input variables that are uncertain should be altered. Small changes in these input variables often lead to large changes in the results, so changes should be made carefully, and no variables should be changed unless there is a logical reason for doing so.

“For example, adjusting any descriptive traffic input parameter, such as volumes, to achieve a better comparison to real-world traffic flow data is usually inappropriate.

Adjusting input parameters beyond either physical or common-sense limits just to obtain a better comparison is also unacceptable" (Owen, *et. al*., 1996). Because calibration requires engineering judgement, the parameters that are available for adjustment depend on the knowledge and skill of the model user.

3.4.2 Network Supply Calibration

Supply calibration is conducted to ensure that the performance of the constructed network matches that observed in the field. Because these relationships are used to define the demand, supply calibration should be conducted before demand calibration. The sub-sections below describe some variables that can be used to calibrate the supply.

3.4.2.1 Capacity

Simulation models use the saturation flow rate for a system to determine how many vehicles can pass through the system during a given period of time. It is defined as "…the maximum flow rate that can be sustained by traffic from a queue on the approach used by the stream" (Bernauer, *et. al*., 1997). The authors of this paper assert that the best way of determining the saturation flow rate is by direct observation. Sometimes, however, this is not possible. In these cases, the saturation flow rate can be determined, based on the roadway's geometric characteristics such as lane width, using accepted procedures such as those found in the Highway Capacity Manual (HCM).

Detector data may be used to calculate saturation flows, too. While most areas do not currently have enough instrumentation to support this task, "some UTC systems are now being enhanced to automatically calculate saturation flows at each junction by using strategically placed detectors at exits from the junction. This data can be used for validating the micro-simulation models" (Bernauer, *et. al*., 1997).

While capacity and Level of Service (LOS) can be determined using the Highway Capacity Manual (HCM) and the associated Highway Capacity Software (HCS), the Highway Capacity Manual cannot include all possible configurations for signalized intersections. A calibrated simulation model can not only determine capacity and LOS for these configuration, but also analyze other situations not covered by the HCM, such as over-saturation, actuated signals, double parking, and lane obstruction. A recent study, in fact, showed that simulation may sometime provide better estimates of capacity than those obtained from the HCS (Wong, 1991).

3.4.2.2 Travel Times

Travel time data collection can be made using floating car observations, license plate readings, or emerging vehicle tracking technologies such as those that rely on GPS. Travel time readings can be used to check that simulated vehicles traverse the network in the same amount of time as vehicles observed in the field. Usually, travel times for all of the vehicles in the simulation are averaged, and compared to some average of the field-measured travel times. Obviously, many field readings are needed for a meaningful analysis. Speed-flow measurements also have the disadvantage of requiring a large amount of field data, but may provide a better indication of how well the network is performing.

3.4.2.3 Intersection Delay

The delay vehicles experience at intersections is a useful indicator of the efficiency of the signal timing plan used. Intersection delay is either measured by the amount of time vehicles spend stopped at the intersection, or by a combination of this and the amount of time vehicles spend accelerating and decelerating. The addition of acceleration and deceleration delay provides a better indication of actual delay, as vehicles will often be in queue for more than one signal cycle, especially during oversaturated conditions.

3.4.2.4 Speed-Flow Relationships

An adequate description of speed-flow relationships is essential for the supply-side calibration of simulation models, and must be applicable for any traffic volume. These speed-flow relationships include capacity, free speed, and jam density (Van Aerde and Rakha, 1995). Speeds and headways are easier to measure than travel times, but have the disadvantage that they vary, on any given link, from one lane to the next.

Because it is not practical to measure these speed-flow relationships for every lane of every link, speed-flow relationships have traditionally been calculated using either single-regime models, such as Greenshield's linear speed-density model, or complex multivariate models. Single-regime models often lack the robustness necessary for real-world situations, and multivariate models require too much data and processing time to be practical (Van Aerde and Rakha, 1995). Some generalized techniques using loop-detector data are under development, and have shown potential to provide better estimates of the speed-flow variables.

Even the new techniques mentioned above need data that is not always readily available, however. The detector data needed will become more widely available in the future with the increased use of instrumentation and incident detection systems. Futhermore, new technologies that collect continuous data on vehicular movements, such as AICC and autonomous vehicles, may be used to validate the speed-flow relationships of simulation models (Bernauer, *et. al*., 1997).

3.4.2.5 Comparing Simulation Changes to Field Changes

Another useful way to determine if the supply variables are calibrated correctly is to make minor adjustments to the simulation that can be replicated in the field. If, for instance, the signal timings are changed, the resultant intersection delay in the field should match that from the same situation in the simulation.

3.4.3 Network Demand Calibration

The next step in model development is determining the demand the network will be required to serve. This step is trivial for a very few applications—for validating the network, and for simulations intended to evaluate a technology or the way in which it is modeled. In these cases, demand is sometimes loaded onto the network indiscriminately, without trying to match any real or expected flows. The flows should still match reasonable and conceivable flow patterns for the given network, even if they are only theoretical. Some studies have loaded networks without any destinations for the vehicles, leaving the vehicles indefinitely, and aimlessly, roaming about the network. This may lead to unrealistic results.

As most simulations are conducted to analyze a particular area, an accurate representation of the traffic demands is needed. This demand is contained in an origin-destination (O-D) matrix.

> "An Origin-Destination (O-D) trip table is a two dimensional matrix of elements whose cell values represents the travel demand between each given origin (row) and destination (column) zone. An O-D trip table can be obtained by conventional surveys such as license plate surveys, home interviews, roadside surveys etc. Such surveys are time consuming, expensive and labor intensive. In addition, many of these approaches involve sampling errors." (Paramahamsan, 1999)

If the study is being conducted using the current demands, turning movements and link counts can be used to calculate an origin and destination matrix. This process is shown in Figure 3-7.

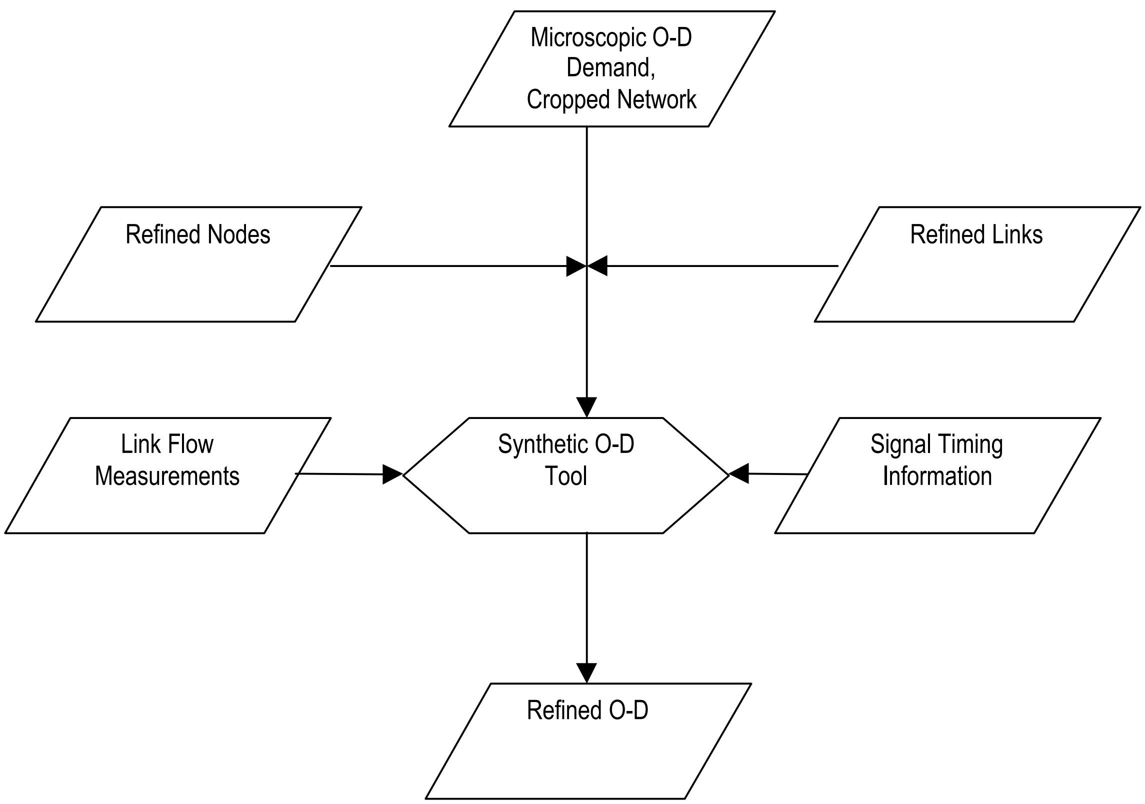

Figure 3-6: Demand Calibration

If the horizon year is in the future, a planning model can be used. Even if new road construction is planned, "…flows down individual links will change, but it will not have a major effect on the number of trips made from each origin to each destination" (Bernauer, *et. al*., 1997).

Microsimulation models use O-D information in either route-based calculations or in turning percentage calculations. "For a route based model, when each vehicle is generated in the model, it will be assigned a route from its origin to its destination by specifying which links it is to travel on to get to the desired destination. For a turning percentage model, vehicles are generated at the entrances to the network and travel down the links until they reach a junction. At this point a choice is made as to the direction to travel based on the percentage of vehicles that typically turn in each possible direction" (Bernauer, *et. al*., 1997). Regardless of the method used, an assignment model is used to interpret the O-D data. Historically, traffic assignment is done using some form of the gravity model.

A number of other models have also been used for generating O-D matrices from field measured flows. "Typically, the entropy maximizing, information minimizing and least square estimators have been proposed and applied. These models seek to update or improve an old O-D matrix" (Yang and Zhou, 1998). The researchers involved in the Salt Lake Study (Rakha, *et. al.*, 1998) recommend using a planning model O-D matrix as the seed for the O-D demand generation. Among other things, using the planning model O-D as a seed alleviates some of the data requirements. These requirements are discusses in Section 3-4.3.1 below.

3.4.3.1 O-D Data Issues

The first requirement for the data used to calculate the O-D trip table is that the data is from the time being studied; this is most likely the peak hour. Data should be taken throughout the peak period, as the modelers will want to simulate the entire peak period. Furthermore, other times that present potential problems should be covered. For instance, Utah Department of Transportation (UDOT) used 24 hr. simulation to capture off-peak construction impacts (Rakha, *et. al.*, 1998).

The data must not only be from the proper time of day, but it must also cover a large enough area to capture traffic diversion. The data must also be current, cover a large enough percentage of the network, and be representative of the expected demand—i.e., it must not be influenced by outside influences such as construction, weather, incidents, events, or seasonal variations.

Traffic counts are available in most cities, but may not be sufficient for one of the reasons mentioned above. If new counts are going to be conducted for any reason, the locations used for the counts should be properly evaluated, because "…the quality of the estimated O-D matrices is greatly dependent upon the accuracy of the input data (Traffic counts and prior matrix and so on) and the number and locations of traffic counting points in the network" (Lam and Lo, 1990, Yang *et. al.*, 1991).

3.4.3.2 Using Planning Model O-D

It is possible to convert the O-D table used in a municipality's planning model for use in the simulation model. If this is done, the O-D trip table will most likely need to be reduced in size—all of the trips that never use the network being studied will be cut out. This can be done using the all-or-nothing approach; if the trips begin, end, or pass through the study area, then they are kept as part of the study area O-D.

The results from running the simulation with the planning model O-D should be compared to the flows observed in the field. A sample comparison of this nature is shown in Figure 3-7, below (Note--the data shown below is from the Southern/Baseline study presented in Chapter 4 of this Thesis).

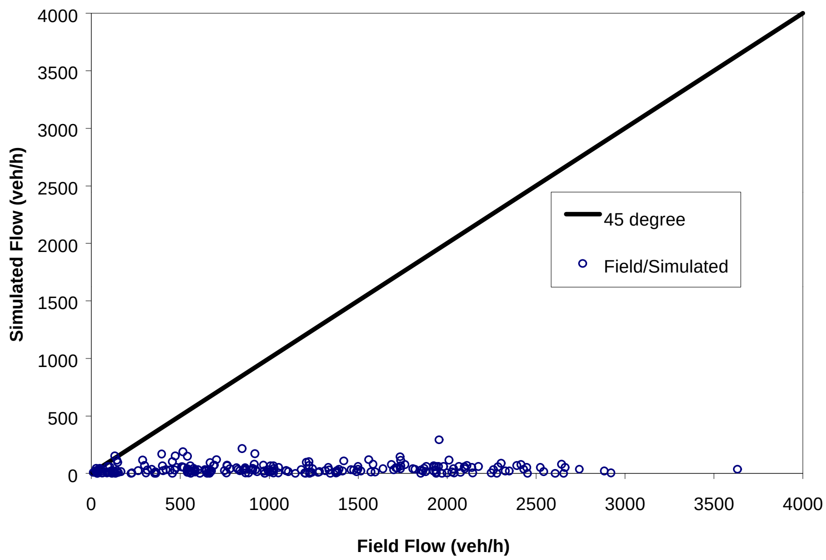

Figure 3-7: Simulated Flows Using the EMME/2 Demand

As illustrated in the figure, the planning model O-D table does not give simulation results that match well with the observed flows. Because such discrepancies are often the case, the O-D table must usually be refined before a simulation produces realistic results.

Methods for making such a synthetic O-D table may use a planning model's O-D table as a starting point, or seed. This was done for the Southern/Baseline simulation that is presented in Chapter 4 and for the Scottsdale/Rural simulation that is presented in Chapter 5. These studies used the synthetic O-D calculation tool QUEENSOD to improve the O-D table obtained from EMME/2. QUEENSOD uses the maximum likelihood approach first formulated by Willumsen and Van Zuylen. This approach is the most prominent technique for synthetic O-D calculations (Rakha, *et. al.*, 2000).

The new O-D obtained from QUEENSOD for the Southern/Baseline project resulted in simulated link flows much closer to observed flows than the simulated flows using the EMME/2 O-D. This is demonstrated in Figure 3-8. Section 3-4.4 discusses using synthetic O-D demand in greater detail.

3.4.3.3 Calculating and Using Synthetic O-D

While it is possible to obtain the data needed for an O-D table using license plate matching, this method "…is extremely expensive and rarely done. Consequently, a number of synthetic techniques have been adopted over the years" (Rilett and Kim, 2000).

These synthetic techniques still need observed volumes to use as input data. Even "…if the link flows are known exactly (which typically is not the case), the [O-D] problem is underspecified (the number of constraints is less than the number of unknowns)" (Rakha, *et. al.*, 1998). "Because the OD problem is underspecified there are many possible solutions that will replicate the observed inputs and the models attempt to find the most likely matrix that best replicates the observed traffic volumes" (Rilett and Kim, 2000).

Furthermore, because there will inevitably be errors in the observed traffic volumes and time lags between observations, there will not be any solution that exactly matches the observed flows. Instead, the objective is to find the most likely solution that minimizes the link flow error. This technique assumes that the O-D demand error is minimized when the link flow error is minimized. A sample comparison is shown in Figure 3-5. It should be noted that the data shown in this figure provides a significantly better fit to the field data than the planning model data, shown in Figure 3-4.

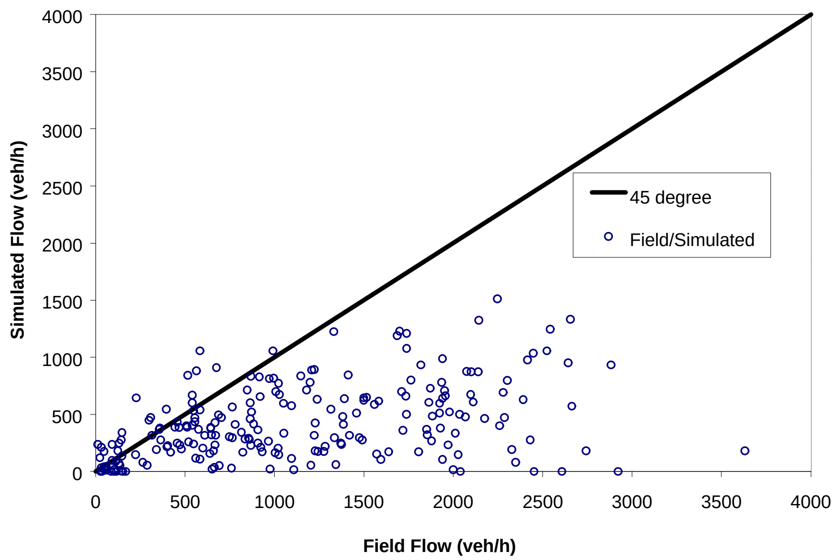

Figure 3-8: Simulated Flows Using the QUEENSOD Demand

Unfortunately, even when these efforts are taken, the actual O-D demand is still unknown. This means that the modeler, in the end, does not know how good the manufactured O-D solution is (Rakha, *et. al.*, 1998).

3.4.3.3.1 Overview of Synthetic O-D Models

Several techniques for estimating O-D tables are available to transportation modelers, including the gravity model, entropy models, equilibrium models, statistical models, fuzzy weight models, and neural networks. Each of these techniques is discussed briefly below.

3.4.3.3.1.1 THE GRAVITY MODEL

Historically, most planning models have used an O-D matrix determined by estimating the number of trips generated or attracted by certain land use areas, and matching and distributing these trips on the network by calculating the impedance to travel between various possible origins and destinations. The gravity model is so named because its mathematical form—and concept—resemble the law of gravity; as the production node and the attraction node move further apart, the pull between the two decreases.

All of the entries in a gravity model O-D table are assumed to be functions of traffic counts and the impedance. While gravity models used for trip distribution use link volumes on zone connectors, gravity models for synthetic O-D generation use link volumes on zone connectors and in-zone links.

3.4.3.3.1.2 ENTROPY MODELS

The entropy method has an advantage over the gravity model because it uses link counts as a direct, rather than indirect measure of network travel. While other O-D methods also use link counts, "…One of the most popular techniques is the one using the maximum entropy approach…" (Paramahamsan, 1999). This method will force "…the trip table to conform a gravity type pattern or cause them to be as close as possible to prior trip table as possible" (Paramahamsan, 1999).

3.4.3.3.1.3 EQUILIBRIUM MODELS

Equilibrium models are "…based on the principle of user optimization of traffic flow, called "Equilibrium Principle" or "Wardrops's principle"…These types of models are more suitable for congested area analysis" (Paramahamsan, 1999). The routes between O-D pairs are assumed, and the solution is adjusted so that link flow counts match those measured in the field. These models iterate between O-D generation and traffic assignment until a solution is obtained.

3.4.3.3.1.4 STATISTICAL MODELS

Some models require link flow continuity, which is not usually found in field data. Statistical models attempt to overcome this problem by using statistical techniques to find the O-D matrix that best fits the observed flows.

3.4.3.3.1.5 NEURAL NETWORK MODELS

Neural networks are basically the parallel combination of many simple processing nodes. This simple combination, which is intended to mimic the human thought process, provides a mechanism to quickly solve complex and/or underspecified problems. It is important to note that neural networks do not find exact solutions, rather, they find the most likely solution (Schilling, 1997).

A large amount of data is required to "train" the network to find correct solutions, and neural network models are unable to synthesize traffic flow data for patterns for which they have not been trained. These models are relatively new, and require much additional research before they can be used with confidence (Paramahamsan, 1999).

3.4.3.3.1.6 FUZZY WEIGHTS MODELS

Another recent approach to determining O-D trip tables is the application of fuzzy logic models. Fuzzy weight models have the advantage of imprecision, an aspect that is not available in a traditional all-or-nothing approach.

3.4.3.3.2 Synthetic O-D Calculation Tools

Because the numerical procedures required to implement the methods discussed above are often time-consuming, computer software designed to evaluate such complex, protracted calculations must be used. For instance, the relationships could be evaluated using Microsoft Excel, MATLAB, or MathCAD. There are also commercially available programs specifically designed to perform O-D calculations. One such program is QUEENSOD, which was used in the case studies presented in Chapters 4 and 5 of this thesis. QUEENSOD is discussed in Appendix B.

3.4.3.3.3 Using Synthetic O-D Models

If the synthetic O-D models discussed above are to be used for real-world applications, the data used as inputs to the models becomes a consideration, because this data is by nature imperfect. Therefore, it is often useful to pre-process the data, and to estimate the quality of the data collected. Furthermore, it must be decided when the O-D has been synthesized satisfactorily, or at what point the synthetic O-D tool can stop iterating to find a potentially better solution. These issues are discussed in the sub-sections below.

3.4.3.3.3.1 PRE-PROCESSING LINK FLOW DATA

Link counts are the most commonly used data to determine O-D matrices. Link counts are usually obtained using loop detectors or pneumatic tubes. “These counting devices are not completely reliable. They do have errors which leads to inconsistencies in link flows. This also occurs when link counts are obtained on different occasions. Hence one of the first steps, before the link volumes can be used to obtain the most likely trip matrix, is to make sure that the link counts satisfy link flow continuity. To obtain an equivalent link count, which is as close as possible to the observed one and simultaneously satisfying link flow continuity, we try to minimize the error between the observed and estimated link flow, while maintaining flow continuity" (Paramahamsan, 1999).

3.4.3.3.3.2 EVALUATING THE VARIABILITY IN TRAFFIC COUNTS

Because traffic flow will change from day to day, it is important to determine the typical variation so that the flow impacts from the traffic projects simulated can be statistically compared to this variation.

The best method for evaluating the variability in traffic counts is to use two-factor analysis of variance (ANOVA). Sometimes, however, there are not enough resources to properly evaluate the data. If this is the case, other, less thorough statistical methods can be used to gain a level of confidence in the results. For instance, in Construction and Calibration of a Large-Scale Microsimulation Model of the Salt Lake Area, Rakha *et. al*. (1998) used least-squares error (LSE), least Poisson error (LPE), and visual inspection.

LSE is computed as the average squared error divided by the average observed link flow. Thus, for a constant average observed link flow, the LSE is sensitive to the absolute error as opposed to the relative error. "In other words, an error of 1 veh/h for a flow of 10 veh/h is equivalent to an error of 100 veh/h for a flow of 1,000 veh/h. Clearly, this should not be the case" (Rakha, *et. al.*, 1998).

LPE error is normalized to the square root of the observed flow. "If a Poisson count distribution is assumed, the LPE error normalizes the error relative to the standard deviation. In other words, the LPE is the number of standard deviations of the link flow from the observed link flow" (Rakha, *et. al.*, 1998).

Visual inspection can be done easily by plotting the simulated flow against the observed flow, and seeing if the data falls close to a line drawn at 45 degrees. Visual inspection is quick, easy, and intuitive, but does not provide any quantitative measure of the results. Furthermore, in the Salt Lake study, visual inspection results did not always correspond with the results from LPE and LSE.

3.4.3.3.3.3 STOPPING CRITERIA

When using synthetic O-D calculation tools, it is important to set a goal for the level of error to be obtained. This can be done by calculating the change in error from one iteration to the next.

In some cases, the program may not be able to converge on a solution that is within the specified error limits. If this is the case, it is important to limit the number of iterations the program will perform. If this is not done, the program may become stuck in an endless loop, or run for an extremely long time.

3.4.3.4 Levels of Calibration

Common levels of calibration are discussed below. During calibration, it is invaluable to have the assistance of someone familiar with the network, especially at the more qualitative levels like visual and link flow calibration.

The calibration process for a large simulation is much different than for a small network. In a large network, it is not feasible to check every aspect of the model and its outputs; rather, aggregate measures are used.

3.4.3.4.1 Calibrating O-D Visually

The most basic level of calibration is done at the visual level. Most simulation models display the network and vehicles on the computer screen during the simulation process, enabling the model user to view the traffic flow. This visual output is very useful during the initial stages of calibration to check the general functioning of the network. For instance, it allows the modeler to see whether or not the general proportions of vehicles on each link appears correct, or is about the same as it is in the field.

For example, Bloomberg and Dale (2000) reported that on-screen animation was used to check coding accuracy and driver behavior in congested areas:

> "Occasionally…driver behavior was observed to be unrealistic (e.g., blocking traffic in the right lane to jump a long queue in the left turn lanes). In other cases, vehicles got "stuck" for periods of time. In these

> cases, changes to…input parameters (e.g., lane alignments, node locations, and driver behavior parameters) were needed."

3.4.3.4.2 Calibrating O-D using Link Flows

Following visual calibration, the most basic level of calibration is checking the simulated link flows against the observed link flows. Some studies have been performed using only visual calibration, but some quantitative measure of the goodness of the model is absolutely necessary. Link flows are the simplest and easiest measure to calculate, as link flows from both the simulation and the field are readily available. It should be noted that the link flows used for calibration must be different than those used for validation.

3.4.3.4.3 Calibrating O-D using Travel Time

Travel time calibration is the next step in accuracy up from link flow calibration. Link flows are much more numerous than travel time measurements, so link flow calibration should be performed as a minimum. Travel time calibration can supplement this.

3.4.3.4.4 Calibrating O-D using Speed and Acceleration Profiles

Even more detailed calibration can be performed using speed and acceleration profiles. These provide an additional level of confidence in the performance of the model by checking the expected behavior of the drivers using the network.

Each type of vehicle may have a unique acceleration profile. For this reason, several vehicle types are usually modeled, and unique speed and acceleration profiles are used for each vehicle. However, these vehicular characteristics are not usually measured in field surveys, or by field detectors.

New technologies such as AICC may provide this information in the future, because systems such as AICC track speed and acceleration continuously.

> "In a vehicle equipped with AICC a pulsed infra-red laser or radar can be chosen as the sensor to measure the distance from the next vehicle ahead and its relative speed…The regulator then calculates from this data the ideal speed at which a safe distance can be maintained. If the car is travelling at anything other than this ideal speed, the regulator issues the command "Faster" or "Slower", and the power output of the motor must then be regulated. Obviously such a system is continually monitoring

> vehicle speeds and headways so if this data was stored it would provide just the data required by micro-simulation models to accurately reproduce vehicle movements." (Bernauer, et. al., 1997)

The acceleration profiles for individual vehicles might also be randomized to capture the effects of different driver behaviors. This is particularly important for calculating emissions, because emission greatly depend on vehicle acceleration rates, which can be related to the relative aggressiveness of individual drivers.

3.4.3.5 Other Factors to Consider

3.4.3.5.1 Generated Traffic

Generated traffic is the combination of trips shifted in time, route, or destination, and induced vehicle trips (from mode shift, trip lengthening, and new vehicle trips).

Generated traffic is significant for a number of reasons. First of all, planning models usually overestimate future traffic, because traffic growth tends to slow as congestion increases. Conversely, increasing capacity does not tend to decrease congestion, because of induced travel and diverted traffic. This is illustrated in Figure 3-9.

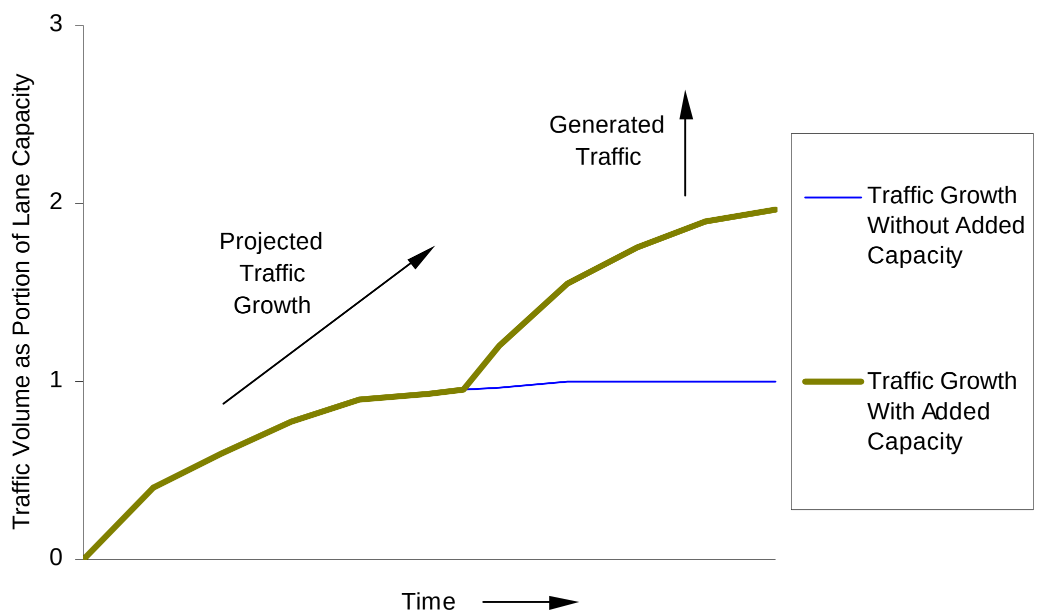

Figure 3-9: Generated Traffic
(Litman, 1999)

Induced Travel / Induced Demand: *If traffic is limited by capacity, there may be latent demand for travel. An increase in capacity will induce these trips, which may include trips shifted from other modes, longer trips, and new vehicle trips.*

Diverted Traffic: *If capacity is limited by congestion, an increase in capacity on that route will divert trips from other times (analogous to reversing peak spreading), routes and destinations.*

Incorporating generated traffic predictions into transportation simulations and evaluations may be difficult, because it is impossible to determine the impact it will have until a project is actually implemented. However, the impact can be estimated based on previous studies. For example, empirical data suggests that, on average, about half of new capacity will be filled by generated traffic in 5 years, and about 80% of the capacity increase will be filled eventually: "...Time-series travel data for various types of roadways indicates an elasticity of vehicle travel (VMT) with respect to lane miles of 0.5 in the short run, and 0.8 in the long run…Urban roads, which tend to be most congested, had higher elasticity values than rural roads, as would be expected due to the greater congestion and latent demand in urban areas" (Litman, 1999).

In California, similar effects have been observed. There, it is estimated that the 5-year elasticity of demand on county roads is between 0.6 and 0.7, and about 0.9 on municipal roads. The National Highway Institute estimates that "…the elasticity of highway travel with respect to users' generalized cost (travel time and financial expenses) is typically -0.5" (Litman, 1999). A composite illustration of the capacity studies is shown below in Figure 3-10.

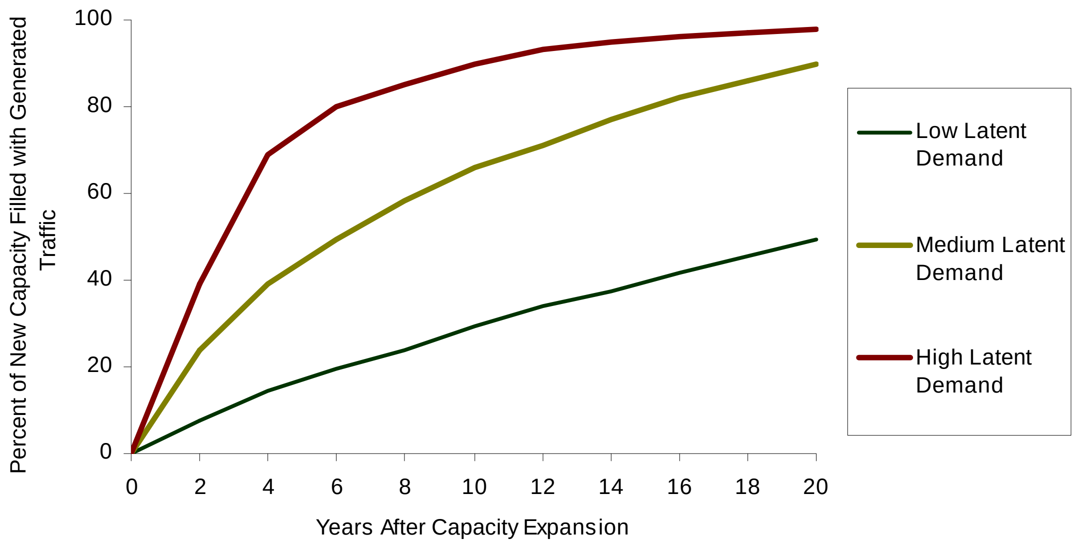

Figure 3-10: Elasticity of Traffic Volume with Respect to Capacity
(Litman, 1999)

Even if the impacts of generated traffic were known, it would be difficult to assess the value of the transportation projects being proposed. While capacity increases may not result in decreased congestion, they will almost certainly result in increased mobility. The conundrum, then, is valuing the benefits actually anticipated. This is complicated when one considers that the generated trips are often non-essential (not for work). Valuing benefits is the single most difficult and imprecise aspect of evaluating transportation projects, and is addressed, in part, in Section 3-5.

3.4.3.5.2 Count Locations

As discussed above, the quality of the traffic counts used to estimate an O-D matrix directly affects the quality of the matrix obtained (Yang and Zhou, 1998). Methods for maintaining flow continuity were discussed above, but these methods will not fix bad data, only make it so the O-D program can find a mathematical solution. Therefore, it is important to structure the data collection effort so that the data obtained provides a good description of the actual network flows. The quality of the data does not only depend on the quality of the link counts, but also on where the link counts are made.

3.4.3.5.3 Peak Period/24 Hour Measurements

Often, the peak period(s) is not the only time that modelers would like to model. For instance, the time before and after the peak period may be of interest to analyze the impacts of traffic control strategies. Also, the impacts of off-peak special events or construction projects may be of interest.

3.4.3.5.4 Incidents

Incidents affect the effectiveness of traffic control strategies. Some traffic control measures such as VMS are most effective during divergent traffic conditions. Many ITS technologies are intended to primarily, or frequently, alleviate congestion caused by incidents. It is therefore necessary to model the use of these technologies or changes in operational strategies during an incident, in order to better understand how they will impact network flow.

3.4.3.5.5 Alternative Routes

Alternative routes should be provided for the vehicles on the network. As discussed previously, some simulation programs do not allow traffic to pass through an O-D node, or assess a penalty for trips made through O-D nodes. This should be considered when constructing the network. In general, the network should include all routes that may be used as alternate routes. This includes routes at the boundary of the study area: the simulation should include major corridors adjacent to the study area if these corridors might be used for traffic re-routing.

3.4.3.5.6 Using Reduced Demand

During the initial stages of network development and calibration, the modeler must verify that the basic configuration of the model is performing correctly. Because running the simulation with the full demand takes a long time, these basic checks can be performed with a reduced demand. Some aspects of the configuration that can be made while running the simulation with a reduced demand are:

- Locations of stop signs and traffic lights
- Signal timings

- Unexpected bottlenecks or obstacles
- Lane striping and network configuration

3.4.3.5.7 Simulation Loading Period

When the simulation model begins, it takes a while before the full demand is loaded onto the network. While some aspects of the simulation can be checked during the loading period, others cannot be checked until the full demand is loaded. Likewise, the Measures of Effectiveness (MOEs) or Measures of Performance (MOPs) cannot be evaluated during the loading phase. Therefore, the data output from the model before the loading is complete should not be used.

3.4.4 Summary of Calibration Recommendations

An unsuccessful calibration attempt may be the result of any number of problems. Unfortunately, it is often impossible to determine which problem or combination of problems is at fault. The problems can be grouped into three major areas:

- Field data may be of insufficient quantity or quality
- Input parameters may be incorrectly calculated from field data
- Model logic may be faulty or incapable of representing some phenomena

In summary, the recommendations below are useful in providing the best chance of avoiding the first of these two problems:

- Start calibration with the off-peak periods in order to isolate problems with the node, link and traffic signal coding.
- During calibration under congested conditions, screen output provides an ideal means to identify bottlenecks.
- Start calibration using visual inspection of traffic flow to identify and fix problem areas
- Start O-D calibration using a visual inspection of the model output flows compared to observed link flows (Rakha, et. al., 1998)

Finally, the calibration parameters must fit the local conditions. Rilett and Kim (2000) found that their results varied "…as a function of the estimated O-D matrix and the calibrated parameters. It was found that the best calibration parameter for TRANSIMS was different than that recommended in the user manual."

3.5 Running the Model and Analyzing the Results

After the model has been calibrated, it will be ready to provide a reliable representation of the system to be studied. The modeler must now decide what situations will be investigated, and what MOEs will be used to evaluate each of these situations.

After the model user has decided what is to be modeled and what scenarios are to be tested, it is important to set up a plan of action for running these scenarios. The scenarios should include sensitivity tests, because the significant variability demonstrated in real-world systems—particularly with respect to demand—requires modelers to attempt to reproduce this variability. For this reason, it is important to determine if the variations in demand seen in the simulation outputs are consistent with the day-to-day variations in field-measured, or predicted field flows. This process, called sensitivity testing, involves conducting several random runs for each scenario. Sensitivity testing is discussed below in Section 3-5.1.

Every permutation studied, however minor, greatly increases the complexity of the study. As discussed below, this complexity is compounded by the need to conduct sensitivity analyses on the results. Model users should therefore be careful in selecting which factors are accounted for in the simulation. Changes in weather, traffic management and control strategies, incidents, and traffic are all areas of interest, but often there is not enough time or money to exhaustively investigate all possible combinations of these. While the interaction between each of these variables cannot be discounted, it is sometimes necessary to study each one independently.

The selection and calculation of MOEs are discussed in Section 3-5.2 and Section 3-5.3, respectively, and the statistical analysis of the results is discussed in Section 3-5.4.

3.5.1 Sensitivity Analyses

As discussed previously, the simulated changes induced by applying different traffic control strategies or demand forecasts must be compared to the day-to-day fluctuations in traffic flow. Stochastic models must use several random seeds for a meaningful analysis. Sensitivity analyses are a vital part of any simulation project; without them, the level of confidence in the results is small.

The following is a description of a typical sensitivity analysis, in this case, a comparison of the VISSIM and CORSIM models:

> "Ten (10) runs were made for each scenario and model. Since both VISSIM and CORSIM are stochastic (random) models, there may be minor differences in the results depending on the random number seed. Averaging the results from multiple runs addressed this issue…
>
> Different measures of effectiveness were used. A qualitative assessment of each scenario was made by observing traffic (using the on-screen animation provided by both models). Then, comparisons of travel time on specific routes (illustrated in Figure 2) were made. Finally, systemwide measures of effectiveness (e.g., delay, speed) were assessed.
>
> A sensitivity analysis was conducted, where demands were increased and decreased by 10%. In other words, factors of 1.10 and 0.90 were applied to all demand inputs, and results were analyzed.
>
> A total of 180 runs were made with each model. There were six design alternatives and ten model runs were conducted for each. With the sensitivity analysis, each set of alternatives was analyzed three times with varying demand assumptions." (A Comparison of the VISSIM and CORSIM Traffic Simulation Models On A Congested Network)

Each set of runs made must then be subjected to a statistical analysis to determine the probability the results from the sets are in fact different.

The statistical analysis of the results is discussed below in Section 3-5.4.

3.5.2 Choosing Measures of Effectiveness

The U.S. DOT developed evaluation measures for six ITS goals. "The ITS Joint Program Office of the U.S. DOT advocates the use of what has been termed "a few good measures," which consists of a "few measures robust enough to represent the goals and objectives of the entire ITS program, yet are few enough to be affordable in tracking the ITS program on a yearly basis". These "few good measures" are crashes, fatalities, travel time, throughput, user satisfaction or acceptance, cost (Turner and Stockton, 1999). Appendix C shows the measures at they relate to each of these goals.

Even when the measures of effectiveness used to evaluate the results of a model are used with a good knowledge of what they mean, it may not be possible to objectively compare different projects. This is because the monetary value of some MOEs are not well-defined (e.g., there's really no consensus on how to measure the value of a life).

Due to this limitation, "…monetary evaluation has been complemented in the past decade with a variety of nonmonetary evaluation methods known as multicriteria methods. It is noteworthy that the debate on conventional cost benefit analysis (CBA) and multicriteria analysis tends to regard these two approaches as complementary rather than competitive analytical tools" (Tsamboulas, *et. al.*, 1999).

It may be impossible to satisfactorily place a value on the measures tracked by simulation models, but these measures can still be used to gauge the performance of competing projects. Guidelines for doing this with ITS projects are prescribed in the TEA-21 ITS Evaluation Guidelines. (JPO, 1999) While these guidelines make recommendations for the MOPs to be used, they do not specify how important each of them is. Instead, the key stakeholders in a project identify the most important goals, and decide the relative importance of each. For instance, a city that is on the brink of violating air pollution regulations set forth in the Clean Air Act Amendments (CAAA) of 1990 may make reducing emissions the primary goal. An independent party is then responsible for evaluating the projects to pick the best MOPs.

A simplified summary of the measures shown in Appendix C is given in Table 3-2. More detailed information about these measures, as well as guidelines for calculating them, is provided in the ITS Evaluation Resource Guide, available from the U.S.DOT's Joint Program Office (JPO).

Table 3-2: Simplified MOEs

Goal	Measure
Safety	Reduce overall crash rate
	Reduce fatal crash rate
	Reduce injury crash rate
	Improve Surrogate Measures of Safety (e.g., reduction in red light violations, drivers shown to slow in response to messages warning of accidents or inclement weather)
Mobility	Reduce travel time delay
	Reduce travel time variability
	Increase Customer Satisfaction [1]
	Improve Surrogate Measures
Efficiency	Increase throughput or effective capacity[2]
Productivity	Cost savings [3]
Energy and Environment	Reduce emission levels [4]
	Reduce energy/fuel consumption

[1] Customer Satisfaction can be evaluated based on the following criteria: Product awareness, Expectations of product benefits, Product use, Usability of Product (if applicable), Quality of Information Provided (if applicable), Credibility of Information Provided (if applicable), Response – Decision-making and/or behavior change, Realization of benefits, and Assessment of value.

[2] The Highway Capacity Manual (HCM) defines capacity as the "…maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a given point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions." Effective capacity, however, is also dependent on roadway and weather conditions.

[3] Either as compared to traditional improvements, or as compared to existing conditions.

[4] Carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOCs) such as hydrocarbons (HC).

The measures described above apply both to commuter and freight projects, to one-mode and intermodal projects. Incident response programs may also want to model the duration of incidents and the resultant impact on the MOEs listed. In addition, it may be desirable to use the simulation package to evaluate the operational strategies that take effect in the case of a local or widespread failure in the ITS control system.

Using the "few good measures" described above will help ensure that the best strategy is selected. It is important to use more than one measure because multiple measures provide a higher level of confidence when comparing alternatives, and because different stakeholders have different interests.

3.5.3 Calculating Measures of Effectiveness

There are many different outputs from a simulation model, and it is important that the model user is cognizant of how these outputs are calculated, as they frequently differ between the competing models, and may not be the same as "standard" practice.

For example, the authors of "Urban Traffic Network Flow Models" had to alter the way NETSIM calculated stopped versus running time in order to be able to compare the results to the macroscopic models.

All MOEs should be calculated based on individual vehicle statistics, because the number of vehicles may vary from one simulation to the next, depending on the seed used to calculate the demand. If this is not done, a random run of the model with a few more cars may demonstrate more delay and more accidents, for example, than another random run using exactly the same network configuration and operational parameters.

Furthermore, the MOEs should be analyzed with the entire network in mind—improvements in one part of the network may cause negative impacts in other parts of the network. While some parties may have a vested interest in only one aspect of the transportation network, and localized impacts are often important, the goal of simulation is usually to provide the best possible transportation system possible, not just one that solves one problem at the expense of another. For this reason, multiple MOEs should be used to illustrate the overall impacts of each project:

> "Often, a single performance measure (e.g., delay or speed) is used to draw conclusions from a study…. Evaluation using multiple measures was found to be superior for three reasons:
>
> - Different models may have different ways of producing results. For example, control delay (at a signal) is measured differently, depending on the model.
> - Multiple measures provided more confidence when comparing alternatives (i.e., demonstrating that more than one performance comparison suggested a superior alternative).
> - Different stakeholders have different interests (e.g., access to a particular garage), while others have system views" (Bloomberg and Dale, 2000)

Important issues regarding some of the more common MOEs are discussed below.

3.5.3.1 Delay

Delay to transportation system users is typically measured in seconds per vehicle or minutes per vehicle. Delay can be measured in many different ways depending on the type of transportation improvement being evaluated. For example, when evaluating mobility gains of an adaptive traffic signal control system, the "floating car" method can be used to measure the delay experienced before and after installation of the system. In the "floating car" method, evaluation personnel measure the time it takes a probe vehicle to traverse an arterial, usually using a stopwatch or other time measurement equipment. Delay can also be measured by observing the number of stops experienced by the drivers before and after a project comes on-line.

It is important to decide which delay measures are paramount, or which combination of delay measures will be used to evaluate the projects studied. For instance, total delay at an intersection may decrease if phase length on the main corridor is increased, but this improvement may increase delay on the side street to an unacceptable level.

3.5.3.2 Fuel Consumption and Emissions

In INTEGRATION, fuel consumption and emissions equations are based on 4^{th} order regression equations; a specific is used for each vehicle type. The equations were derived from experimental data provided by the Oakridge National Laboratory (Ahn, *et. al.*, 1999).

The emissions equations are irrelevant, however, if the simulated vehicle speeds and accelerations do not closely represent actual speed and acceleration profiles. For example, Rilett and Kim (2000) found that the TRANSIMS model underestimated travel times, and the CORSIM model overestimated travel times. More importantly, "…the variability in TRANSIMS link travel times was significantly lower than what was observed on the actual highway system. It was hypothesized that this might effect certain MOE's that are derived from the model such as vehicle emissions" (Bloomberg and Dale, 2000).

3.5.3.3 Crash Rates

It is difficult to predict how traffic projects will impact crash rates without using simulation. Instead of predicting the accident risk based on driver behavior, simulation models that incorporate crash risks do so by converting accident data into relationships describing the frequency and severity of crashes as a function of facility type and traffic volume.

Existing data about crash rates is sometimes recorded by police. However, because some accidents are unreported, it is difficult to know how many accidents actually occur. Furthermore, only some of the factors influencing these accidents are recorded. Even in areas where accident statistics are kept, there is often not enough information to correlate changes in accident rates with modifications to the transportation facility.

For these reasons, some simulation models supplement the crash database records with vehicle exposure data. For instance, the INTEGRATION model began by deriving crash rates from a database containing over six million crashes throughout the United States. This information was supplemented with vehicle exposure data, which was stratified by facility type.

Overall, injury and fatality crash rates can be measured in the number of crashes per unit time. However, given that highway crashes are highly random events with a likelihood of occurrence that increases as travel increases, normalizing crash rates by including an exposure factor, such as million vehicle miles traveled, is recommended.

3.5.4 Statistical Significance of Measures of Effectiveness

Because each simulation is a likely outcome of many stochastic events, the results for each run will be different—several different outcomes may be observed for each scenario. Therefore, the modeler must check these outcomes—first, using sensitivity tests to ensure that the model behaves as the subject, and second, to use statistical tests to determine if the outputs from different simulation scenarios are the same. More exactly, the modeler must check that the changes in the MOEs between the scenarios are smaller than the changes between different random runs of the base case.

Therefore, the results from each of the simulations conducted must be analyzed to determine if the changes between each scenario are statistically significant. Because random simulations will produce normally distributed results, and because fewer than thirty runs for each permutation are typically conducted, the student's *t*-test should be used. More detailed information about conducting the student's *t*-test is presented below.

3.5.4.1 The Student's t-test

When conducting a statistical analysis, if the sample size is larger than 30, then the standard deviation of the entire population (σ) can be estimated using s, the sample standard deviation. The central limit theorem can then be used "…to find bounds on the error of estimate and confidence intervals for μ" (Brase and Brase, 1999). This is not the case, however, for most simulations, which conduct several runs with each configuration. For example, the case study presented in Chapter 4 of this thesis used 5 runs for each scenario investigated to account for the effects of fluctuations in the day-to-day demand.

For those situations where large samples are not available, the standard deviation of the *sample* must be used instead of the standard deviation of the population, which cannot be estimated. “There are many practical and important situations, however, where large samples are simply not available…To avoid the error involved in replacing σ by s—i.e., approximating σ by s—when the sample size is small (less than 30), [the] *Student’s t variable* [is used]” (Brase and Brase, 1999). The *t* variable is defined in Equation 1.

$$t = \frac{\bar{x} - m}{\frac{s}{\sqrt{n}}} \qquad [1]$$

In Equation 1, $\bar{x}$ is the mean of a random sample of n measurements, is the population mean of the x distribution, and s is the sample standard deviation. It is helpful to note that *t* is nearly the same as the *z* statistic used for analyses involving more than 30 measurements, except z is calculated based on s instead of *s*.

The first step in using the *t* statistic is deciding what to test. For instance, the travel times reported from re-timing the signals on a network could be tested to see if they are different than the travel times for the base case. In order to test this, a null hypothesis (H_o) must first be developed. It is convenient to use the hypothesis that the average travel times for the new case and the base case are the same. If this hypothesis is not rejected at the end of the test, it cannot be concluded that there is any statistical difference between the base case new case.

The second step is deciding what level of significance to use—how important is it to avoid rejecting a true hypothesis? That is, how important is it to avoid believing that the two means are equal when in fact, they are not? For engineering applications, a critical value of $\alpha = 0.05$ is usually used; this is equivalent to saying that the confidence interval is 95%. Furthermore, a two-tailed test should be used—the variable being measured may may be either higher or lower than the mean. The critical *t* values using a two-tailed test for $\alpha = 0.05$ are given in Table 3-3. Because several runs are necessary for a trustworthy statistical analysis, only those values used for sample sizes of five or more are presented.

Finally, the statistical measures are calculated, and the sample *t* value is evaluated and compared to the critical *t* value (*T*), which is looked up in a reference table. Table D-1 is a short version of such a table. If the sample *t* value is greater than the critical *t* value, the hypothesis is rejected—i.e., the means are probably different.

If the hypothesis is rejected, the sample t value will give no indication of how different the means might actually be. There is another statistical measure, however, that does this: the *P* value (for *P*robability). The *P* value is the probability that the observed values could have been taken from the base case values. Therefore, the smaller the *P* value is, the greater chance that the two samples came from different populations.

To calculate the *P* value, the sample t statistic is calculated as discussed above, then instead of comparing it to *t*-test, it is used to find the corresponding confidence interval from the *t* tables. The P value will fall between two of the confidence intervals, for example, between .010 and .020. This says that the probability that the two means are equal is between 1 and 2%.

A recommended modification to the student's *t*-test, one that was used for the studies presented in Chapters 4 and 5 of this thesis, is the paired *t*-test. The paired *t*-test is discussed in Appendix D.

3.6 Further Research

Some of the factors discussed in the body of this document warrant additional research, such as generated traffic, real-time control, human behavior, improved evaluation metrics, and emissions modeling. The review of microscopic simulation model capabilities presented in Chapter 2 highlights the inadequacies of current simulation packages. For instance, very few models are capable of modeling on-street parking, variable speed limits, or the effects of weather. Some additional aspects that need to be investigated are discussed below.

3.6.1 Generated Traffic

As discussed in previous sections, generated traffic has a significant effect on actual network operations: empirical evidence shows that about 80% of any capacity increase is eventually consumed by generated traffic. This has profound implications for operational-level projects, because it indicates that benefits from these projects will not be in the form of travel time savings. Increasing the credibility and accuracy of simulation tools depends on satisfactorily modeling all major real-world phenomena, and generated traffic is one of these phenomena.

3.6.2 New Evaluation Methodologies

Because the benefits from operational level projects are likely to be in forms other than travel time savings (please see the discussion of Generated Traffic above), it is important to have comprehensive measures that quantify the impacts of many different measures of effectiveness. No evaluation methodologies currently provide an objective and comprehensive function for accomplishing this.

Before this idealistic, universal formula is pursued, however, transportation modelers should first be aware of the importance of using multiple measures of performance, which are desirable because they help ensure a project is judged based on all of the impacts it may have. This is particularly important because there are different ways to calculate any given measure, and because the stakeholders in the project may be interested in different impacts, or may only be interested in the generalized impacts

3.6.2.1 Monetary Evaluation Methodologies

The most straightforward way to evaluate the effectiveness of an engineering project is to express the costs and benefits of the project in monetary terms. It is, however, impossible to adequately value some measures. For example, while it is possible to place a value on emissions or a human life, it is not likely that everyone will arrive at a consensus on these values.

Because of this inherent difficulty, transportation projects are usually evaluated based on the qualitative value of some specific quantitative measures. In the future, a more comprehensive assessment of the impacts from transportation projects may be possible using other evaluation methods. Coupling monetary measures with nonmonetary measures should be regarded as “…complementary rather than competitive analytical tools" (Tsamboulas, et. al., 1999).

3.6.3 Temporal Changes in Traffic Flow

Current Microscopic simulation models are based on average flow rates, which do not capture the fluctuations in flow, which can significantly impact network performance. These short-term ebbs and flows in demand should be captured to more accurately reproduce the dynamic traffic flow behaviors.

3.6.4 Simulation and Real-Time Network Control

Ultimately, simulation could provide network owners a means of constantly updating control strategies to achieve the best possible traffic control. The growing communications infrastructure, in conjunction with AVI, improved network detection, and other, emerging, technologies, will expand the possibilities for intelligent traffic control.

This real-time, coordinated network optimization may make use of neural networks or other semi-optimal approaches techniques, but simulation will prove a useful tool to develop and evaluate these techniques.

3.6.5 More Robust Emissions Modeling

Many simulation packages do not have emissions models, and many that do use only an incomplete array of simple factors such as distance and speed to calculate emissions. Even the more advanced emissions models—those that use speed and acceleration profiles—are woefully inadequate.

Pollution dispersion is also an area of interest, especially for types of pollution typically unaccounted for such as noise pollution. The universal emissions modeling inadequacies found in the traffic simulation field present a large area of useful research that can, given current technology, be improved in the near future.

3.6.6 Modeling Human Behavior

Human behavior is the most complicated of all the phenomena modeled in simulation. First of all, there is not sufficient research to document human behavior, and human behavior is more variable than other factors of transportation modeling. Second, even when behavioral patterns are well documented, it is difficult to express human behaviors using uncomplicated probabilistic relationships. Some technology such as neural networks may hold promise for representing complicated human behaviors, but such techniques are only just emerging. The lack of research in this area, and the large potential it has to improve simulation results, make it an exciting and promising, if daunting, avenue for future research.

3.6.7 Modeling Multiple Modes

Typically, traffic simulation models do not account for pedestrian, cyclist, or public transportation traffic. While some models do incorporate these, they cannot do so at a truly microscopic level.

3.6.8 ITS

Many simulation packages cannot model some common ITS strategies, and many cannot model common geometric configurations such as HOV lanes and roundabouts. More importantly, very little research has been done on the effects of ITS on non-recurrent congestion, such as during an incident.

3.6.9 Conclusions

Continuing research will increase the capabilities and the usefulness of microsimulation models. Because increases in processing speed "…generally result in greater capabilities of the models that run on them…it should soon be possible to see much more detailed micro-simulation models developed that deal with aspects that today's models consider too computationally expensive" (Bernauer, *et. al.*, 1997). The aspects discussed above will certainly benefit from these increases in processing capabilities, but some of the aspects mentioned need a better theoretical foundation before they can be used in the simulation framework.

3.7 Summary

Microscopic simulation, already a useful tool for evaluating many kinds of transportation projects, shows the potential to become an invaluable tool for evaluating traffic control projects both off-line and on-line. This chapter has established the recommended procedures and the other factors that should be considered when using microsimulation models.

This chapter has presented background information about microscopic simulation, and an outline of the more important considerations made during the construction and operation of a microscopic simulation network. Network construction, calibration, and data analysis, the core items of the simulation process, were covered in great detail.

The suggestions made in this chapter constitute a comprehensive, if necessarily superficial, coverage of the issues encountered during a microscopic simulation endeavor; many researchers will continue to investigate the items addressed herein. However, these suggestions provide a good overview for applying microscopic simulation tools to traffic analysis projects. The following chapters—Chapter 4 and Chapter 5—present case studies; these will reinforce the topics addressed in this chapter, and provide useful insight to the issues encountered during real projects.

CHAPTER 4: THE SOUTHERN/BASELINE STUDY

4.1 Introduction

This section presents a case study of the Southern/Baseline roadway corridors in Phoenix, Arizona. This study was conducted as part of the Metropolitan Model Deployment Initiative (MMDI), and was done to help quantify the benefits of installing and operating different Intelligent Transportation Systems (ITS) within urban areas. Peak hour traffic on the corridor was modeled, and ITS strategies were implemented within the model to estimate the impacts of each strategy.

4.1.1 Objective

The objectives of the study were twofold. First, it was intended to show that simulation provides unique opportunities to conduct different sensitivity analyses to evaluate conditions that were not necessarily observed in the field. Second, the study provides specific results in terms of potential benefits of alternative ITS scenarios.

The ITS control strategies investigated herein include real-time traffic signal optimization, and variable message signs. Each of these control strategies is evaluated using simulation to determine potential benefits in traffic flow, traffic safety and environmental impacts.

4.1.2 Metropolitan Model Deployment Initiative

The Metropolitan Model Deployment Initiative (MMDI) is a project designed to evaluate the benefits of deploying and using Intelligent Transportation Infrastructure (ITI) in an urban environment. Four cities were chosen to receive funding for the MMDI project: New York, San Antonio, Phoenix, and Seattle. The Center for Transportation Research (CTR) at Virginia Tech was chosen to assist in the evaluation of the Seattle, San Antonio, and Phoenix deployments.

4.1.2.1 Phoenix MMDI

The Phoenix portion of the MMDI, also known as AZTech, is a seven-year project that attempts to develop and integrate ITS for the Phoenix Metropolitan area. The goals of AZTech are to produce freeway and arterial street networks that are safer and more efficient for the traveling public, to decrease travel time, and to enhance mobility.

AZTech implements and integrates several ITS projects to achieve a regional ITS system. The major efforts include the instrumentation of eight arterial Smart Corridors for cross-jurisdictional signal coordination and traffic detection. Part of this system includes a multi-modal Advanced Traveler Information System (ATIS) to provide real-time traveler information via an array of media and devices. The system will also include a GPS-based Automatic Vehicle Location (AVL) system with a Mobile Data Terminal (MDT) to assist transit operations and provide real-time bus status information to transit users. Furthermore, a Total Station computer-aided incident investigation system is being deployed to reduce incident clearance time. Finally, a regional communication network and a central server are being developed to integrate traffic, transit, and incident management functions across different jurisdictions.

4.1.2.2 The Southern/Baseline Corridor

The Southern Avenue/Baseline corridor was selected as one of the smart corridors within the AZTech MMDI proposal because it is one of the busiest east-west arterial corridors in the Phoenix Metropolitan area. Although the plan was to coordinate traffic signals across the jurisdictional boundary between the City of Mesa and the City of Tempe, this effort did not materialize. Consequently, hypothetical modifications to different operational strategies were evaluated, including interjurisdictional traffic signal coordination. Other ITS control strategies that were evaluated included real-time adaptive signal control and the use of Variable Message Signs (VMS) for the display of traffic information. Each of these control strategies was evaluated using simulation to determine their efficiency, energy, environmental, and safety impacts. This chapter will focus on the Southern and Baseline corridor of the Phoenix deployment.

4.1.3 Study Area

The study area encompasses approximately 10.5 square miles in the cities of Tempe and Mesa, Arizona. This area, shown in Figure 4-1, includes three major parallel corridors oriented East to West: Southern Avenue, US 60 (Superstition Highway), and Baseline Road. The Western boundary of the study area is 48th Street in Tempe; the Eastern boundary is Gilbert Road in Mesa.

The three primary corridors are approximately 10.5 miles long: 5 miles in Tempe, and 5.5 miles in Mesa. Traffic in the study area is primarily from the East to the West during the AM peak, and West to East during the PM peak.

Mesa Community College and Arizona State University, which are significant trip generators and attractors, are located in the middle of the study area and approximately one mile North of the study area, respectively.

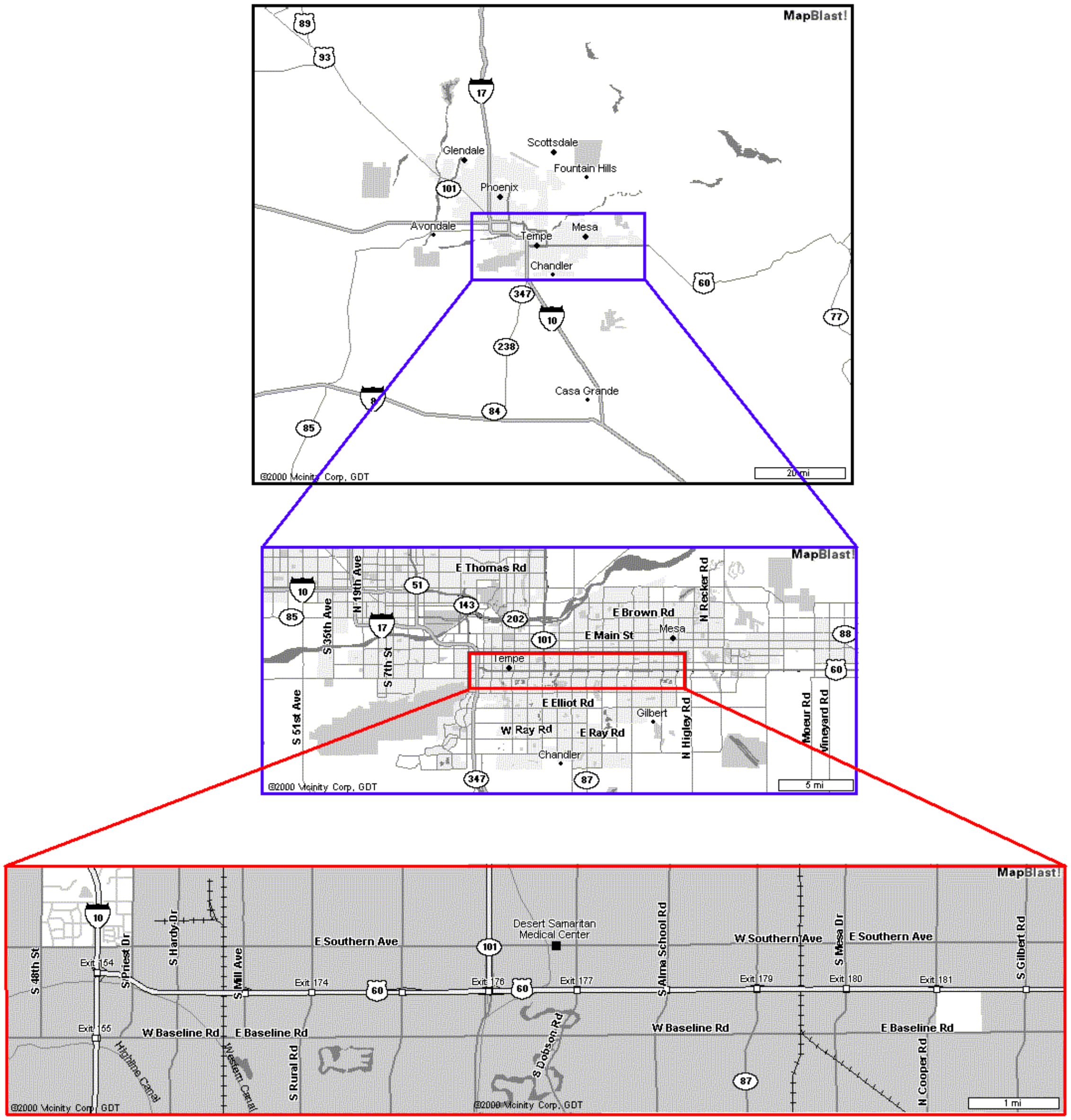

Figure 4-1: Southern/Baseline Study Area
(maps courtesy of MapBlast!)

4.2 Data Collection

In order to establish the base case field conditions and to investigate the potential for traffic growth over a two-year period, two data collection efforts were conducted. The first of these data collection efforts involved collecting tube and turning movement counts at a number of traffic signals in 1998. This data was used to calibrate the demand for modeling the network benefits of hypothetical ITS control strategies. The second data collection effort included collecting speed measurements from floating cars that traveled along Southern Avenue, Baseline Road, and US 60. The floating car data runs were performed in August 1997 and in June 1999.

4.2.1 Turning Movement and Tube Counts

Turning movement counts were collected at 18 intersections within the study area, including the intersection of Southern Avenue or Baseline Road with the following roads: Gilbert, Stapley, Horne, Mesa, Country Club, Extension, Alma School, Longmore, Dobson, Freeway 101, McClintock, Rural, Mill, Karen, Hardy, Priest and 48th Street.

The turning movement counts were collected for the AM peak and PM peak periods at 15-minute intervals. In addition to these counts, pneumatic tube traffic counters were installed at 14 locations to collect traffic volumes for an entire day. Figure 4-2 illustrates an example of the temporal variation in traffic volume over a typical weekday. The figure demonstrates a peak in demand in the westbound direction during the AM peak and a peak in demand in the eastbound direction during the PM peak.

The turning movement and tube counts were utilized to calibrate the traffic demand within the simulation environment to the field conditions.

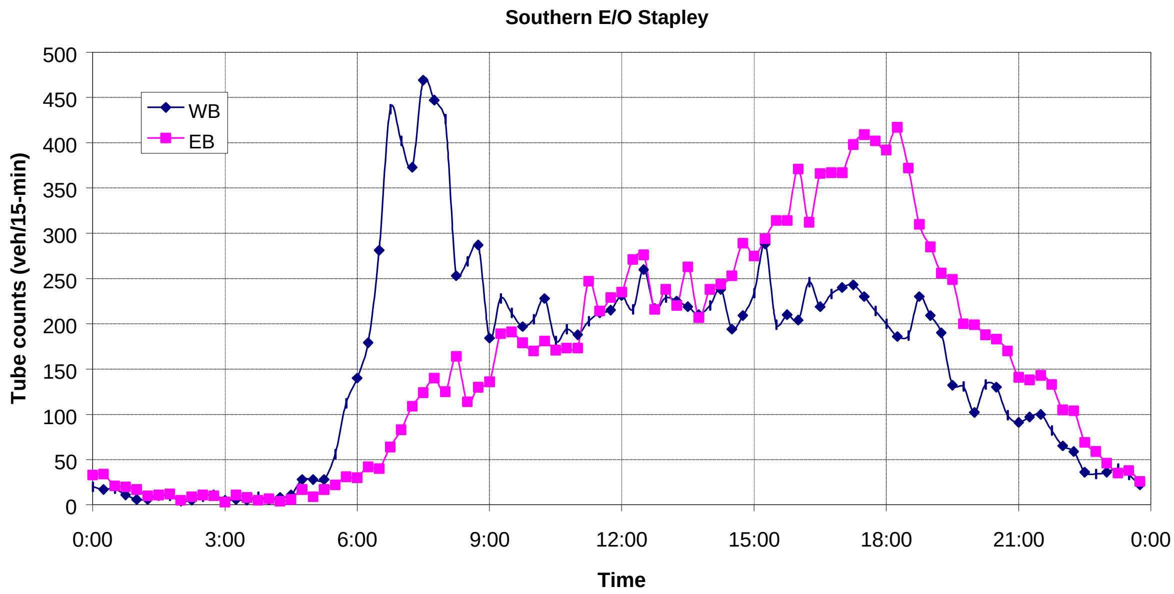

Figure 4-2: Temporal Variation in Traffic Flow along Southern Road (Southern E/O Stapley)

4.2.2 GPS Data Collection

The data collection effort also included collecting instantaneous speed measurements from floating cars that traveled along Southern Avenue, Baseline Road and US 60 in 1997 and 1999. These floating cars were equipped with a Global Positioning System (GPS) unit that measured the vehicle's speed every second.

A number of GPS-equipped vehicles were driven along the study corridor (along the three parallel roadways) for three days (Tuesday through Thursday) in 1997 and 1999. The GPS runs were conducted during the AM peak (7:00 to 9:00 AM) and the PM peak (4:00 to 6:00 PM). The GPS unit measured the vehicle's latitude and longitude location, its heading, and its speed every second or in some cases every two seconds. The speed was measured based on the shift in the GPS signal (Doppler technology). It should be noted that the GPS unit did not include any differential correction resulting in a vehicle location accuracy to within 100 meters. However, the relatively low accuracy in locating the vehicle had no bearing on the accuracy of the speed estimates given that they were not computed from the vehicle location.

The runs covered an approximately 20-km section of the corridor that ran from Gilbert Road to the East to 48th street to the West. A total of 60 runs were made, with 38 runs conducted in 1997, and 22 runs in 1999. While the data obtained were not used in an iterative calibration procedure, they were used to reinforce the statistical tests performed on the simulation outputs.

4.3 Simulation Model Development

The simulation network was created using the Maricopa Association of Governments (MAG) planning model (in this case EMME/2) of the greater Phoenix area. The planning model covered over 7,200 square kilometers with a total of 9,529 nodes, 27,840 links and a total demand in excess of 2 million trips for the AM peak. The O-D demand for the AM peak included Single Occupancy Vehicle (SOV), High Occupancy Vehicle (HOV), and bus trips, and was created using the standard four-step planning process.

The network was modeled using the INTEGRATION microscopic traffic simulation and assignment model (Van Aerde, 1999). The INTEGRATION model was selected for the evaluation for three main reasons:

- In order to capture differences in energy and emissions as a result of traffic signal coordination the model had to be able to capture instantaneous vehicle speeds and accelerations, a feature unique to microscopic simulation models.
- In order to capture spatial and temporal diversion in demand as a result of changes in signal timings, the model had to include routing capabilities, which is a unique feature that distinguishes INTEGRATION from other microscopic simulation models.
- The model had to be a validated model that has been applied in the field to numerous real-life problems.

4.3.1 Defining Node and Link Characteristics

In order to effectively model the study area, the planning model had to be reduced to a manageable size, while still being large enough to allow the modeling of traffic diversion. The procedure used is summarized in Figure 3-4.

The links and nodes from MAG's planning model were first converted to INTEGRATION format; then, the INTCROP tool was used to extract those links and nodes within the study area. As mentioned in Chapter 3, INTCROP is a tool designed for use with the INTEGRATION microscopic simulation model. INTCROP added several nodes around the perimeter of the network to serve as boundary origins and destinations. It should be noted that several widening projects were underway at the time the INTEGRATION model was constructed. The model represents the conditions as of June 1999.

The Southern/Baseline INTEGRATION network used for the evaluation of this project, shown in Figure 4-3, ultimately included a total of 883 nodes, 1484 links, and a total peak hour demand of approximately 54,250 vehicles.

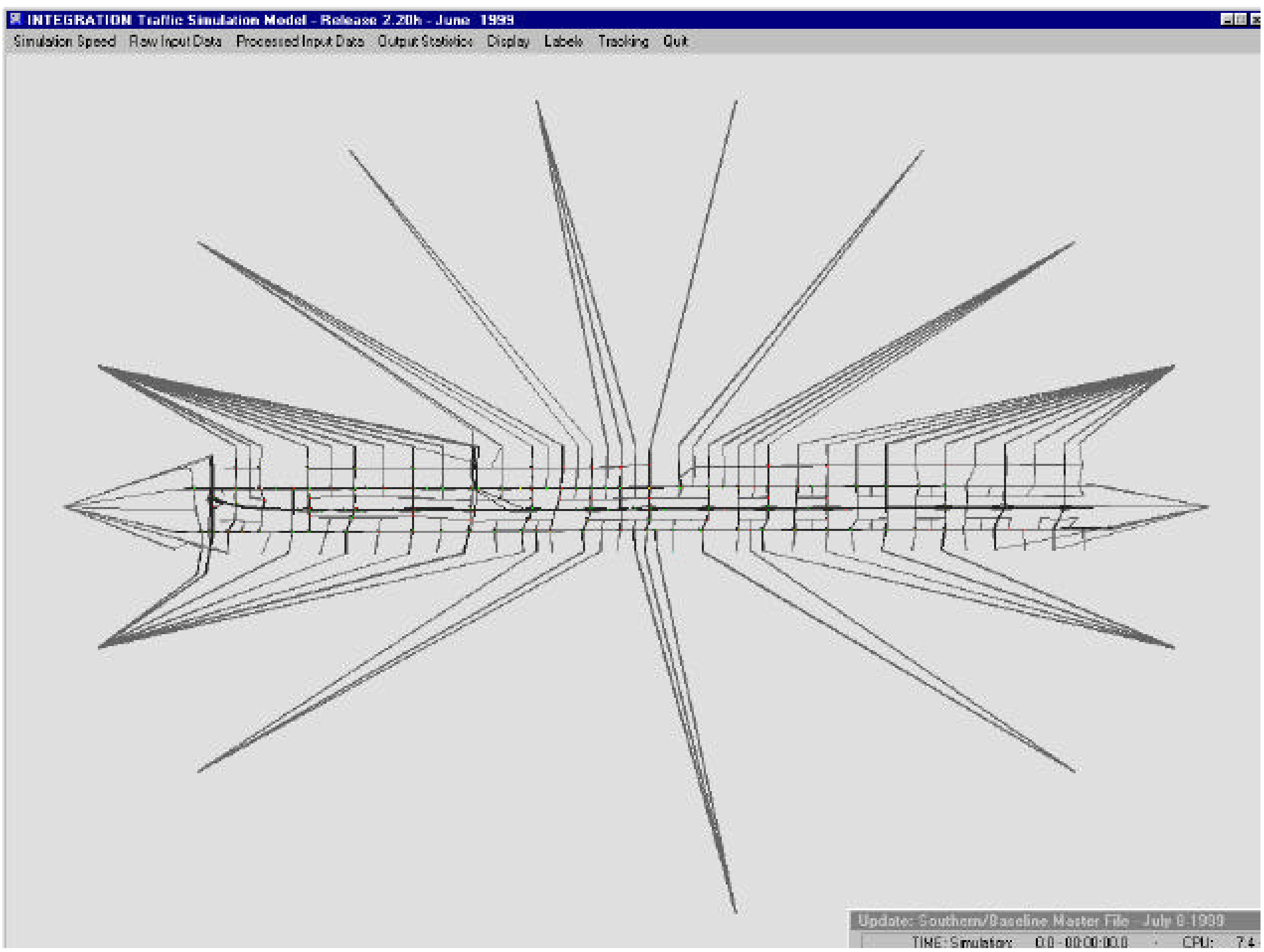

Figure 4-3: Southern/Baseline INTEGRATION Network

4.3.2 Network Refinement

4.3.2.1 Turning Bays

Because the INTEGRATION model, like many other models, assumes uniform geometric characteristics along a link, additional links were added to the network in order to model pocket lanes at signalized approaches. The Southern/Baseline was modified to match conditions as observed in the field as of June 1999.

4.3.2.2 Lane Striping

Lane striping information is important to the simulation model because it governs the restrictions on vehicular movement. The simulation network was further enhanced by adding lane striping characteristics at the approaches to the signalized intersections. Original lane striping information was obtained from a Synchro file provided by the cities of Tempe and Mesa. In addition, the lane striping information was confirmed during a field visit in June of 1999 and was supplemented by aerial photos provided by MAG.

4.3.2.3 Traffic Control

Within the ITS scenario evaluation, three types of traffic control were simulated: traffic signals, ramp meters, and VMS. This section describes the number and the location of each of these types of control.

4.3.2.3.1 Signalization

Signal timing information was made consistent with the signal timings provided by the City of Tempe and the City of Mesa. Signal timings in the City of Mesa were taken from a Synchro file provided to the Center for Transportation Research in 1998. The Traffic Department of the City of Tempe provided updated signal timing information in June of 1999. This information replaced the Synchro information for all main corridor signals from the Western boundary of the network until Evergreen Street.

A total of 131 signals were modeled, including 69 traffic signals along Southern Avenue and Baseline Road. The locations of the primary signals are shown in Figure 4-4, below. An additional 53 signals were used throughout the network.

It should be noted that at the time the model was constructed, some of the existing signal standards were in the process of being updated to allow protected left turns.

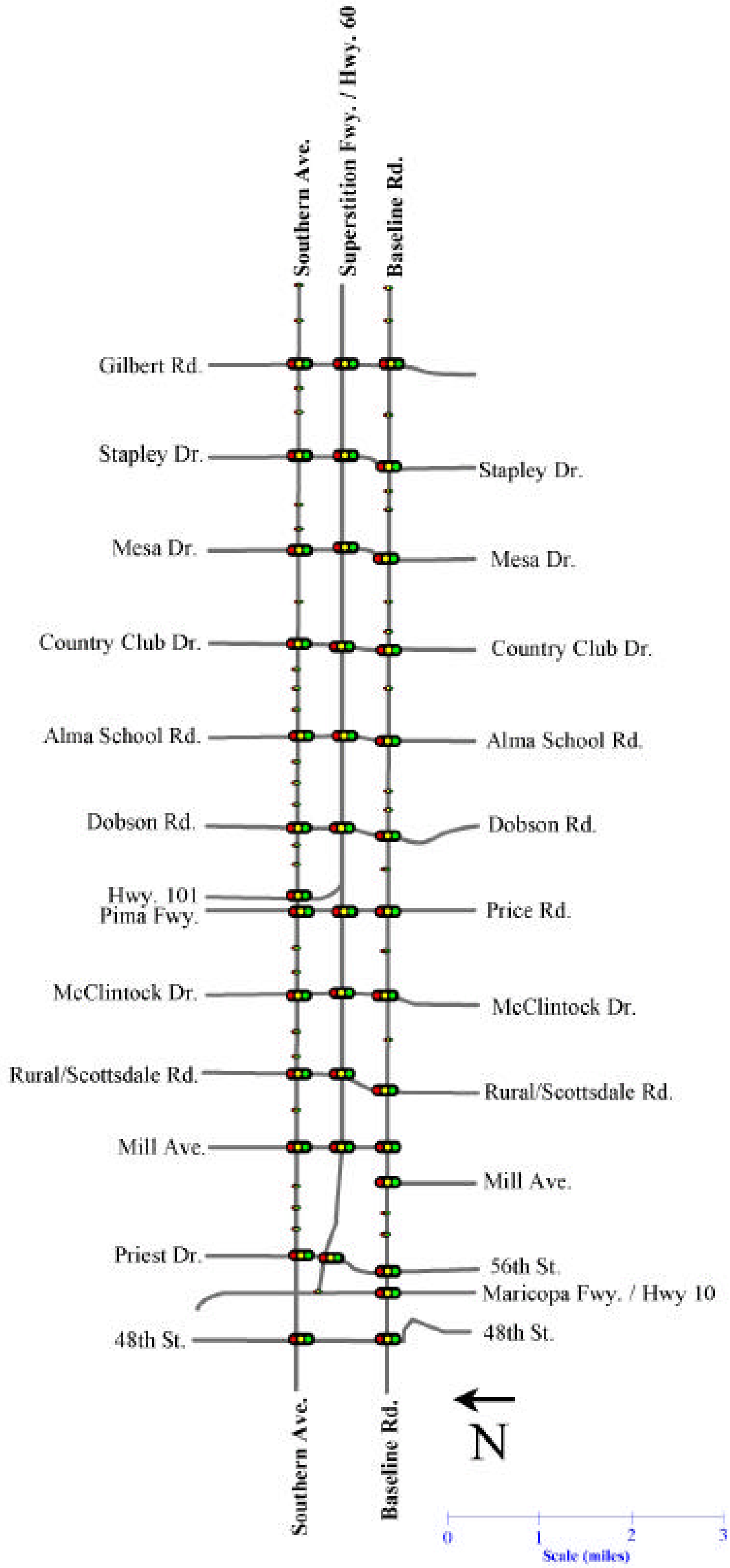

Figure 4-4: Schematic of Primary Signal Locations

4.3.2.3.2 Ramp Meters

A total of 12 ramp meters were added to the network to reflect the roadway network as of June 1999. The ramp meters were set to provide a fixed-time metering rate of 1800 veh/h by providing a cycle length of 2 seconds with a green time of 1 second.

4.3.2.3.3 Variable Message Signs

Four permanent Variable Message Signs were included in the simulation to reflect the roadway network as of June 1999. These VMS were located along Southern Avenue in the westbound direction prior to Dobson Road (Figure 4-5), along Baseline Road in the westbound direction upstream of Dobson Road (Figure 4-6), along Dobson Road in the southbound direction upstream of Southern Avenue (Figure 4-5), and along Dobson Road in the northbound direction upstream of Baseline Road (Figure 4-6). An example sign is illustrated in Figure 4-6. The signs were located near the boundary between the City of Tempe and the City of Mesa, with the expectation that they would better facilitate smooth flow transitions between the two jurisdictions (FHWA, 1999). The City of Tempe uses mobile VMS for special events, but these were not included in the study.

Figure 4-5: Dobson Road and Southern Avenue VMS Locations
(background photo provided by MAG)

Figure 4-6: Dobson Road and Baseline Road VMS Locations
(background photo provided by MAG)

Figure 4-7: Typical Variable Message Sign

In INTEGRATION, a percentage of vehicles passing the signs are provided with real-time information as they pass the sign. Driver response to VMS for this project was assumed to be either 10, 20, 30, 40, or 50 percent response to the information provided; the simulation was coded accordingly.

4.4 Network Calibration

4.4.1 Network Supply Calibration

Supply calibration was not conducted for the Southern/Baseline network because there was insufficient data to do so. Instead, recommended values from the Highway Capacity Manual (HCM) were used to establish typical capacities and speed-flow relationships.

4.4.2 Network Demand Calibration

Although the planning O-D demand (from EMME/2) was available, this demand was found to be inconsistent with the tube and turning movement counts that were observed in the field, as illustrated in Figure 4-8. Consequently, the O-D demand was fine-tuned to match the tube and turning movement counts more accurately using the synthetic O-D demand calculation tool QUEENSOD, which was briefly discussed in Chapter 2.

The cropping of the Southern/Baseline Road network involved extracting the O-D pairs that traversed the sub-network from the full O-D matrix. In order to identify whether an O-D demand traversed the network, an All-or-Nothing (AOL) traffic assignment was made between each origin/destination combination; if the tree passed through the network it was included in the sub-network O-D demand. The cropped O-D pairs were converted to INTEGRATION format, then input into QUEENSOD along with pneumatic tube counts and turning movement counts made by BRW in February of 1998. Because statistical analysis of GPS data collected during 1998 and 1999 did not indicate a statistically significant difference (5% level of confidence) between the data from the two years, it was concluded that the tube and turning movement counts that were collected in 1998 were reasonable for modeling the traffic conditions in 1999. The final O-D demand generated in QUEENSOD consisted of 54,250 vehicles for the AM peak period.

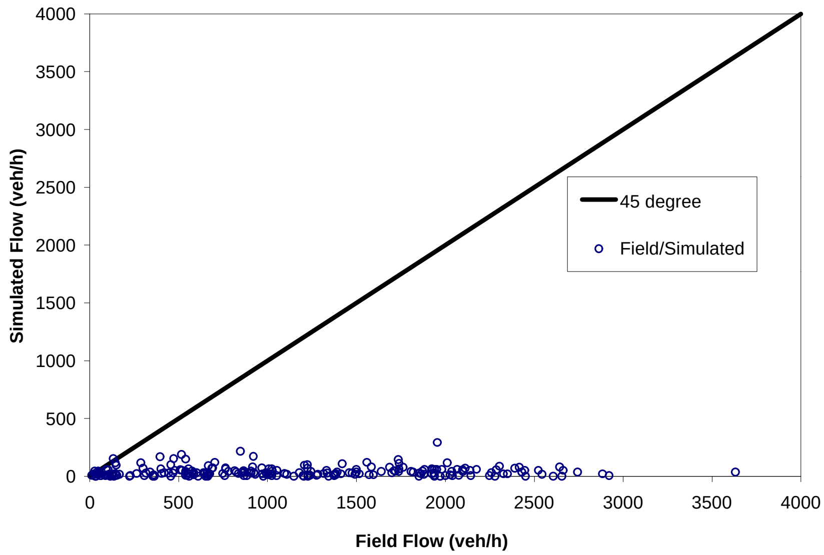

Figure 4-8: Simulated Flows Using the EMME/2 Demand

The calibration of the O-D demand to the tube and turning movement counts resulted in a better match between the simulated flows and the field observed flows, as illustrated in Figure 4-9. The match obtained from the synthetic O-D, while much better than that from the planning model, is still far from ideal.

The relatively poor match to the observed flow demonstrates that the calibration of demand is not simply a mechanistic procedure, ands typically requires expertise in identifying congestion bottlenecks and coding errors. A number of procedures can be utilized to identify problem areas. As discussed in Chapter 3, visual inspection using reduced demand is particularly useful for situations such as this. If congestion is observed using a reduced demand, coding errors are likely. Also, visual inspection at any demand level is useful, because it shows how problem areas evolve.

Because the synthetic demand resulted in simulated flows much closer to field-measured flows than simulated flows using the planning model demand, the synthetic demand was used for all of the INTEGRATION runs.

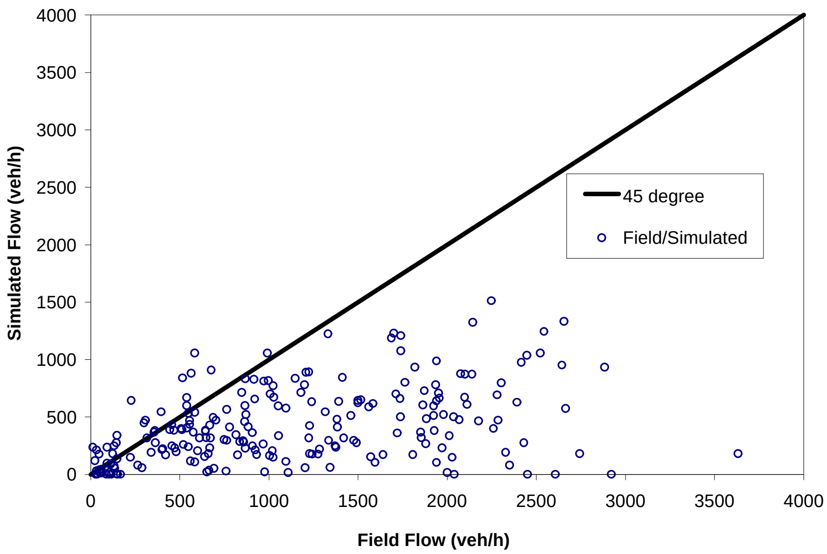

Figure 4-9: Simulated Flows Using the QUEENSOD Demand

4.4.2.1 Levels of Calibration

Demand calibration for the network began with a visual inspection of the on-screen output while the network was running with a reduced demand. This inspection showed problem areas, such as where mistakes in coding lane stripings or signal timings had been made. Once the traffic appeared to flow in a reasonable manner, the model was run with the full base case demand. These runs were also visually inspected, and any bottlenecks or unexpected flow patterns were investigated.

Once the visual calibration was completed satisfactorily, the model outputs from simulating the full base case demand were then analyzed to determine if the link flows matched those observed in the field. Although the match was much better than that obtained with the planning model O-D, it was less than expected. However, no mistakes in modeling technique or coding could be found. Thus, it was impossible to determine the source of the remaining error. In light of the fact that link counts were made at different times of the day, it is probable that much of the error is due to variations in measured flows.

The GPS floating car runs were not used for travel time or speed profile calibration.

4.5 Running the Model and Analyzing the Results

4.5.1 Sensitivity Analysis

The study was begun with the expectation that the signal timings on the corridor would be changed in the field, thus allowing a comparison of the field results to the simulated results. However, a coordinated, cross-jurisdictional effort to optimize the signal timings was never made in the field. Therefore, a number of hypothetical ITS scenarios were evaluated within the simulation environment. These scenarios included two variations of cycle length and phase split optimization, as summarized in Table 4-1.

The first of these cycle length optimization scenarios only considered the two arterial roadways, namely, Southern Avenue and Baseline Road. The second analysis included these two arterials and US 60. Both of these cycle length/phase split optimization scenarios set the minimum cycle length to 40 seconds and the maximum cycle length to 150 seconds, typical values for downtown areas. It should be noted that the INTEGRATION model utilizes the Highway Capacity Manual (HCM) procedures to optimize the cycle length and phase split of a traffic signal. This procedure is based on the Webster-Cobbe delay minimization principle that states that the delay incurred by drivers at a signalized intersection is minimized when the available green time is allocated to each phase in proportion to the critical "*y*" ratio of each phase (ratio of volume to saturation flow rate).

In addition to the cycle length optimization scenarios described above, three variations of real-time offset optimization were conducted, as summarized in Table 4-1. The offsets were optimized each cycle length by minimizing the performance index (combination of stops and delay) using a cyclic profile approach.

The final set of scenarios investigated the impact of providing real-time traffic information to drivers under recurring congestion: i.e., in the absence of any incidents. Different percentages of driver compliance levels were modeled ranging from 10 percent compliance to 50 percent compliance, as summarized in Table 4-1. The modeling of VMS within the INTEGRATION model is achieved by modifying the characteristics of some vehicles once they passes the VMS. The vehicle maintains then these characteristics for 3 minutes. In the study presented in this document, the vehicles were assumed to access real-time traffic information that was updated every five minutes.

Table 4-1: List of Scenarios Analyzed

Scenario	Sub-Group	Description
0	Base Case	No signal optimization No VMS Off-line ramp metering
1	Cycle Length Opt.	Cycle length/phase split optimized every 300s for signals along Southern and Baseline Offsets held constant
2		Cycle length/phase split optimized every 300s for signals along Southern, Baseline, and US 60 Offsets held constant
3	Offset Opt.	Four sub-area offset optimization: Southern/Mesa, Southern/Tempe, Baseline/Mesa, Baseline/Tempe. Cycle length in Mesa set to 94s ; cycle length in Tempe set to 110s
4		Two sub-area offset optimization: Southern and Baseline. Cycle length set to 110s on Southern and Baseline only
5		Single sub-area offset optimization with cycle lengths set to 110s on Southern, Baseline, and US 60
6	VMS Conformity	10% driver compliance
7		20% driver compliance
8		30% driver compliance
9		40% driver compliance
10		50% driver compliance

4.5.2 Measures of Effectiveness Chosen

The Measures Of Effectiveness (MOEs) used during the analysis of the study area are reported in terms of individual vehicle statistics, because the total number of vehicles varies slightly from one simulation to the next. The MOEs chosen for this evaluation are travel time, number of stops, fuel consumption, emission of hydrocarbons, carbon monoxide and nitrogen oxides, total delay, stop delay, and the number of accidents. These MOEs are part of the "few good measures" suggested by the ITS Joint Program Office of the U.S. DOT and discussed in Chapter 3.

4.5.3 Calculating Measures of Effectiveness

This section describes how the efficiency, energy, emission and safety MOEs were computed using micro-simulation second-by-second speed estimates. It is important to note that all of the estimates were based on the simulated data obtained from the entire study area, not just the primary corridors. Therefore, the changes shown would most likely be greater if quantified only in those areas where ITS measures were used.

4.5.3.1 Efficiency Estimation

The primary efficiency measures used for evaluation were speed, instantaneous delay, total delay, and number of stops. The computation of the average trip speed from second-by-second speed estimates involved summing up all speed measurements and dividing by the number of observations. Conversely, the instantaneous delay (d_i) was computed using Equation 1 as the difference in time it would take the vehicle to travel at free-speed (u_f) versus traveling at the instantaneous speed estimate (u_i). The total delay for the entire trip was computed as the sum of all instantaneous delay estimates.

$$d_i = 1 - \frac{u_f}{u_i} \quad \forall\, i \qquad [1]$$

The estimation of stops was computed as the ratio of the instantaneous reduction in speed to the free-speed, as indicated in Equation 2. Consequently, a reduction in speed from the free-speed to a speed of zero would constitute a complete stop, while a reduction in speed from a speed equal to half the free-speed to a speed equal to one quarter the free-speed would constitute 0.25 of a stop. The total number of stops was computed as the sum of the stops compile for all vehicles for each second of the simulation.

$$S_i = \frac{u_i - u_{i-1}}{u_f} \quad \forall\, i \quad \ni u_i < u_{i-1} \qquad [2]$$

4.5.3.2 Energy and Emission Estimation

The evaluation of energy and emissions used second-by-second vehicle speeds to compute second-by-second vehicle accelerations. These speed and acceleration profiles were used to estimate fuel consumption and emissions by applying a set of 4^{th} order regression equations that were fitted to experimental data collected at the Oak Ridge National Lab (ORNL) (West *et. al*., 1997). The specifics of how the statistical models were derived using the ORNL data are described by Ahn *et. al*. (1999) and the application of these models within a microscopic simulation environment are described by Rakha *et. al*. (1999).

The use of instantaneous speed and acceleration estimates for the estimation of energy and emissions provides a major advantage over state-of-practice methods, which compute fuel consumption and emissions based exclusively on the average speed and the number of vehicle miles traveled. Specifically, the method explicitly considers that different speed profiles, while exhibiting the same average speed, may result in very different fuel consumption and emission rates, depending upon the amount of speed variability about this average.

It should be noted that the only direct measurement of fuel usage and vehicle emissions took place during the data collection effort at the Oak Ridge National Lab, where a set of vehicles were systematically paced through a sequence of different speed and acceleration sequences in an instrumented laboratory setting. All other estimates of fuel consumption were based on simulated speed and acceleration estimates.

4.5.3.3 Safety

The evaluation of the safety impacts of alternative ITS scenarios was based on regression models that predict the expected frequency of 14 different crash types every second based on the facility type that the vehicle is traveling on. In addition, the expected damage and injury levels, per crash event, are estimated based on the instantaneous speed each vehicle is traveling at each second (Avgoustis *et. al*., 2000).

The crash rates, in each of the above applications of the safety computational method, were derived from the General Estimates System (GES) national crash database of more than 6,000,000 annual crashes. This crash database was subsequently supplemented with vehicle exposure data, which were stratified by facility type. The merging of crash frequencies with exposure data resulted in crash rates per unit distance and per unit time for different facility types. The conversion, from crash frequencies into crash frequencies by damage and injury level, was performed by considering speed dependent damage and injury levels for each of the 14 different crash types.

Again, as was the case for efficiency, energy, and emissions, the safety model was applied to the second-by-second simulated vehicle data.

4.5.4 Results

The simulation analysis involved adding ten different ITS scenarios to the base case. This section reviews the impacts each ITS measure had on the performance of the network, including a statistical analysis of these impacts.

The average results for each of the scenarios are summarized in Table 4-2, while Table 4-3 presents the percentage change in the different MOEs relative to the base case for the entire network.

Table 4-2: Individual Vehicle Statistics Averaged for All Seeds

	Base Case	VMS Compliance Level					Cycle Analysis		Offset Analysis		
		10%	20%	30%	40%	50%	Opt. A	Opt. B	Opt. A	Opt. B	Opt. C
Travel Time (s)	701	703	699	694	694	691	667	643	725	717	727
Stops	4.44	4.46	4.45	4.44	4.44	4.44	4.26	4.25	4.41	4.44	4.47
Fuel (l)	0.81	0.81	0.81	0.81	0.81	0.81	0.79	0.77	0.82	0.82	0.82
HC (g)	10.74	10.72	10.73	10.74	10.75	10.74	11.01	11.13	10.73	10.66	10.73
CO (g)	75.65	75.57	75.58	75.61	75.66	75.64	76.92	77.79	75.54	75.41	75.68
NO (g)	2.03	2.03	2.03	2.03	2.03	2.03	2.00	2.00	2.02	2.03	2.03
Crashes* 10^{-6}	19.7	19.8	19.7	19.6	19.6	19.6	18.1	17.2	20.3	20.3	20.4
Total Delay (s)	315	317	316	313	313	312	268	243	334	331	336
Stopped Delay (s)	168	170	168	166	166	166	142	123	181	179	178

Table 4-3: Percent change in Vehicle Statistics Averaged over all Seeds

	Base Case	VMS Compliance Level					Cycle Analysis		Offset Analysis		
		10%	20%	30%	40%	50%	Opt. A	Opt. B	Opt. A	Opt. B	Opt. C
Travel Time (s)	0.0%	0.4%	-0.2%	-1.0%	-0.9%	-1.4%	-4.8%	-8.3%	3.4%	2.3%	3.7%
Stops	0.0%	0.4%	0.1%	0.1%	0.0%	0.0%	-4.0%	-4.3%	-0.8%	0.0%	0.7%
Fuel (l)	0.0%	0.1%	0.0%	-0.2%	-0.2%	-0.2%	-3.3%	-4.7%	1.0%	1.1%	1.5%
HC (g)	0.0%	-0.2%	-0.1%	0.0%	0.1%	0.1%	2.6%	3.6%	-0.1%	-0.7%	-0.1%
CO (g)	0.0%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	1.7%	2.8%	-0.2%	-0.3%	0.0%
NO (g)	0.0%	0.1%	0.0%	-0.1%	-0.1%	-0.1%	-1.3%	-1.3%	-0.4%	0.1%	0.1%
Crashes* 10^{-6}	0.0%	0.4%	0.1%	-0.5%	-0.3%	-0.6%	-8.4%	-12.7%	3.2%	2.7%	3.4%
Total Delay (s)	0.0%	0.6%	0.2%	-0.9%	-0.6%	-1.1%	-15.1%	-22.8%	5.8%	4.9%	6.7%
Stopped Delay (s)	0.0%	1.2%	0.0%	-1.3%	-1.2%	-1.4%	-15.6%	-27.1%	7.2%	6.4%	6.0%

4.5.4.1 Base Case Results

As mentioned above, because so few floating car observations were made, the floating car GPS runs conducted were not used as a definitive baseline for calibration, but were used to check the general correctness of the simulation output. A quick review of the results from the GPS and simulation runs shows that the travel times along the mainline corridors from each are similar: the average travel time within the simulation was in the range of 12 minutes, and the average floating-car travel time along the three corridors ranged from a minimum of 10 minutes to a maximum of 20 minutes. The number of vehicle stops, however, were lower in the in the simulation than they were in the floating car observations: 4.4 stops/trip versus 5.4 stops/trip.

4.5.4.2 Cycle and Phase Length Optimization (Real-time Isolated Signal Control)

Cycle and phase length optimization have the most beneficial impacts on most of the measures of effectiveness. Both cycle optimization options demonstrate a statistically significant decrease in travel time, number of stops, fuel consumption, crashes, total delay, and stop delay. All of the cycle optimizations, however, show an increase in hydrocarbons and carbon monoxide emissions. This may be a result of higher speeds on the network, as the emissions equations used are highly sensitive to accelerations at high velocities.

When the optimization is applied to Southern and Baseline only, the travel time is reduced by 4.8%, and total delay drops by 15.1%. When the optimization is conducted on Southern, Baseline, and US 60, the travel time decreases 8.3%, and total delay decreases 22.8%. The remaining MOEs are summarized in Table 4-2.

As shown in Table 4-4, a paired student’s t test indicates that, with a level of confidence of 5%, there is a statistically significant difference between both Cycle Option A and Cycle Option B and the Base Case.

Table 4-4: Change in Mean MOE Value for Each Scenario; Paired *t*-test Results

	VMS Compliance Level					Cycle Analysis		Offset Analysis		
	10%	20%	30%	40%	50%	Opt. A	Opt. B	Opt. A	Opt. B	Opt. C
Travel Time	2	-1	-7	-7	-10	-34	-58	24	16	26
Stops	0.02	0.00	0.00	0.00	0.00	-0.18	-0.19	-0.04	0.00	0.03
Fuel	0.001	0.000	-0.002	-0.001	-0.002	-0.027	-0.038	0.008	0.009	0.012
HC	-0.017	-0.006	0.000	0.009	0.007	0.278	0.391	-0.011	-0.079	-0.010
CO	-0.085	-0.069	-0.041	0.004	-0.014	1.265	2.135	-0.118	-0.248	0.026
NO_x	0.002	0.000	-0.001	-0.002	-0.002	-0.026	-0.026	-0.008	0.003	0.002
Crashes	0.1	0.0	-0.1	-0.1	-0.1	-1.7	-2.5	0.6	0.5	0.7
Total Delay	2.0	0.5	-2.7	-1.9	-3.5	-47.6	-72.0	18.3	15.6	21.1
Stopped Delay	2.0	-0.1	-2.1	-2.0	-2.4	-26.3	-45.6	12.2	10.8	10.1

Note: Dark Shading Indicates Rejected Values: $\mu 1 \neq \mu 2$ @ α=0.05

4.5.4.3 Offset Optimization (Real-time Signal Coordination Results)

The adaptive signal coordination algorithm within the INTEGRATION model did not result in positive impacts for most of the MOEs. Statistical analysis, again performed with a confidence interval of 95%, indicates that the results for Option A were not statistically significant for the number of vehicle stops, CO, and NOx emissions, and were statistically significant for the remainder of the MOEs. The results for Option B and C were similar (Table 4-2).

It appears that because the algorithm started with an initial poor solution (offsets equal to 0 seconds), and because the demand varied from cycle the cycle, the algorithm was unable to converge to an equilibrium solution. A better initial solution would have likely yielded improvements in more of the MOEs.

4.5.4.4 Variable Message Signs

Five VMS scenarios were modeled by varying the degree of driver compliance to the VMS. For this case study, driver's compliance to the VMS was varied from 0 (base case) to 50 percent, in increments of 10 percentage points. No incidents were modeled; however, further analyses are needed to investigate the benefits of the VMS during non-recurring congestion.

The results indicate that under typical non-recurring congestion the provision of real-time traffic information via VMS does not result in any network-wide improvements in the various MOEs. This is in part due to the small number of signs, and in part because no incidents were modeled.

4.5.4.5 Inter-jurisdictional Signal Coordination

The investigation of the Southern/Baseline corridor precedes the field implementation of ITS in the study area. Therefore, although this investigation will be useful for measuring the predictive utility of simulation after the proposed changes take effect, no field data is currently available for comparison.

4.5.4.6 Statistical Significance of Results

The results from the sixty simulations described above were analyzed to determine if the changes between each scenario were statistically significant. The five base case runs are compared to the five runs from each of the other permutations. Because varying seeds in the INTEGRATION input file will produce normally distributed results, the student's t-test is used to determine the significance of the results.

4.6 Recommendations for Further Study

Further analysis of the study presented herein should address the following issues:

- Generated traffic
- Coordinated real-time signal optimization
- Offset optimization techniques
- Signal optimization during an incident
- VMS during an incident
- Comparison of simulated changes to field changes

A brief discussion of recommendations for each is presented below.

4.6.1 Generated Traffic

While it is not plausible to expect that the myriad difficulties confronting the economic analysis of transportation projects will be resolved in the near future, some of the larger problems such as generated traffic should be addressed. Any attempt to do this will be imprecise and incomplete, but nonetheless a necessary precursor to making informed decisions.

As reported in Chapter 3 of this thesis, studies suggest that about half of new capacity on urban roadways is filled by generated traffic in 5 years, and about 80% ultimately. With this expectation, the best strategy for achieving the desired goal may be very different than it would be otherwise.

4.6.2 Coordinated Real-time Signal Optimization

The results presented indicate that the corridor would benefit from real-time cycle and phase optimization. Because the corridors are not yet instrumented to an extent to allow this, however, the possibility of implementing more signal timing plans during the peak hour would result in improved network flow. In addition, these new timings could be hard-coded into the signal control devices. This will be necessary if real-time optimization is utilized in the future, because the signal control boxes at each intersection are responsible for appropriate operation of the network in the case of a central control failure. For these reasons, shorter duration signal timing plans should be investigated. Part of this investigate should include finding the best duration for these shortened plans.

4.6.3 Offset Optimization Technique

The offset optimization technique used within INTEGRATION did not effectively converge on a better offset than was used initially. It is probable that this is because the demand profile changed quickly, or because the starting offset value was too far from optimal, causing each successive offset to overshoot optimal. Therefore, the frequency at which the offsets are optimized could be altered, the starting/seed offset could be altered, or the algorithm used to arrive at the new offset could be modified by using a different smoothing technique.

4.6.4 Cycle and Phase Length Optimization During An Incident

As mentioned above, neither Tempe nor Mesa currently have the requisite instrumentation in place to conduct real-time signal optimization. Unlike operations under normal conditions, which are constant enough to determine short-duration signal timing plans, the location and duration of an incident cannot be estimated with enough accuracy to develop applicable plans. More research must done in this area.

4.6.5 Variable Message Signs Modeling during an Incident

As with cycle and phase length optimization, VMS strategies will be most efficient when the instrumentation in place is sufficient to allow automated network control, including the dissemination of information. Variable Message Signs, however, can still be beneficial without this instrumentation. The impact of the information provided should be modeled to determine the benefits.

4.6.6 Comparison of Simulated Changes to Field Changes

As mentioned above, the signal timings were not changed in the field during the course of the study. They will invariably be changed in the future, however. When this is done, the insight obtained from comparing the changes measured in the field to those predicted in the simulation environment will be invaluable.

4.7 Summary

Even though the simulated scenarios presented in this paper were hypothetical, the results indicate that the study area corridor would benefit from real-time isolated signal control. Specifically, the adaptive isolated signal control algorithm resulted in statistically significant positive impacts for most MOEs except for HC and CO emissions, which resulted in negative impacts. Because the corridors are not yet instrumented to an extent to allow for adaptive signal control, the possibility of implementing more signal timing plans during the peak hour could potentially result in improved network flow.

The results of the simulation indicate that the adaptive offset optimization module within the INTEGRATION model results in negative impacts. These negative impacts could have been a result of either the poor initial seed solution or of the flow variability from cycle to cycle.

The simulation results indicate, as would be expected, that there appear to be no benefits to providing real-time traffic information via a VMS under typical non-recurring conditions. Further analyses are required in order to establish the benefits of disseminating traffic conditions via VMS during non-recurring congestion.

CHAPTER 5: THE SCOTTSDALE/RURAL STUDY

5.1 Introduction

The Scottsdale/Rural Road Project is part of the Phoenix Metropolitan Model Deployment Initiative introduced in Chapter 4. The objective of the Scottsdale/Rural Road project was to evaluate the benefits of coordinating traffic signal timings across jurisdictional boundaries. Parts of this research have been published previously (Rakha, *et. al.,* 2000).

The Scottsdale/Rural Road corridor is located in the cities of Scottsdale and Tempe, Arizona. This area is shown in Figure 5-1. The study area consisted of a 9.6-kilometer section of Scottsdale/Rural Road that traversed the City of Tempe to the South and the City of Scottsdale to the North, as illustrated in Figure 5-2. The section of the roadway in the city of Tempe is named Rural Road, while the section in the city of Scottsdale is named Scottsdale Road. The 9.6-kilometer section included a railway crossing (near University Drive) and 21 traffic signals: 16 located in the City of Tempe and 5 in the City of Scottsdale.

The corridor was ideal for evaluating the benefits of coordinating traffic signal timings across jurisdictional boundaries because it is a major corridor on which two municipalities operate signals. The traffic signals within each city are operated at different cycle lengths, resulting in a break in traffic signal coordination at the boundary between the two cities. Specifically, the traffic signals in the City of Tempe operated at a cycle length of 110 seconds while the signals in the City of Scottsdale are operated at a cycle length of 102 seconds. Ideally, both cities would operate at a common cycle length in order to improve traffic progression, however, that was not possible due to other complicating factors. Consequently, an attempt was made to improve traffic progression by shifting the break in traffic signal coordination from the less efficient city boundary to a functional boundary where traffic signal coordination was less of an issue. The shift in the boundary was achieved by changing the cycle length of three traffic signals, namely, at the intersection of Scottsdale/Rural Road with McKellips Road, Weber Road, and Curry Road (Figure 5-2).

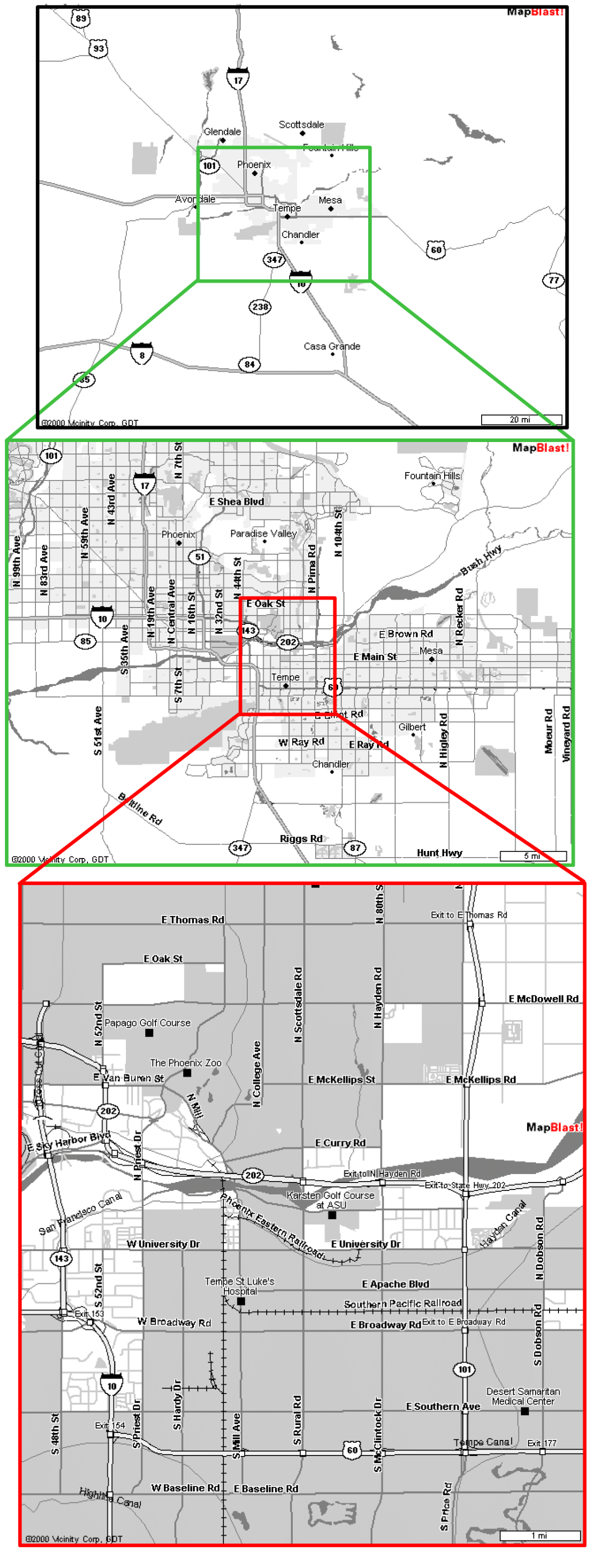

Figure 5-1: Scottsdale/Rural Road Study Area
(maps courtesy of MapBlast!)

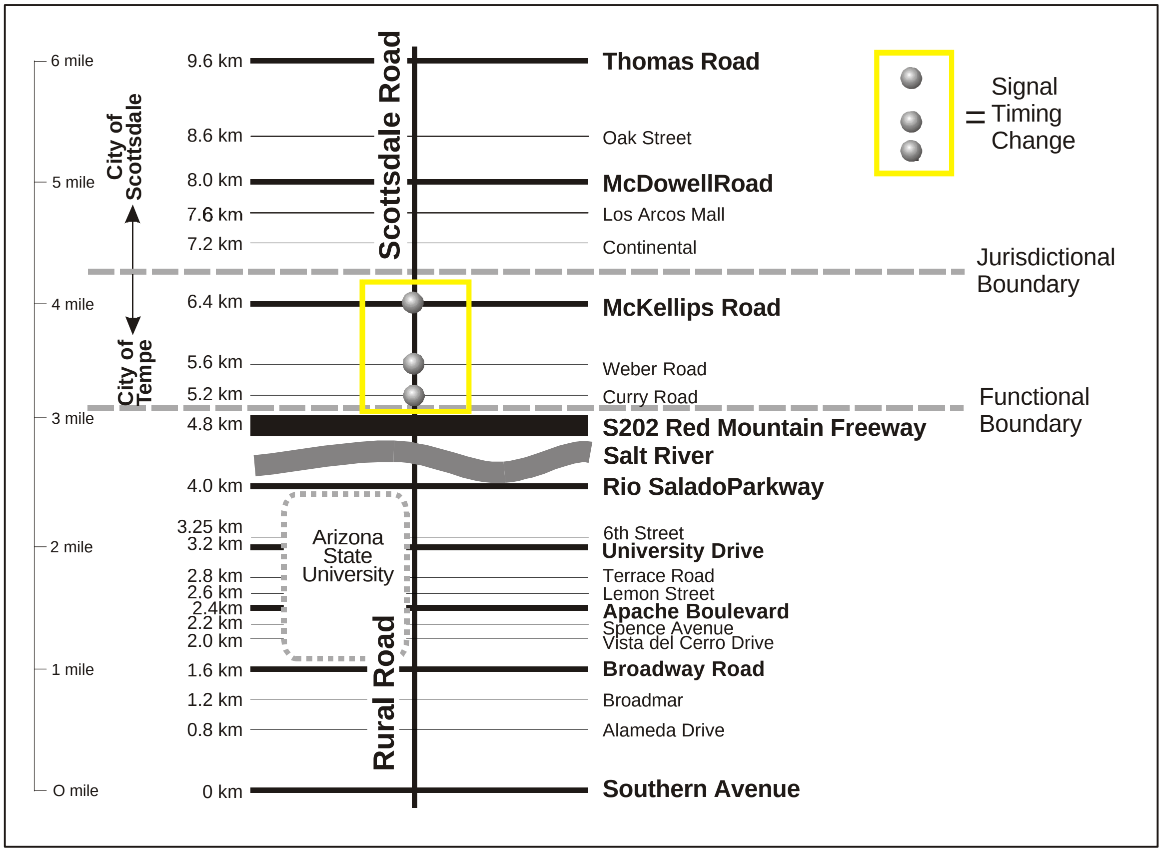

Figure 5-2: Schematic of Scottsdale/Rural Road Study Corridor

5.2 Field Data Collection and Analysis

In order to evaluate the efficiency, energy, environmental, and safety benefits of traffic signal coordination across a jurisdictional boundary, two data collection efforts were conducted within a month of one another (January 1999 and February 1999). One month was considered a short enough time span to consider any observed changes a result of the signal timing changes made. This time span also allowed enough time to test and fine-tune the signal timings.

The data collection efforts were conducted during the mid-week period (Tuesday through Thursday) in order to reflect typical weekday traffic conditions. Mondays and Fridays were not considered because studies have shown that they are not necessarily reflective of typical weekday conditions (Rakha and Van Aerde, 1995).

The only abnormal conditions observed during the data collection effort was the closing of a railway crossing along Scottsdale/Rural Road. This closure occurred at approximately the same time (4:30 PM on Thursday) during both the before and after data collection efforts. Because the closure occurred at the same time for both the before and after data collection efforts, and because the PM peak is only compared to the PM peak, it was felt that it would not bias the results. This chapter presents only the AM peak analysis

The first part of these data collection efforts involved collecting mainline and turning movement counts at a number of traffic signals before and after the signal timings were changed. The second portion of the data collection efforts included collecting speed measurements from floating cars that traveled along Scottsdale/Rural Road before and after the signal timings were changed. These floating cars were equipped with a Global Positioning System (GPS) unit that measured the vehicle's speed every second.

The objective of the first data collection effort was twofold. First, the data were utilized to quantify any short-term induced traffic and induced demand (e.g. changes in routes or time of departure) impacts on the corridor as a result of the traffic signal re-timing. Second, the data were utilized to calibrate the demand for purposes of modeling the network benefits of the signal coordination. The objective of the second data collection effort was to utilize the before and after instantaneous speed measurements in order to quantify the fuel consumption, emission and safety impacts of the traffic signal re-timing. Furthermore, the GPS data were also utilized to calibrate the microscopic simulation model.

5.2.1 Turning Movement and Tube Counts

Turning movement counts were collected at seven intersections along the 9.6-kilometer section of Scottsdale/Rural Road. The turning movement counts were collected for the AM, midday, and PM peaks at 15-minute intervals for a single day (Wednesday) for the before and after conditions. The intersections for which turning movement counts were collected included the intersections of Scottsdale/Rural Road with the following roads: Southern, Broadway, University, Curry, McKellips, McDowell, and Thomas.

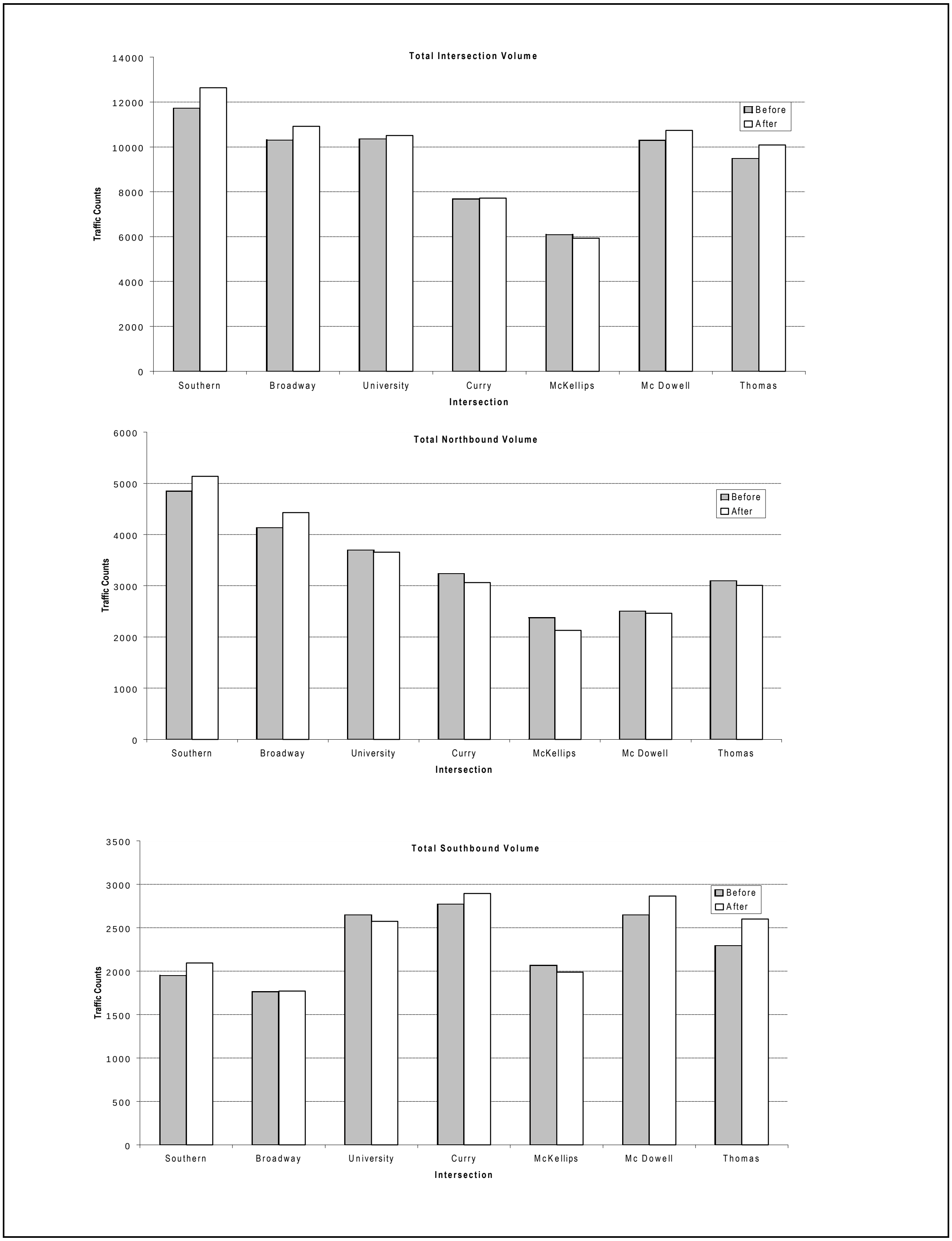

Figure 5-3: Before/After Intersection Volumes (Tube Counts)

Figure 5-3 illustrates how the before and after northbound and southbound total intersection counts compared. Generally, the northbound volumes appear lower, and the southbound volumes appear higher for the after conditions. The statistical analysis of these apparent differences is described later in the paper.

In addition to the 15-minute turning movement counts that were collected, pneumatic-tube traffic counters were also installed at six locations, namely: Lakeshore, Hermosa, Alameda, Rio Salado, Weber, and Oak. The traffic counters collected 15-minute counts for three continuous days. Figure 5-4 illustrates the temporal variation in traffic volume at all six locations for the northbound and southbound directions for one of the analysis days (Wednesday). The figure demonstrates a peak in the northbound direction for the AM peak for all locations south of Arizona State University (ASU). Similarly, the southbound direction indicates a peak in traffic volume for the locations north of ASU during the AM peak. Consequently, it is evident from the temporal variation in the volume that ASU is a major trip attractor during the AM peak. Also, it is a major southbound generator for the PM peak. Figure 5-4 illustrates that the average volume across all locations in either direction appeared to be similar for both the before and after conditions. Again, the differences in total volumes were tested using Analysis of Variance (ANOVA) techniques in order to establish any statistically significant differences; this analysis is presented later in this chapter.

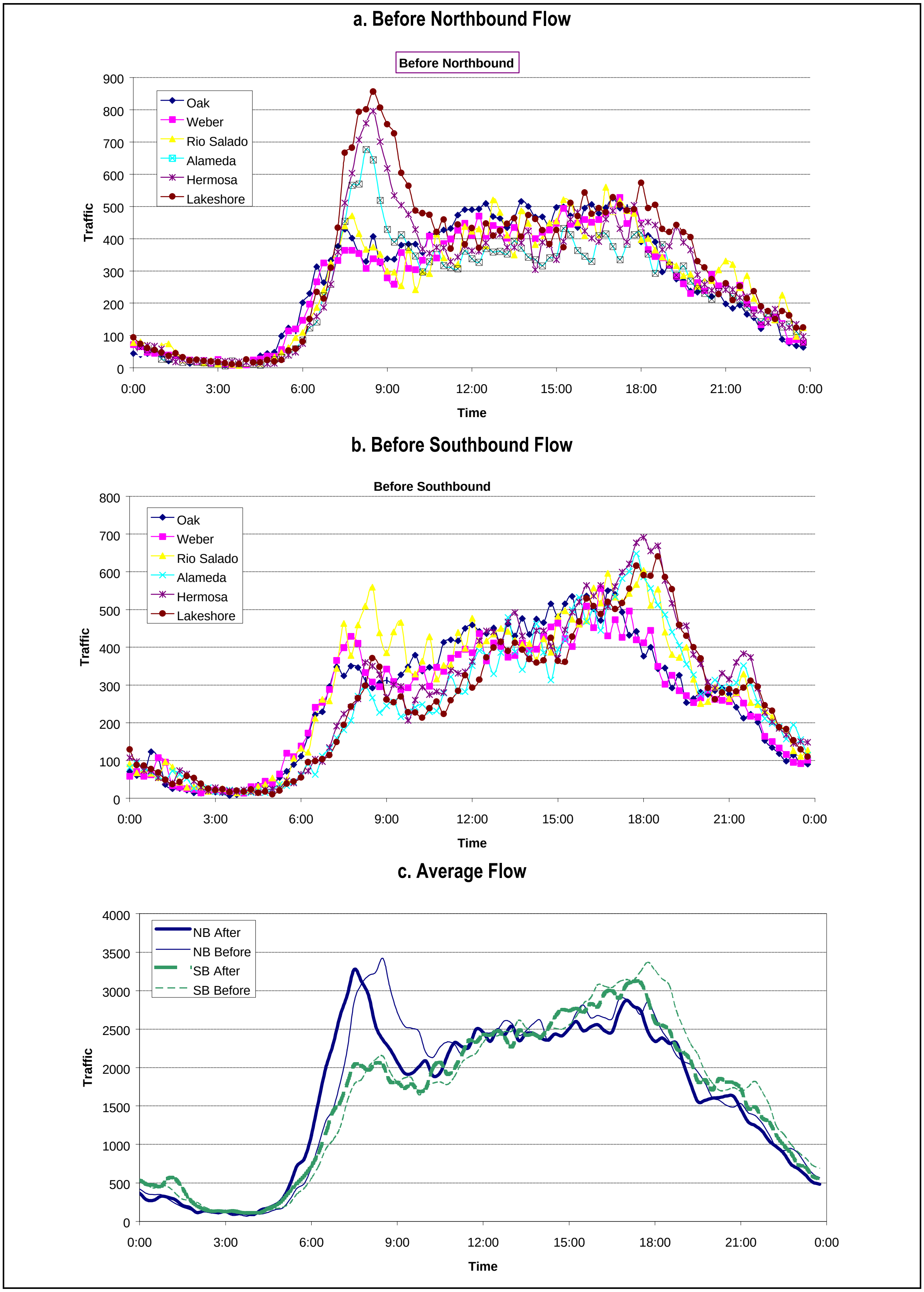

Figure 5-4: Before/After Temporal Variation in Demand

5.2.2 GPS Data Collection

Three GPS-equipped vehicles were driven along the study corridor during three days (Tuesday through Thursday) before and after changing the signal timings. The GPS runs were conducted during the AM peak (7:00 to 9:00 AM), the off-peak (11:00 to 1:00 PM), and the PM peak (4:00 to 6:00 PM) periods. The GPS unit measured the vehicle's location (latitude and longitude), its heading, and its speed every second. It should be noted that the GPS unit that was utilized did not include any differential correction, which reduced the location accuracy from 2 meters to within 100 meters. However, the relatively low accuracy in locating the vehicle had no bearing on the accuracy of the speed estimates because they were not computed from the vehicle location.

A total of 141 runs were conducted for the before conditions and a total of 160 runs were conducted for the after conditions. Each run involved driving the 9.6-kilometer section from one end of the network to the other.

Using the GPS speed measurements, it was possible to compute the vehicle's acceleration every second. Because the acceleration levels included some unrealistic observations (acceleration levels beyond the capabilities of the vehicle), a form of robust Kernel smoothing was applied to the acceleration levels. The details of the data smoothing are beyond the scope of this thesis, but can be found in Sin (2000).

The estimates of fuel consumption based on the smoothed speed and acceleration levels were found to range from a minimum of 0.96 to a maximum 1.59 liters/trip, which is consistent with the Environment Protection Agency (EPA) standard Federal Test Procedure (FTP) drive cycles (Dion, *et. al.*, 2000).

5.3 Signal Timing Changes Made

The signal timings for the AM peak before and after making the signal changes are illustrated in

Figure 5-5. The figure illustrates the phase sequencing and numbering for each of the traffic signals together with the duration of each phase. For example, the traffic signal at the intersection of Rural Road and Curry Road included four phases and was operated at a cycle length of 110 seconds for the before scenario versus 102 seconds for the after scenario. The four phases included an advanced left turn phase for the eastbound and westbound direction (Curry Road) followed by a through phase for the eastbound/westbound direction, followed by the phases for the northbound/southbound direction (Scottsdale/Rural Road).

Figure 5-5 shows that only minor changes were made to the signal timings between the before and after AM peak signal timings. Alternatively, major changes were made to the traffic signal offsets as indicated in Table 5-1. Consequently, the signal changes focused on changing the traffic signal coordination as opposed to changing the phase split.

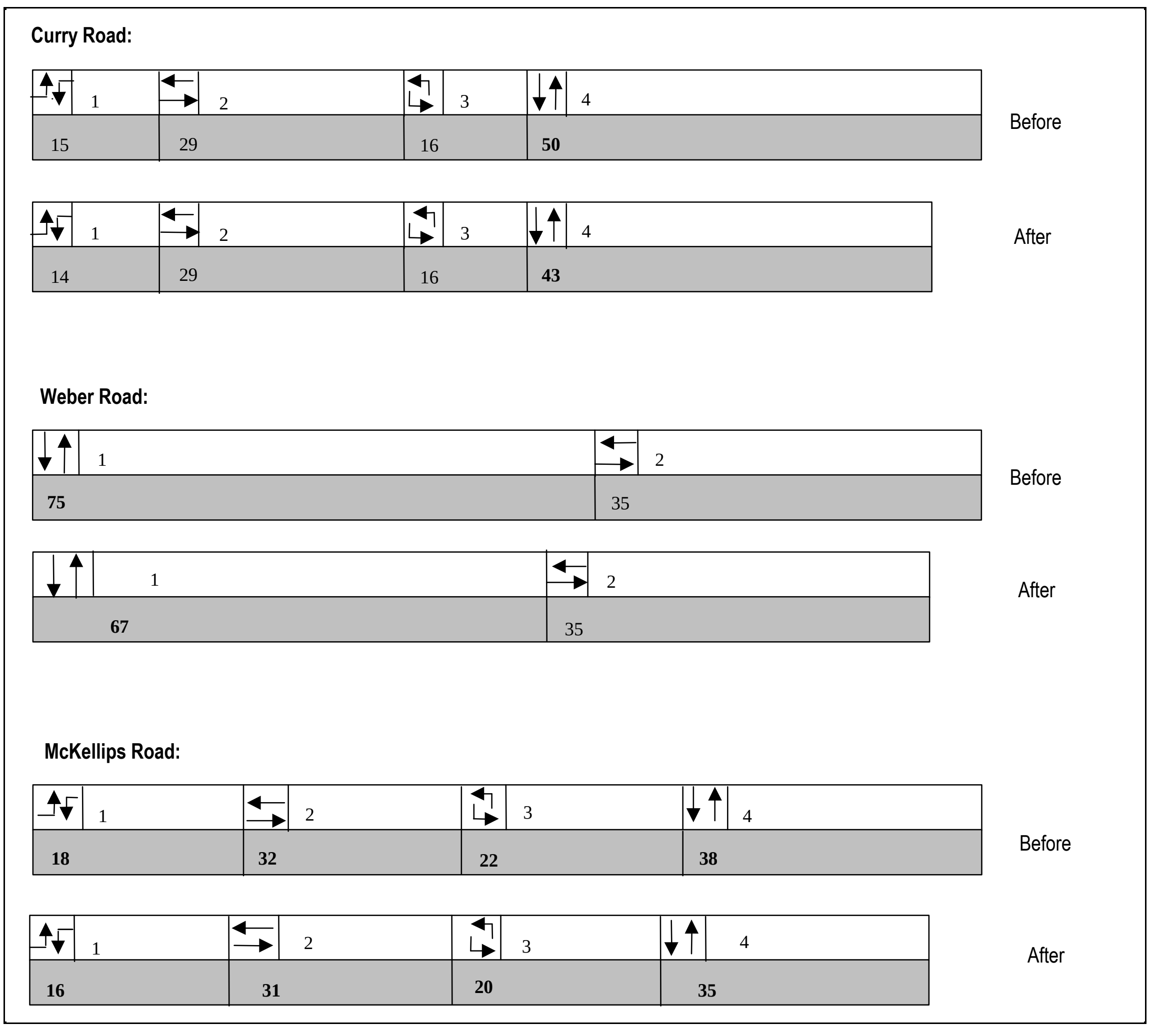

Figure 5-5: Before/After Signal Timings (AM Peak Plan)

Table 5-1: Before and After Traffic Signal Offsets

	AM Peak Plan		PM Peak Plan		Off-Peak Plan	
	Before	After	Before	After	Before	After
Rural/S202	10	10	0	0	20	20
Rural/Curry	95*	41*	100*	58*	55*	37*
Rural/Weber	75	22	2	51	45	32
Rural/McKellips	36*	98*	46*	4*	0*	4*
Scottsdale/Continental	38	38	38	38	32	32

* Offsets refer to phase 4 in

Figure 5-5.

5.4 Mainline Impacts of Traffic Signal Coordination: Field Results

This section summarizes the field results of the study. The first step in the evaluation was to quantify any induced demand/traffic into the Scottsdale/Rural Road corridor as a result of the improved traffic signal timings. The next step in the evaluation was to compute and statistically compare the various Measures of Effectiveness (MOEs) for the before and after scenarios.

5.4.1 Traffic Counts

The first step in the evaluation of the induced traffic and demand impacts of the traffic signal coordination performed was to statistically quantify the difference in total intersection volume and tube counts for the AM peak between the before and after scenarios. An analysis of variance that considered three factors was performed on the turning movement counts, as summarized in Table 5-2. The three factors included the intersection location (variable INT), a before/after flag (B_A) and the approach direction (DIR). As the table indicates, seven intersections, two before/after conditions, and four directions of traffic movement were considered.

Table 5-2: ANOVA Results on Turning Movement Counts

```
General Linear Models Procedure
                                    Class Level Information

                                Class    Levels    Values
                                INT           7    1 2 3 4 5 6 7
                                B_A           2    1 2
                                DIR           4    1 2 3 4


                            Number of observations in data set = 56


                                     The SAS System         15:51
Thursday, June 3, 1999  10

                                General Linear Models Procedure

Dependent Variable: COUNT

Source                  DF         Sum of Squares           Mean Square  F Value     Pr > F
Model                   10      45362980.10714280      4536298.01071429    11.58     0.0001
Error                   45      17635119.60714280       391891.54682540
Corrected Total         55      62998099.71428570

                  R-Square                   C.V.              Root MSE          COUNT Mean
                  0.720069               26.07764          626.01241747      2400.57142857

Source                  DF            Type III SS           Mean Square  F Value     Pr > F
INT                      6      12860597.96428570      2143432.99404762     5.47     0.0003
DIR                      3      32383149.00000000     10794383.00000000    27.54     0.0001
B_A                      1        119233.14285714       119233.14285714     0.30     0.5840
```

The analysis of variance indicated that both the intersection location and the approach direction were statistically different. However, there did not appear to be a statically significant difference, using a 95% confidence interval, in the approach flows between the before and after conditions. Consequently, there is no statistical evidence to indicate that the changes in traffic signal timings resulted in generated traffic.

5.4.2 Floating Car Runs

The next step in the analysis was to quantify the efficiency, energy, environmental and safety impacts of the traffic signal re-timing. The differences in the various MOEs, as computed from the GPS runs, were evaluated considering all three periods of analysis collectively (AM peak, Midday, and PM peak), and considering each period separately. Furthermore, the analysis considered the localized impacts signalized intersection approaches in addition to the general impacts on the 9.6-kilometer study corridor.

The various MOEs were computed for each of the 301 floating car runs and were summarized by direction and period. Statistical analysis of these runs indicated that the signal timing changes resulted in benefits at those intersections that were re-timed. However, no network-level benefits were found to be statistically significant at a 5% level of significance. Generally, the results observed matched those found in the simulation runs. A more detailed description of the analysis of the floating car runs can be found in Sin (2000).

5.5 Simulation Model Development

5.5.1 Network Construction and Cropping

The simulation model of the Scottsdale/Rural Road network was constructed using the INTEGRATION microscopic traffic simulation and assignment model. Model construction began by converting the Maricopa Association of Governments (MAG) planning model (in this case EMME/2) of the Greater Phoenix area into an INTEGRATION format, as illustrated in Figure 3-2. The planning model covered an area of over 7,200 square kilometers with a total of 9,529 nodes, 27,840 links and a total demand in excess of 2 million vehicle trips for the AM peak.

The EMME/2 O-D demand for the AM peak included Single Occupancy Vehicle (SOV), High Occupancy Vehicle (HOV), and bus trips. This demand was created using the standard four-step transportation planning process. After the network was converted from the EMME/2 format to a format usable by INTEGRATION, it was cropped to include the Scottsdale/Rural section and any alternative parallel routes. The network, which was approximately 60 square kilometers, was large enough to allow the modeling of traffic diversion. This network included Scottsdale/Rural Road from Southern Road in the south, to a couple of kilometers north of Thomas Road to the north. The network also included Hayden Road, an alternate parallel route to Scottsdale/Rural Road. The resulting Scottsdale/Rural Road network included a total of 499 nodes and 1021 links.

The cropping of the Scottsdale/Rural Road network also involved extracting the O-D pairs that traversed the sub-network from the full O-D matrix. In order to identify whether an O-D demand traversed the network, an All-or-Nothing (AOL) traffic assignment was made between each origin/destination combination: if the tree passed through the network it was included in the sub-network O-D demand. The final O-D trip table for the two-hour AM peak period included 123,518 vehicles.

After constructing the network, further details were added to the network, including turning bays, lane striping at signalized approaches, signal timings, and the type of control of traffic signals. A total of 72 traffic signals were added to the base network. Information on signal timings, type of signal phasing, and type of signal control (actuated, coordinated, or actuated/coordinated) were provided by the Maricopa County Department of Transportation (MCDOT) and the cities of Tempe and Scottsdale.

5.6 Network Calibration

5.6.1 Network Supply Calibration

Supply calibration for the Scottsdale/Rural Road Corridor was primarily done by comparing the effect that changes made in the field had on field-measured and simulated network performance. The amount of quality data obtained from the GPS floating car runs made this method of calibration feasible. Supply calibration was done using GPS probe observations made during the AM peak hour, and comparing the profiles of the observed probes to the results from 200 simulated probes.

Given that the speed profile of a particular vehicle changes depending on when within a signal's cycle length the vehicle encounters a signalized intersection, using the profile from a single probe vehicle could be misleading. Consequently, both the GPS probe profiles and the simulated probe profiles were individually averaged. Confidence intervals for the GPS probe data were then computed at a 5% level of significance. These average profiles are shown in Figure 5-6, along with the calculated confidence limits for the data.

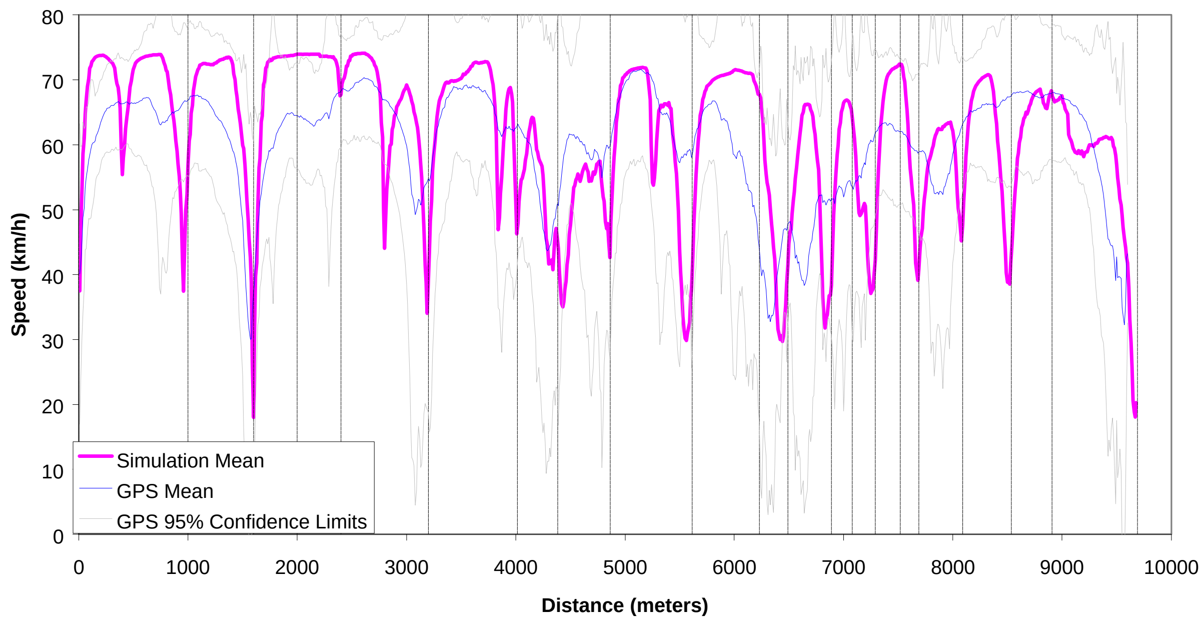

Figure 5-6: Speed Variability in Field Data (Southbound Direction during AM Peak)

Figure 5-6 shows that there is a significant amount of variability in the speed profiles. Despite this variability, it is evident that the GPS speed profiles match the simulated profiles quite well. In order to better evaluate the match between the average GPS profile and the average simulated profile, the confidence interval about the mean was computed by dividing the confidence interval of the data by the square root of the number of observations. These new confidence limits are shown in Figure 5-7. This figure, which shows both the northbound and southbound profiles for the AM peak, demonstrates that there is a good match between the simulated profiles and the GPS measured profiles. While some differences are evident, the general trends in both profiles are the same.

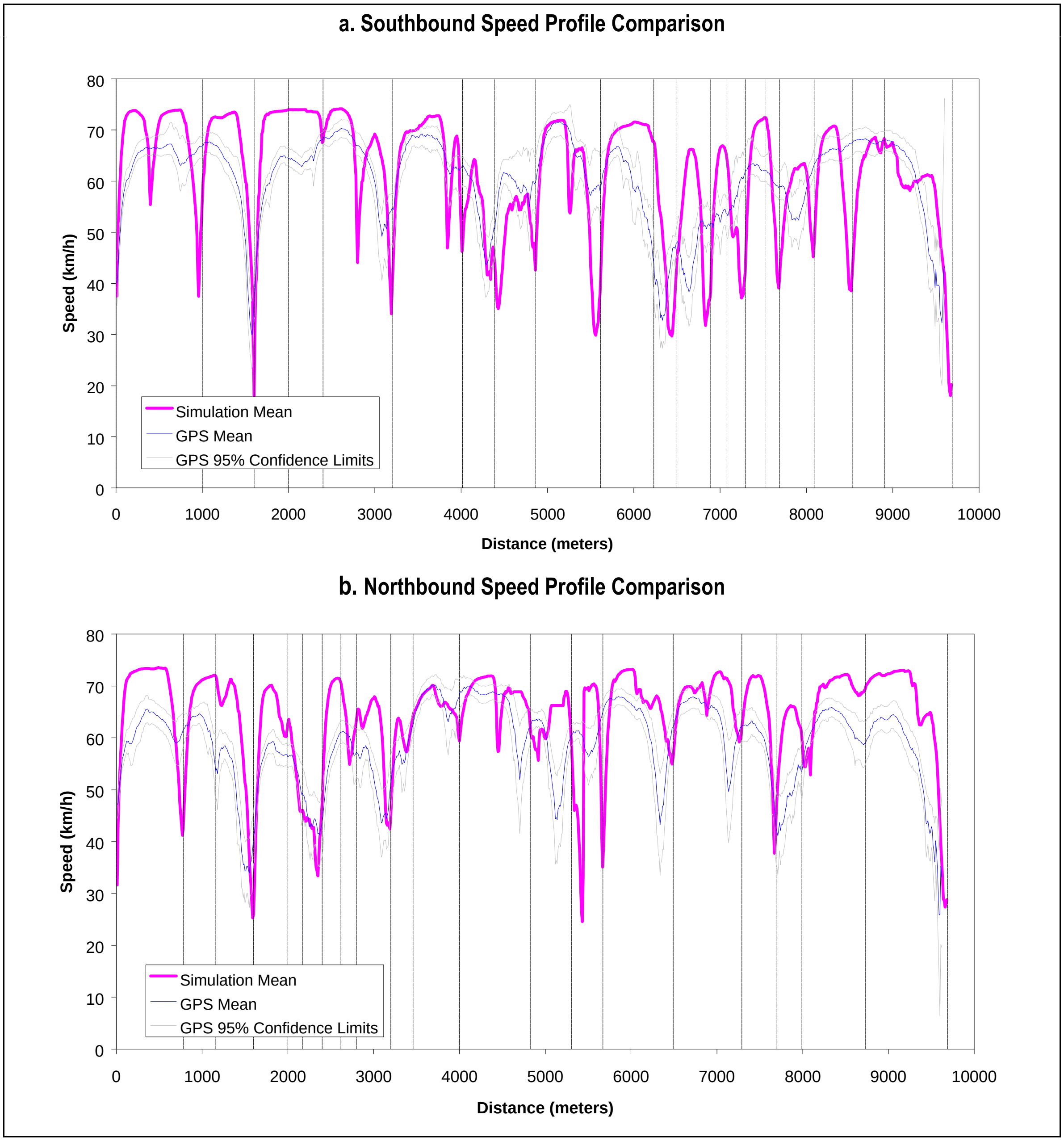

Figure 5-7: Simulated versus Field Speed Profile (S.B. and N.B. Before)

In addition to the consistency between the field and simulated results displayed in Figure 5-7, Figure 5-8 illustrates that there was no systematic error between the simulated and field observed speed estimates along the entire 9.6-kilometer section.

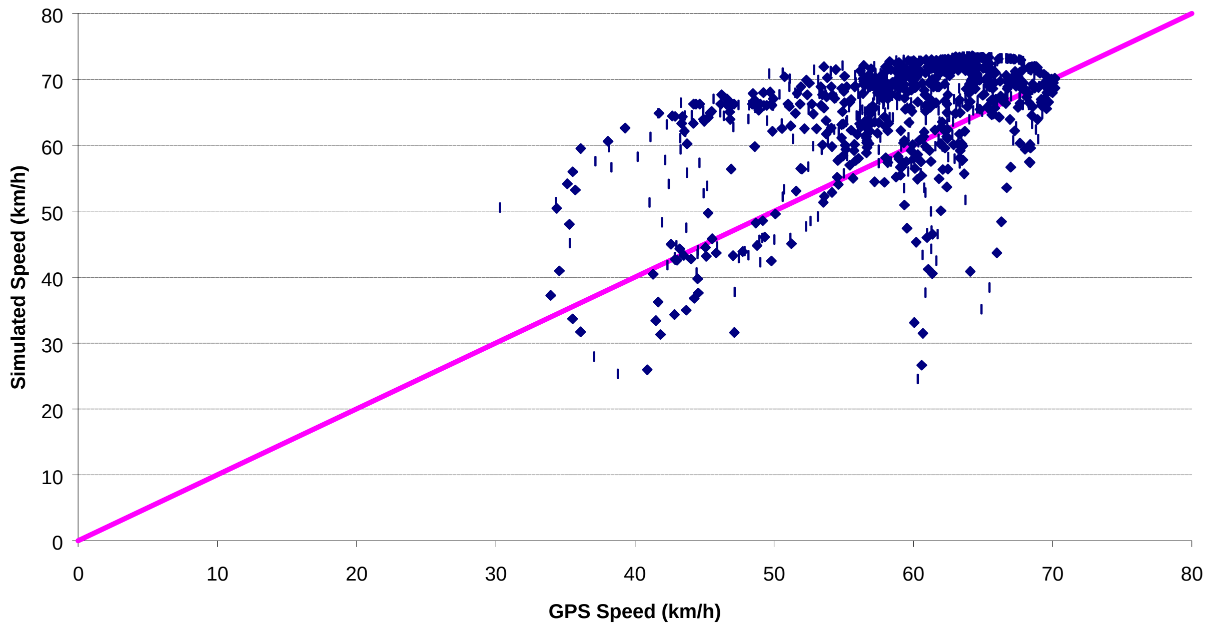

Figure 5-8: Scatter Plot of Simulated versus Field Speed Estimates (N.B. Before)

5.6.2 Network Demand Calibration

Although the EMME/2 O-D demand was available, it was not consistent with the tube and turning movement counts that were collected in the field (coefficient of determination of 0.42 between the observed and estimated flows). Consequently, the O-D demands were fine-tuned to match the tube and turning movement counts more accurately. The O-D demand was calibrated using the QUEENSOD synthetic O-D calculation tool, which was discussed in Chapter 3.

The calibration of the O-D demand to the tube and turning movement flows resulted in better consistency between the final O-D demand and the field conditions (coefficient of determination of 0.94 between the estimated and observed flows), as illustrated in Figure 5-9. The refined O-D demand was then simulated within the microscopic simulation environment, demonstrating a high correlation between the synthetic flows (Flow "B" in Figure 5-9) and the simulated flows (Flow "C" in Figure 5-9). The final test that was conducted was to compare the micro-simulated flow estimates to the tube and turning movement flows that were observed in the field. This comparison indicated a relatively good correlation (coefficient of determination of 0.72) between the simulated (Flow "C" in Figure 5-9) and field observed flows (Flow "A" in Figure 5-9).

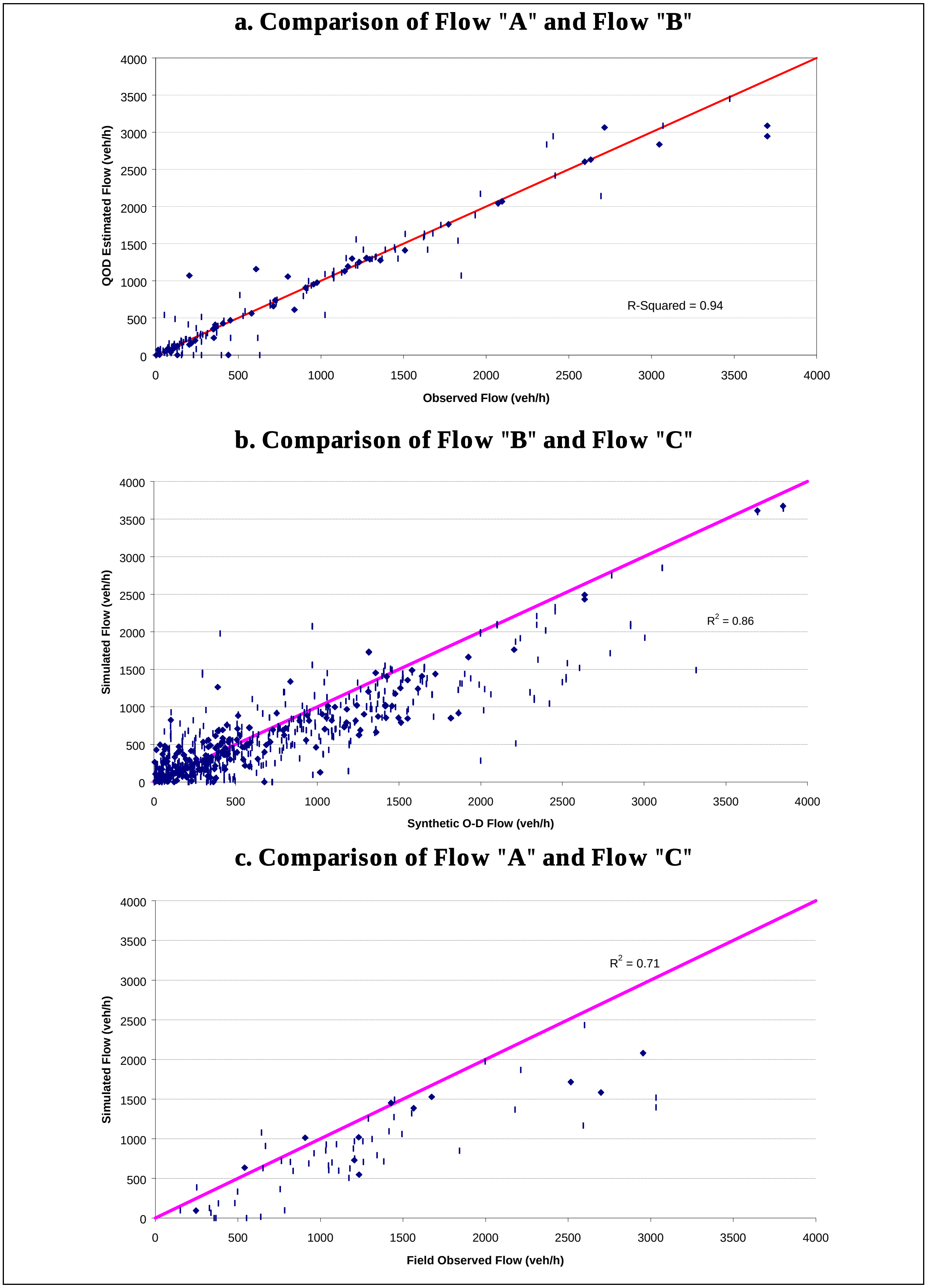

Figure 5-9: Comparison of Estimated Flows to Tube and Turning Movement Flows

In order to put the level of calibration in context, an attempt was made to quantify the typical day-to-day variability in 15-minute tube flows during the AM peak (i.e., the variability in flow from 8:00 to 8:15 on day 1 versus 8:00 to 8:15 on day 2). An analysis of the seven tube locations indicated that the daily 15-minute flow variability during the AM peak ranged from a coefficient of determination of 0.70 to one of 0.98. Consequently, it was concluded that the error between simulated and observed flows was within the typical daily variability that was observed in the field.

5.7 Running the Model and Analyzing the Results

This section summarizes the simulation results of the study. The results for the mainline are presented first in order to demonstrate consistency between the field and simulation approaches. Subsequently, the results for the cross streets are presented, followed by the network impacts of the signal re-timing. Each of these scenarios was analyzed for the AM peak for both the before and after conditions.

5.7.1 Mainline Results

As described earlier, probe vehicles traveling along Scottsdale/Rural Road were simulated within the simulation environment. A total of 200 probe vehicles completed the 9.6-kilometer section between Southern Avenue to the south and Thomas Road to the north. These probe vehicles included 103 trips for the after case and 97 trips for the before case.

In order to ensure consistency between the simulated and field results, ANOVA tests were performed on the simulated MOE estimates. The ANOVA results, again, at a 95% confidence interval, indicated statistically significant localized benefits as a result of the traffic signal re-timing. However, the results were statistically insignificant when the entire 9.6-kilometer mainline section was considered. Specifically, the differences in MOEs were statistically significant for the re-timed signals, with the exception that the number of vehicle stops per signalized approach was found to be marginally statistically insignificant (p=0.0534) and the HC and CO emissions that were not statistically significant. As was the case with the field data, the differences in MOEs were found to be statistically insignificant for the signals that were not re-timed.

5.7.2 Cross-Street Results

In order to evaluate the impact of signal coordination on the cross streets, additional probe vehicles that traveled along selected cross-streets were simulated within the simulation environment. Two cross-streets were selected, one with a traffic signal that was re-timed (Weber Street) and another with a traffic signal that was not re-timed (Terrace Road). Weber Street was selected because is was the only re-timed traffic signal that maintained the same cross street green interval duration between the before and after scenarios, as illustrated in

Figure 5-5.

Figure 5-10 illustrates the total delay for each simulated probe vehicle for the cross-street where the signal timings were not altered, and Figure 5-11 shows the total delay for each simulated probe vehicle on a cross street where the signal timings were changed. The figures clearly indicate that the delay associated with the traffic signal that was not re-timed (Terrace Road) is consistent between the before and after conditions. Alternatively, for the case of the re-timed signal, the delays for the after condition for the AM peak are significantly lower than for the before condition. These results were supported by a *t* test conducted at a 5% level of significance. Specifically, the differences in delay were not found to be statistically significant for the traffic signal that was not re-timed (Terrace Road (P $(T<t)=0.996$)), while the difference in delay for the re-timed traffic signal (Weber Street) was found to be statistically significant (P $(T<t)=0.029$). Consequently, while the results are not conclusive because not all signals were considered, it appears that the signal re-timing did result in localized benefits to both the mainline and cross-streets.

As mentioned earlier, field GPS data for the cross-streets were not available to compare simulation and field results. However, these findings demonstrate the importance of simulation for replicating field conditions and for evaluating conditions that were not measured or observed in the field.

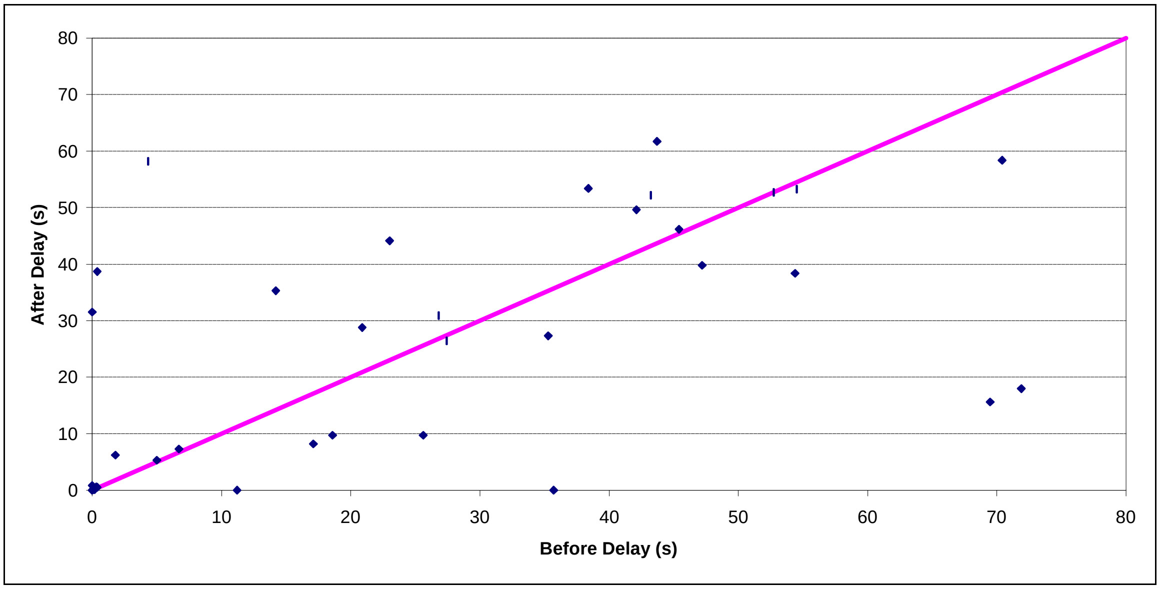

Figure 5-10: Change in Delays for a Non-Optimized Signal (Terrace Road)

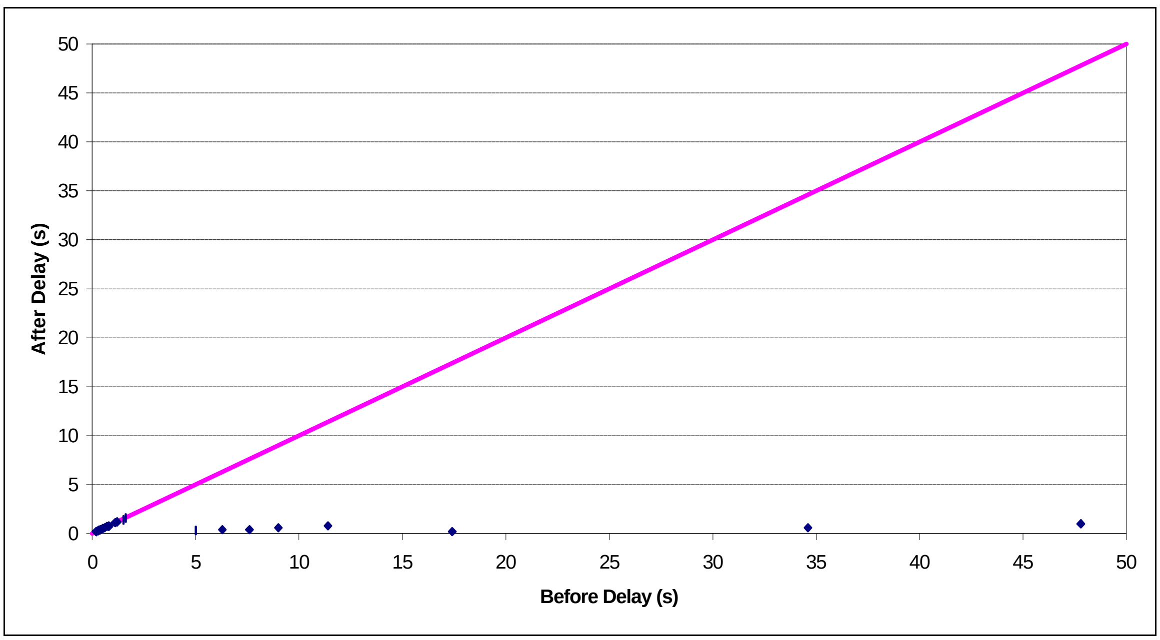

Figure 5-11: Change in Delays for an Optimized Signal (Weber Street)

5.7.3 Network Results

As described earlier, the field and simulation results indicated that the changes in signal timings resulted in localized benefits to the mainline (Scottsdale/Rural Road). However, it was not possible to evaluate the network impacts of the signal coordination using the field data.

The calibration of the demand to the field observed tube and turning movement counts resulted in a total demand of 123,518 vehicles over the two hour AM peak period. The demand was then simulated several times (5 random number seeds representing 5 different days) using the before signal timings and after signal timings. The results of the simulation indicate that, on average, the changes in the signal timings resulted in an increase in the system efficiency and positive environmental and safety impacts, as demonstrated in Table 5-3. A statistical analysis of the results indicates that the differences are not statistically significant compared to the noise within typical days, as shown in Table 5-3 and in Figure 5-12. For example, while Figure 5-12 illustrates that the changes in signal coordination reduced the average delay and the variability in delay, the reduction is within the noise across different runs.

Table 5-3: Summary of Network Simulation Results

	Before		After		P(T<t)
	Mean	Std. Dev.	Mean	Std. Dev.	
Avg. trip duration (minutes)	8.7	0.77	8.3	0.24	0.31
Avg. delay (minutes)	4.5	0.33	4.5	0.15	0.89
Avg. stopped delay (minutes)	2.5	0.22	2.6	0.11	0.22
Avg. accel./decel. delay (minutes)	2.0	0.16	1.9	0.06	0.27
Avg. number of stops	4.1	0.06	4.1	0.03	0.65
Avg. fuel consumption (l)	0.6	0.01	0.6	0.01	0.76
Avg. HC emissions (g)	9.9	0.12	9.9	0.11	0.46
Avg. CO emissions (g)	67.8	0.34	67.9	0.74	0.73
Avg. NO_x emissions (g)	1.6	0.01	1.6	0.01	0.18
Avg. crash risk x 10^{-6}	15.2	0.69	15.3	0.31	0.78

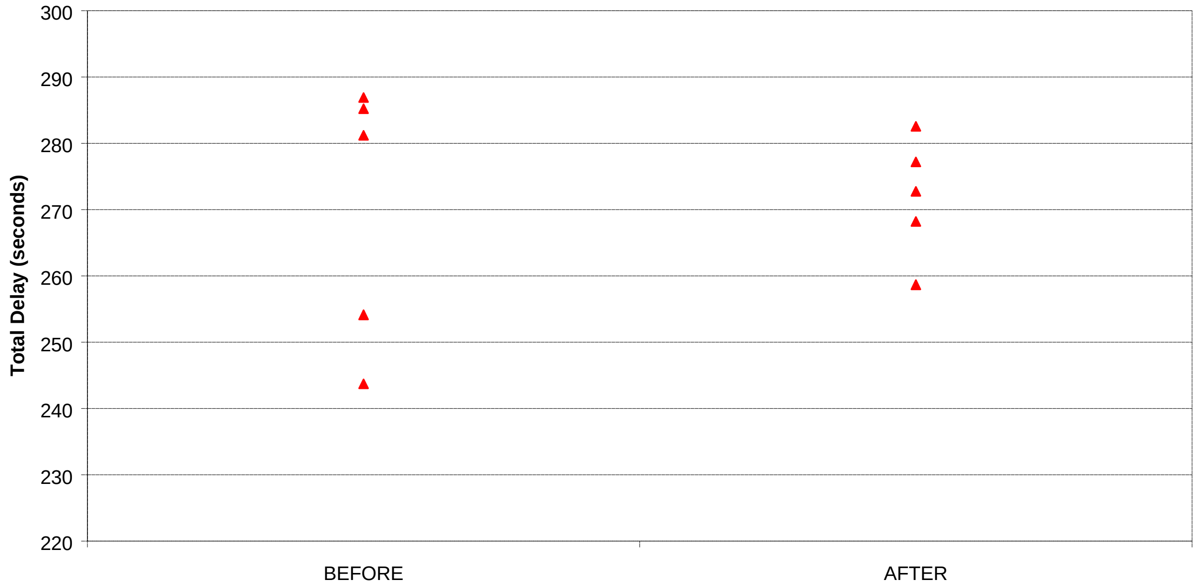

Figure 5-12: Average Total Delay for Different Simulation Runs

The statistically insignificant difference between the before and after conditions can be attributed to the fairly large extent of the network under consideration (approximately 60 km^2) and to the fairly minor changes that were made to the signal timings (offsets changed for only 3 signals of the 72 signals).

It should be noted, however, that the changes in the signal timings reduced the variability in the different MOEs in most cases. The variability for the different MOEs between the before and after conditions were compared using statistical *F* tests. The results concluded that, for a level of significance of 10 percent, there was statistically significant evidence that the variance of the speed, total delay, stopped delay, acceleration and deceleration delay and average crash risk were reduced as a result of the traffic signal re-timing. For the other MOEs there is not statistical evidence to conclude that the variances between the before and after situation were different.

5.8 Recommendations for Further Study

Because GPS data was only collected for the mainline (Scottsdale/Rural Road), it was not possible to quantify the impacts of the signal coordination on the cross-traffic, nor was it possible to quantify the overall network impacts of the signal re-timing. The modeling effort described above evaluates the overall benefits of the signal re-timing ignoring traffic diversion (i.e., the vehicle routes were held constant). Further analyses should consider the potential for temporal and spatial diversion of traffic in evaluating the traffic signal changes.

5.9 Conclusions

While this study does provide some insight as to the potential benefits of coordinating traffic signals across jurisdictional boundaries, it, more importantly, demonstrates the feasibility of using GPS second-by-second speed measurements and simulation tools for the evaluation of operational-level traffic improvement projects. Specifically, the use of statistical models allows for the evaluation of the efficiency, energy, emissions and safety benefits of operational-level traffic improvement projects without having to invest in expensive equipment.

The INTEGRATION simulation model demonstrated mainline findings that were consistent with the field data; specifically, both found statistically significant localized impacts with statistically insignificant overall mainline impacts. Furthermore, the simulation results indicated that the signal re-timing resulted in localized cross-street benefits, but the benefits of the signal re-timing were not found to be significant at the network level. The simulation results did indicate, however, that the traffic signal re-timings resulted in a statistically significant decrease in the variance of the speed and delay at the network level. It should be pointed out that the network-level analysis did not consider changes in vehicle routing, changes in time of departure, nor did it consider changes in mode of travel.

Further work is required to investigate long-term impacts of operational-level traffic improvement projects and to quantify the potential benefits of coordinating the entire corridor off-line as one sub-area, applying isolated adaptive signal control, and applying coordinated adaptive signal control.

CHAPTER 6: CONCLUSIONS

This thesis has presented a framework for the development and application of microscopic simulation tools to operational-level traffic engineering projects. Moreover, it has described a well-founded, comprehensive, and universal approach to using these microscopic simulation tools.

Chapter 2 presented a literature review covering the general purposes and goals of simulation, as well as the current state of simulation capabilities, theories, and techniques. Special attention was paid to microscopic simulation considerations, because a microscopic level of detail is needed to accurately capture the sometimes subtle impacts of intelligent transportation systems.

The literature review revealed that while many contemporary simulation packages are capable of providing satisfactory results for either operational or planning phenomena, none of the models integrates the two at a microscopic level. Within operational microscopic simulation packages, the literature indicates that it is impossible to categorically define which simulation package best fits a defined situation—each simulation model has its relative merits and disadvantages, and must be evaluated on a case-to-case basis.

Generally, authors feel that increases in computing power will improve the functionality, accuracy, and scope of simulation modeling, culminating in region-wide, intermodal, microscopic scenarios being run with many random seeds.

Increased computing power may also expand the ways in which simulation is used. Real-time analyses and predictions will become a more realistic endeavor, thereby enabling the use of simulation for predictive traffic control. Improving technology and increasing use of ITS will also improve future data collection efforts, thereby greatly improving the amount of data available for calibration and validation.

The literature review also noted specific areas of microscopic simulation that are most in need of improvement:

- Flexibility—Most models are incapable of adequately modeling the impacts of ITS measures. Developers of simulation packages must find generalized ways to model ITS systems.
- Phenomena—Many important phenomena, such as intermodal traffic, on-street parking, pedestrians, and transit vehicles, are often unaccounted for.
- Driver Behavior—Better representations are needed.
- Variability—Real-world conditions are not modeled with adequate variability—e.g., temporal changes in traffic flow or driver behavior that changes in response to weather.
- Generated Traffic—Most models are incapable of modeling induced demand or diverted traffic.
- MOEs—More realistic modeling of measures of effectiveness is needed; some of these measures, such as noise pollution and emissions migration, are totally neglected today. Furthermore, there is not a standardized, comprehensive method for analyzing the outputs from microscopic simulation models. A generalized objective function would provide this.

Following the literature review, Chapter 3 delivered a thorough discussion of the ideal approach and framework for microscopic simulation on a network scale. Chapter 3 also presented a discussion of the verification and verification of microscopic simulation models, and presented methods for constructing and refining the network geometry within a simulation package. Thereafter, a detailed narrative of the best calibration practices was given, followed by a discussion of relevant considerations for interpreting the results from simulation models.

Chapter 3 showed that simulation is an intricate and involved process, and emphasized that simulation usually requires more effort than anticipated. Extra time should be allotted for mitigation of complications, especially for the data collection and calibration steps.

Chapter 4 presented a case study that reinforced the concepts introduced in Chapter 3; and Chapter 5 reviewed another case study that, while using the techniques recommended in Chapter 3, had to make necessary concessions to the ideal approach. The case studies outlined in Chapters 4 and 5 show that simulation is, indeed, a relevant and powerful tool for evaluating real-world projects.

Chapter 4 evaluated signal control strategies beyond the capabilities of the traffic control equipment present in the field. Therefore, although the results were promising, no field operational test was available to reinforce the results. This, however, illustrates that simulation can be used to evaluate not only operational strategies, but also combinations of infrastructure deployment. Chapter 4 was also interesting because some of the scenarios evaluated resulted in negative impacts when only benefits were expected. This illustrates not just the complexity of the systems being evaluated, but also the importance of diligently scrutinizing both model inputs and outputs. The simulation results also indicated that there appears to be no benefit to providing real-time traffic information via a VMS under typical non-recurring conditions. Further analyses are required in order to establish the benefits of disseminating traffic conditions via VMS during non-recurring congestion.

Chapter 5 showed that coordinating signals across jurisdictional boundaries may provide more benefits than coordinating within the boundaries. More importantly, however, Chapter 5 showed that GPS probe data can effectively be used both to evaluate operational-level traffic improvement projects, and to calibrate microscopic simulation models. Moreover, the GPS probe measurements of field implementation were consistent with the results of simulation in INTEGRATION.

Chapters 4 and 5 showed that the approach presented in Chapter 3 is only a starting point for any microscopic simulation project. Each new project will bring new conditions that cannot be accounted for in a generalized approach.

This thesis has demonstrated that microscopic simulation is a valuable tool for evaluating operational-level transportation projects. Indeed, it was shown that the uses for microscopic simulation extend outside of this area, and that the capabilities of simulation models will increase in the future.

It was shown that microscopic simulation is capable of estimating the impacts of different operational-level measures such as ITS on network-wide performance indicators such as emissions and travel time. Simulation models were shown to be effective for the evaluation of these projects in cases where it would otherwise be impossible or infeasible to do so. It was thence shown that microscopic simulation tools can be used not only to determine the impacts of these transportation projects, but also to optimize these projects.

REFERENCES

1. Activity Based Highway Capacity Analysis: A Case Study. Luis Alvarez. Proceedings of the 1997 IEEE Conference on Intelligent Transportation Systems, ITSC, pp 153-158. IEEE, 1997.

2. The Ali-Scout Route Guidance Simulation. A. Hadj-Alouane, N. Hadj-Alouane, O. Juma, G. Sarathy, S. Underwood. The University of Michigan, November 21, 1996.

3. Analysis of Intersection Delay Under Real-Time Adaptive Control. P. Brian Wolshon and William Taylor. The 77th Annual Meeting of the Transportation Research Board, 1998.

4. An Approach for Evaluating Throughput, Energy, Emission and Safety Benefits of Traffic-Flow Improvement Projects. Heung-Gweon Sin. Ph.D. Dissertation, Virginia Polytechnic Institute and State University, 2000.

5. An Assessment of Adaptive Co-ordination of Traffic Signal Offsets within INTEGRATION. J. A. Stewart, M. Van Aerde. The 77th Annual Meeting of the Transportation Research Board, 1998.

6. ATMS in Phoenix. John Prowse. ITS Arizona Newsletter, March 1996.

7. Benefit Sensitivities of Adaptive Traffic Control Strategies at Isolated Traffic Signals. J. A. Stewart, K. Lepik, M. Van Aerde. The 77th Annual Meeting of the Transportation Research Board, 1998.

8. Capacity and level of service by simulation--A case study of TRAF-NETSIM. Shui-Ying Wong. Highway Capacity and Level of Service, pp 467—483. Balkema, 1991.

9. Combining Traffic Management and Driver Information in Traffic Integrated Networks. M. Van Aerde and S. Yagar. IEE Third International Conference on Road and Traffic Control, 1990

10. A Comparison of the Low Fidelity TRANSIMS and High Fidelity CORSIM Highway Simulation Models Using ITS Data. L. R. Rilett, Kyu-Ok Kim. The 79th annual meeting of the Transportation Research Board, January 2000.

11. A Comparison of the VISSIM and CORSIM Traffic Simulation Models On A Congested Network. Loren Bloomberg, Jim Dale. The 79th annual meeting of the Transportation Research Board, January 2000.

12. A Compendium of Traffic Model Validation Documentation and Recommendations, Phase I, Tasks A-H. Larry E. Owen, Gary Brock, Scott Mastbrook, Rick Pavlik, Lei Rao, Charlie Stallard, Srinivasa Sunkari, and Yunlong Zhang. Prepared for FHWA, December 1996.

13. Construction and Calibration of a Large-Scale Microsimulation Model of the Salt Lake Area. H. Rakha, M. Van Aerde, L. Bloomberg, and X. Huang. Transportation Research Record 1644, pp 93-102. 1998.

14. Coordination of Traffic Signal across Regional Boundaries: Field and Modeling Results. H. Rakha, A Medina, and J. Jenq. The 79th Annual Meeting of the Transportation Research Board, January 2000.

15. Crop: A Program for Cropping INTEGRATION Files. Transportation Systems Research Group and M. Van Aerde. 1997.

16. Developing a Testbed for Evaluating the Impacts of Truck Performances on Surrounding Traffic. Francis J. Martin. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. March 15, 1999.

17. Development of Data-Based Light-Duty Modal Emissions and Fuel Consumption Models. West, B., McGill, R., Hodgson, J., Sluder, S., and Smith, D. Society of Automotive Engineers Paper No. 972910. 1997.

18. Estimating Induced Travel for Evaluation of Metropolitan Highway Expansion. Patrick DeCorla-Souza and Harry Cohen. Submitted for publication in Transportation, January 4, 1999.

19. Estimating the Network-wide Safety Impacts of Operational-Level Transportation Improvements. Avgoustis A., Van Aerde M., and Rakha H. The 79th Annual Meeting of the Transportation Research Board, January 2000.

20. Estimation of an O-D Matrix from Traffic Counts: A Review. Willumsen L.G.. Institute for Transport Studies, Working paper no. 99, Leeds University. 1978.

21. Evaluating the Efficiency, Energy, Environmental and Safety Impacts of Intelligent Transportation Systems along the Southern/Baseline Corridor. H. Rakha, A. Medina and J. Diekmann. Draft 1.1, October 4, 1999.

22. An Evaluation of Integrated Freeway Traffic Control and Route Diversion using Microscopic Simulation. David Cuneo, Mithilesh Jha, Moshe Ben-Akiva. The 78th Annual Meeting of the Transportation Research Board, 1999.

23. Evaluation Tools of Urban Interchange Design and Operation. A. Essam Radwan and Roger L. Hatton. Transportation Research Record 1280, pp 148-155. 1990.

24. Field Evaluation of Traffic Signal Coordination using GPS Data: Issues and Proposed Solutions. H. Rakha, Diekmann J., Sin H., Van Aerde M. and Dion F. Draft 1.1 - Feb. 18, 1999.

25. Freeway Simulation Models Revisited. Adolf D. May. Transportation Research Record 1132, p 94-99. 1987.

26. Fundamentals of Digital Simulation Modeling. J.W. Schmidt. 1983

27. Fundamental Issues in Intelligent Transportation Systems. S Ghosh. Proc. Instn. Mech. Engrs. Vol 213 Part F, p 125-131. 1999.

28. Fundamental Properties of Synthetic O-D Generation Formulations and Solutions. Harinarayan Paramahamsan. Master's Thesis, Virginia Polytechnic Institute and State University. 1999.

29. Generated Traffic: Implications for Transport Planning. By Todd Litman, Victoria Transport Policy Institute. November 1999.

30. Guidelines on the use of Changeable Message Signs. Report FHWA TS-90-043. USDOT. May 1991.

31. INTEGRATION Release 2.10 For Windows: User's Guide Volumes I and II. M. Van Aerde. Blacksburg, VA. 1998.

32. Interjurisdictional Traffic Signal Committees--Do They Work? James R. Helmer. ITE Compendium of Technical Papers, pp 159-162. 1990.

33. ITS Evaluation Resource Guide. The US DOT ITS Evaluation Joint Program Office, 1999.

34. Mapblast! Maps. www.mapblast.com.

35. Mesoscopic Fuel Consumption and Vehicle Emission Rate Estimation as a Function of Average Speed and Number of Stops. Dion F., Van Aerde M., and Rakha H. The 79th Annual Meeting of the Transportation Research Board, January 2000.

36. A Methodology for Evaluating Systems Architectures. Stein Weissenberger, Hong Lo, and Mark Hickman. Proceedings of the 6th Vehicle Navigation and Information Systems Conference, pp 397-402. IEEE, 1995.

37. Metropolitan Model Deployment Initiative: Phoenix Evaluation Report (DRAFT). Prepared for the FHWA. July 1999.

38. Microscopic Fuel Consumption and Energy Emission Models. Ahn K., Trani A., Rakha H., and Van Aerde M. The 78th Annual Meeting of the Transportation Research Board, January 1999.

39. Modeling Aircraft Fuel Consumption With a Neural Network. Glenn D. Schilling. Master's Thesis, Virginia Polytechnic Institute and State University. February, 1997

40. Modeling the Driving Behaviour Influenced by Information Technologies. Uwe Reiter. Highway Capacity and Level of Service, pp 309-320. Balkema, 1991.

41. Modeling the Effects of ITS on Route Switching Behavior in a Freeway and its Effect on the Performance of O-D Prediction Algorithm. Debashish Bhattacharjee, Kumares C. Sinha, and James V. Krogmeier. The 77th Annual Meeting of the Transportation Research Board, 1998.

42. Models for Assessing the Impacts and the Potential Benefits of Intelligent Transportation Systems. Ajay K. Rathi. Prepared for the IVHS Research Division, Joint Program Office. August 15, 1995.

43. The Most Likely Trip Matrix Estimated from Traffic Counts. Van Zuylen J. H and Willumsen L. G. Transportation Research. 14B, pp 281-293. 1980.

44. Multi-Jurisdictional Computerized Signal System Project Case Study. Adres E. Nunex, Jr., Dan Brame. Compendium of Technical Papers, 53rd Annual Meeting, pp 3.9-3.12. ITE, 1983.

45. Multivariate Calibration of Single Regime Speed-Flow-Density Relationships. Van Aerde M. and Rakha H. Vehicle Navigation and Information Systems (VNIS) conference, Seattle, Washington, August, 1995

46. NETSTREAM: Traffic Simulator for Evaluating Traffic Information Systems. Eiji Teramoto, Miyako Baba, Hiroko Mori, Yoshikau Asano and Hiroshi Morita. Proceedings of the 1997 IEEE Conference on Intelligent Transportation Systems, ITSC, pp 484-489. IEEE, 1998.

47. Optimal Traffic Counting Locations for Origin-Destination Matrix Estimation. Hai Yang and Jing Zhou. Transportation Research Record-B, Vol 32, No. 2, pp. 109-126, 1998.

48. Optimizing Networks of Traffic Signals in Real-Time--The SCOOT method D.I. Roberston and R.D. Bretherton. IEEE Transactions on Vehicluar Technology, Vo. 40, No. 1, pp.11-15. IEEE, February 1991.

49. An Overview of the Ramp Metering Subsystem for the Phoenix Freeway Management System. John L. Hibbard, James D. Carvell, Jr., and Blair G. Marsden. ITE 1990 Compendium of Technical Papers. pp 51-54. ITE, 1990.

50. Performance Measurement for Traffic Management Systems. James H. Banks. The 77th Annual Meeting of the Transportation Research Board, January 1998.

51. A Proposed ITS Evaluation Framework for Texas. Shawn M. Turner and William R. Stockton. FHWA Report Number FHWA/TX-99/1790-2. March 1999

52. QUEENSOD Release 2.10 User's Guide. The Transportation Systems Research Group and M. Van Aerde. Blacksburg, VA. July 1998.

53. A Real-Time Simulation Environment for Evaluating Traffic Signal Systems. Darcy Bullock and Alison Catarella. The 77th Annual Meeting of the Transportation Research Board, January 1998.

54. The Relationship Between Detector Location and Travel Characteristics on Arterial Streets. Gary B. Thomas. ITE Journal, October 1999.

55. Relationships Between Highway Capacity and Induced Vehicle Travel. Robert B. Noland. The 78th Annual Meeting of the Transportation Research Board, Jan. 1999.

56. A Simulation for the Evaluation of Signal Control at Traffic Networks. M. Katakura, Sh. Mukai and Y. Sakurada. IFAC-Proceedings-Series, Number 6: Control in Transportation Systems, pp 246-249. Pergamon Press. 1987.

57. SMARTEST (Simulation Modelling Applied to Road Transport European Scheme Tests): Best Practice Manual. Gunnar Lind, Kristina Schmidt, Helene Andersson, Staffan Algers, Gianni Canepari, Carlo Di Taranto, Eric Bernauer, Laurent Bréheret, Jean-François Gabard, and Ken Fox. Project Coordinated and Published by the University of Leeds, GB. May 1999.

58. SMARTEST (Simulation Modelling Applied to Road Transport European Scheme Tests): Final Report. University of Leeds, Universitat Politècnica de Catalunya, Mizar Automazione, CERT-ONERA, SODIT, Transek, Softeco Sismat, Hägskolan Dalarna. January 2000.

59. SMARTEST (Simulation Modelling Applied to Road Transport European Scheme Tests): Micro-simulation Workshop. Eric Bernauer, Laurent Bréheret,

Jean-François Gabard, J. Barceló, J. Casas, J.L. Ferrer, D. García, Gianni Canepari, Carlo Di Taranto, Ken Fox, and Ronghui Liu. Project Coordinated and Published by the University of Leeds, GB. July 1999.

60. SMARTEST (Simulation Modelling Applied to Road Transport European Scheme Tests): Appendix D, Review of Micro-Simulation Models. Eric Bernauer, Laurent Breheret, Staffan Algers, Marco Boero, Carlo Di Taranto, Mark Dougherty, Ken Fox, and Jean-François Gabard. Project Coordinated and Published by the University of Leeds, GB, June 1997.

61. A Statistical Analysis of Day-to-Day Variations in Real-Time Traffic Flow Data. Rakha H. and Van Aerde M. Transportation Research Record No. 1510, 1995.

62. Systematic Verification, Validation and Calibration of Traffic Simulation Models
H. Rakha, B. Hellinga, M. Van Aerde, Perez. 75th Annual Meeting of the Transportation Research Board, January 1996

63. The Traffic Management Laboratory: System Design. Alberto J. Santiago, Ammar Kanaan, and Craig Franklin. Proceedings of the 6th Vehicle Navigation and Information Systems Conference (VNIS), pp 498-502. IEEE, 1995.

64. Traffic Signals and Control, Ramp Metering, and Lane Control Systems. Justin Black and Joe Wanat. LEAP Online ITS Database, maintained by the California PATH Program. June 8, 1998.

65. Understandable Statistics, Sixth Edition. Charles Brase and Corrinne Brase. Houghton Mifflin Company, 1999.

66. Urban Traffic Network Flow Models. James C. Williams, Hani S. Mahmassani, and Robert Herman. Transportation Research Record 1112, pp 78-88. 1987.

67. Use of Multicriteria Methods for Assessment of Transport Projects. D. Tsamboulas, G. S. Yiotis, and K. D. Panou. Journal of Transportation Engineering, September / October 1999.

68. Use of Simulation to Improve Diversion Routes for Incident-Management Programs. Nikiforos Stamatiadis and Eugene Culton. ITE Journal, pp 90-94, May 1999.

69. Using FREQ8PE to Simulate Holiday Traffic Management Strategies for the Tolled Freeway of Taiwan. Lawrence W. Lan and Shu-Ken Sheu. ITE 1990 Compendium of Technical Papers, pp 55-59. ITE, 1990.

APPENDIX A: GLOSSARY AND LIST OF ACRONYMS

This glossary is intended to be a reference for those using this document, especially for those terms that have historically had more than one meaning. While an attempt was made to make the definitions as current and applicable as possible, the meanings of certain terms are constantly evolving, and may change. An attempt was made to verify each addition; the references used in doing so are listed at the end of the glossary. Please note that not all of the terms below are contained in the main document.

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A

AASHTO - American Association of State Highway and Transportation Officials. An interest group based in Washington, D.C.; involved in research, advocacy and technical assistance. Develops guidelines for the construction, maintenance, and operation of surface transportation facilities.

ACC - Adaptive cruise control. Also see: AICC, ICC.

ACN - Automatic collision notification

Actuated Controller - Traffic Signal Controller that detects the presence of vehicles, and adjust the phase length of the signal in response to traffic flow. Also see: full actuation and semi-actuated control.

ADIS - Advanced Driver Information System.

ADOT - Arizona Department of Transportation.

ADVANCE - Advanced Driver and Vehicle Advisory Navigation Concept A cooperative effort to evaluate the performance of the first large scale dynamic route guidance system in the U.S.

AHS -Automated Highway System; Advanced Highway System.

AICC –Automatic (Autonomous) Intelligent Cruise Control. Also see: ACC, ICC.

ALI - Automatic Location Identification.

ANOVA – Analysis of Variance. Test to check if the means of two populations are equal. Often used when comparing many different populations to one base population.

APL – Applied Physics Laboratory (The Johns Hopkins University).

APS – Advanced Payment Systems.

APTS – Advanced Public Transportation Systems.

Architecture - The overall structure and unifying design characteristics of a system.

ARSI - Automated Roadside Safety Inspection.

Arterial Street - A major thoroughfare, used primarily for through traffic rather than for access to adjacent land, that is characterized by high vehicular capacity and continuity of movement.

ARTS - Advanced Rural Transportation Systems.

ASC - Actuated Signal Controller.

ASCE - American Society of Civil Engineers.

ASTM - American Society for Testing and Materials.

ATC - Automated Toll Collection, aka Electronic Toll Collection. An application of AVI technology.

ATC - Advanced Transportation Controller.

ATIS - Advanced Traveler Information Systems. provides travelers with information to help in trip planning and changing course en route to bypass congestion, e.g., broadcast traffic reports, in-car computerized maps and highway CMSs. Also can include automated transit trip planning and automated rideshare matching.

ATMS - Advanced Traffic Management Systems. Uses a variety of means to more efficiently manage traffic. It can include roadside sensors, ramp metering, HOV lanes and synchronized traffic signals that respond to traffic flows.

AVC - Automatic/Automated Vehicle Classification.

AVCS - Advanced Vehicle Control Systems. New techniques to ease stresses and strains of driving are evolving, possibly leading to the day when you may be able to sit back and leave your car in charge. AVCS spans the gamut from ordinary cruise control to "smart cruise control" that helps maintain safe following distance to, researchers hope, "platooning" -- the ability to electronically link and guide a dense pack of cars moving in formation at high speed.

AVI - Automated Vehicle Identification. Combines an in-car device as well as a roadside receiver that will identify for vehicles for purposes of automated toll collection, stolen vehicle recovery, etc. Identifies vehicles using light, microwave, or radio frequencies. Combines roadside receivers with on-board transponders to automatically identify vehicles. This includes license plate readers.

AVL - Automated Vehicle Location (System). Employs satellites and other technologies to track vehicles in a fleet, assisting with dispatching and other applications. Currently used by truckers and courier services, it could be used in the future by transit systems to provide real-time schedule information for patrons. There are several types of AVL: Dead Reckoning AVL and Radio determination AVL.

AVLS – See: AVL.

AVM - Automatic Vehicle Monitoring. Any system that keeps track of vehicle positions.

Index

B

BMP – Best Management Practice.

Index

C

CA - Cellular Automata.

CAA - Clean Air Act, aka FCAA. Federal legislation that sets national air quality standards; requires each state with areas that have not met federal air quality standards to prepare a SIP. The sweeping 1990 amendments to the CAA, sometimes refereed to as CAAA, established new air quality requirements for the development of metropolitan transportation plans and programs.

CAAA - Clean Air Act Ammendments of 1990. The comprehensive federal legislation which establishes criteria for attaining and maintaining the federal standards for allowable concentrations and exposure limits for various air pollutants; the act also provides emission standards for specific vehicles and fuels.

Calibration Adjusting a model so that it matches observed data--The iterative process of modifying certain model input parameters with the objective of improving the consistency between the model's output and the data observed in the field; the input parameters changed are only those with some degree of uncertainty, and no parameters should be outside of acceptable engineering limits.

Capital Costs - Costs of long-term assets such as property, buildings, vehicles, etc.

CAS – Collision Avoidance Systems.

CBD – Central/Commercial Business District. The downtown retail trade and commercial area of a city or an area of very high land valuation, traffic flow, and concentration of retail business offices, theaters, hotels and services.

CCI - Corridor Congestion Index.

CCTV - Closed Circuit Television.

CFR - Code of Federal Regulations. A codification of the general rules published in the Federal Register by executive departments and agencies of the Federal Government.

CMA - Congestion Management Agency. A countrywide organization responsible for preparing and implementing the county's CMP. The CMA can be a new or existing public agency designated by a county's cities and board of supervisors. CMAs came into existence as a result of state legislation and voters' approval of Prop. 111 in 1990.

CMAQ - Congestion Mitigation and Air Quality Program. A pot of money contained in ISTEA for projects and activities that reduce congestion and improve air quality in regions not yet attaining federal air quality standards.

CMP - Congestion Management Program. What a CMA is responsible for. Required of every county with an urbanized area of at least 50,000 people. Updated biennially, a CMP sets performance standards for roadways and public transit, and shows how local jurisdictions will attempt to meet those standards through TDM strategies (including a TRO) and a seven-year capital improvement programs. A CMP is necessary in order to qualify for certain funds made available through the state gas tax increase authorized in 1990.

CMS - Congestion management systems.

CMS - Changeable Message Sign. Also see: VMS.

CO - carbon monoxide The most widely distributed and the most commonly occurring pollutant caused by vehicular traffic. Most atmospheric CO is formed by the incomplete combustion of organic materials used as fuels.

COG - Council of Governments. A voluntary organization of local governments that strives for comprehensive, regional planning. A COG can also be an MPO, an RTPA or a CMA. Or any combination of the four.

Conformity - A process in which transportation plans and spending programs are reviewed to ensure that they are consistent with federal clean air requirements; transportation projects collectively must not worsen air quality.

Corridor - A broad geographical band that follows a general directional flow connecting major sources of trips that may contain a number of streets, highways and transit route alignments.

CORSIM - CORridor microscopic SIMulation – A combination of two other micro-simulators, NETSIM and FRESIM. FRESIM must be used for modeling the freeway portions of the network, and NETSIM is used for modeling the relationships on the sub-network. Interface links and nodes are used to connect the two models.

CSA - Canadian Standards Association.

CTR - The Center for Transportation Research at Virginia Tech; now known as the Virginia Tech Transportation Institute (VTTI).

CVIS - Commercial Vehicle Information System.

CVISN - Commercial Vehicle Information Systems and Networks. CVISN is the collection of state, federal and private sector information systems and communications networks that support commercial vehicle operations (CVO). Many improvement initiatives are currently underway to develop new systems and upgrade existing systems to add new capabilities and allow electronic exchange of information using open interface standards. This will enable delivery of new electronic services to states and carriers in the broad areas of safety, credentials, and electronic clearance.

CVO - Commercial Vehicle Operations. Includes all the operations associated with moving goods and passengers via commercial vehicles over the North American highway system and the activities necessary to regulate these operations.

Index

D

Database - A collection of interrelated data stored with controlled redundancy to serve one or more applications; the data is stored so that it is independent of programs that use the data; a common and controlled approach is used in adding new data, and in modifying and retrieving existing data within a database.

DCO - Dynamic Corridor Optimization.

Dead Reckoning AVL - Dead reckoning AVL uses a magnetic compass and odometers to track distance and direction of travel from a known starting point. Vehicle tracking must be continuous. With recalibration every 20 miles, dead reckoning AVL is accurate within 100 feet. The newest map matching systems use expert systems software to reconcile the truck's path and current location against an electronic roadmap displayed on a video screen in the truck cab. Location information can be stored onboard or transmitted to the fleet office.

Demographic Data – Usually basic census information including name, address, and identifiers.

DGPS - Differential Global Positioning System.

DITCS (Distributed Intelligence Traffic Control System) **-** DITCS is a control system in which intersection controllers use timing plans but can dynamically adjust the splits to suit traffic conditions at the controller level. DITCS are closed loop systems providing real-time traffic adaptive control. The central system sends synchronization pulses, but most functions are performed at the intersection level maximizing the use of computing power. Some well known DITCS are SCATS and TracoNet.

Diverted Traffic – If capacity is limited by congestion, an increase in capacity on that route will divert trips from other times (analogous to reversing peak spreading), routes and destinations. Also see: Generated Traffic.

DMS - Dynamic Message Sign. Also see: VMS.

DMV – Department of Motor Vehicles.

DOT - Department of Transportation. At the federal level, a cabinet agency with responsibility for highways, mass transit, aviation and ports; headed by the secretary of transportation. The DOT includes the FHWA, the FTA and the FAA, among others. There are also state DOTs.

DR - Delay Reduction.

DRGS - Dynamic Route Guidance System.

DTMS – Dynamic Traffic Management System. A combination of ATMS and ATIS.

Index

E

EBS - Emergency Broadcasting System.

EDI - Electronic Data Interchange.

EMME/2 - EMME/2 is a transportation planning computer program initially developed by Michael Florian and Heinz Spiess at the Center for Research on Transportation of the University of Montreal. EMME/2 provides a general framework for implementing a wide variety of travel forecasting models. These can range from the simple implementation of a four step model to more refined demand models and their integration into a variety of road and transit assignment procedures. Impact and evaluation analysis is also possible.

EMS - Emergency Management System.

EMS - Emergency Medical Services.

En-route Transit Information - Provides travelers with real-time, accurate, transit and ride sharing information while en route to their destination.

ETC - Electronic Toll Collection **-** The process that allows a driver to pay tolls electronically.

Expert System – programs the attempt to incorporate human expertise into the model's logic in order to help solve under-specified or ambiguous problems.

Index

F

FARS - Fatal Accident Reporting System A database containing information related to fatal collisions.

FCAA - Federal Clean Air Act. Also see: CAA.

FCC - Federal Communications Commission.

FCW - Front Collision Warning.

FGM - Few Good Measure.

FHWA - Federal Highway Administration. An agency within the U.S. Department of Transportation.

Fidelity - Simulation models can be low or high fidelity. Low fidelity microsimulation models, for example, consider fewer variables, and may not even model inter-vehicle dynamics.

First Generation Signal Control - First generation control systems use pre-stored signal timing plans. While there can be more than one plan implemented during the day, these plans are developed off-line.

Fixed Time Control – Uses signal controllers with one or more pre-specified signal timings that do not react to changing demand. This type of control is often appropriate for intersections where all approaches are operating at or near capacity. Also see: fully actuated control, semi actuated control.

FM - Freeway Management.

FOT - Field Operational Test.

FRA - Federal Railroad Administration (of U.S. DOT).

Frontage Road - A roadway generally paralleling an expressway, freeway, parkway, or through street designed to intercept, collect and distribute traffic desiring to cross, enter, or leave such facility and to furnish access to property which otherwise would be isolated as a result of controlled-access features. The frontage road may be within the same traffic way as the main roadway or in a separate traffic way.

FSP - Freeway Service Patrol.

FTA - Federal Transit Administration. Part of the U.S.DOT.

Fully Actuated Control - Fully actuated intersections have controllers that measures traffic from all directions, and adjusts the green time for each approach. Because they are fully actuated, these signals are not coordinated with other signals on the network. This type of control is usually appropriate at intersections with very complicated phasing or geometrics, and which are operating close to saturation on all approaches, and where the other signals can function as a system wih a considerably lower cycle length. Also see: fixed control and semi-actuated control.

Fuzzy Logic – Fuzzy logic is a tool to allow a computer programming environment to use subjective information (rules of thumb, expert opinion, etc.) in a predictable, systematic way.

Index

G

Generated Traffic – The combination of trips shifted in time, route, or destination, and induced vehicle trips (from mode shift, trip lengthening, and new vehicle trips). Also see: Induced Travel; Diverted Traffic.

GIS - Geographical Information System. A computerized data management system designed to capture, store, retrieve, analyze, and report geographic and demographic information.

GPS - Global Positioning System A government-owned system of 24 earth orbiting satellites that transmit data to ground-based receivers. GPS provides extremely accurate latitude and longitude ground positions in WGS-84 coordinates.

Index

H

HAR - Highway Advisory Radio.

HCM – Highway Capacity Manual.

HC - hydrocarbons These are compounds whose molecules consist of atoms of hydrogen and carbon only. Hydrocarbons are not, by themselves, a health hazard. However they frequently react with oxides of nitrogen and sunlight to produce photochemical haze or smog. The presence of NOx is a precursor to O3 formation.

Heuristic - a model that finds the most likely solution at several steps of the programming process; significantly reduces computing time, but does not guarantee an exact solution.

HOT – High Occupancy Toll.

HOV - High-Occupancy-Vehicle (Lane). The technical term for a carpool lane, commuter lane or diamond lane.

HPMS - Highway Performance Monitoring System (FHWA).

HUD - Head-Up Display.

Index

I

ICC - Intelligent Cruise Control. Also see: ACC, AICC.

IDAS - ITS Deployment Assessment System. Uses a sketch planning approach.

IM - Incident Management – An attempt to minimize the negative effects of non-recurrent roadway disturbances, either planned (construction) or unplanned (accidents), through the use of ITS.

Induced Travel / Induced Demand- If traffic is limited by capacity, there may be latent demand for travel. An increase in capacity will induce these trips, which may include trips shifted from other modes, longer trips, and new vehicle trips. Also see: Generated Traffic.

INTEGRATION - The INTEGRATION microscopic simulation model. This most current release of the INTEGRATION model, 2.20, is a trip-based microscopic traffic assignment, simulation, and optimization model that is capable of modeling networks of up to 10,000 links and 500,000 vehicle departures. The model, which has been extensively validated, is designed to trace individual vehicle movements from a vehicle's origin to its final destination at a level of resolution of one deci-second. INTEGRATION was initially developed in 1983 by the late Michel Van Aerde. The name of the model stems from the fact that the model was developed to integrate the modeling of freeway/arterial corridors and to integrate traffic assignment with traffic simulation. Originally, INTEGRATION was a mesoscopic model; by 1995 it had evolved into a microscopic model. Further enhancements to the model included the incorporation of a multi-modal dynamic traffic assignment, the modeling of adaptive signal control, the modeling of transit vehicles and transit priority, the inclusion of microscopic energy and emission models, the incorporation of a crash risk model, and the inclusion of tolls and High Occupancy Lanes (HOVs). The model is commercially sold in North America through M. Van Aerde and Assoc., Ltd. the IBI Group and McTrans. The model is also being marketed in Europe and Asia.

ISO - International Organization for Standardization.

ISTEA - Intermodal Surface Transportation Efficiency Act (1991). Pronounced "Ice Tea," this landmark $155 billion federal legislation signed into law in December 1991 calls for broad changes in the way transportation decisions are made. ISTEA emphasizes diversity and balance of modes, as well as the preservation of existing systems before construction of new facilities. This act requires all states to participate in IFTA and IRP by September 30, 1996. Provides primary federal funding for highway programs in the U.S. Contains IVHS Act of 1991 (Title VI, Part B).

ITE - Institute of Transportation Engineers. Maintains references on a variety of standards and guidelines affecting the surface transportation industry.

ITI - Intelligent Transportation Infrastructure.

ITS - Intelligent Transportation Systems (formerly IVHS) The term refers to a wide range of advanced electronics and communications technology applied to roads and vehicles. Designed to improve safety and productivity, ITS also can have a positive impact on air quality by cutting congestion. When the term is applied to transit, it is called APTS; in commercial trucking, it is referred to as CVO.

ITS - Institute for Transport Studies, University of Leeds.

ITSA - Intelligent Transportation Society of America. A Federal Advisory Committee to advise the U.S. Department of Transportation on the ITS program.

IVHS - Intelligent Vehicle-Highway Systems. Also see: ITS.

IVI - Intelligent Vehicle Initiative.

IVN - In-Vehicle Navigation (Unit).

IVNS – See IVN.

Index

J

JPL - Jet Propulsion Laboratory.

JPO - Joint Program Office (of FHWA).

Index

K

KPh - kilometers per hour.

Index

L

LCS - Lane Control Signals.

LEAP – Learning from the evaluation an analysis of Performance. A database project maintained by the California PATH program.

LPE - Least Poisson Error. The LPE error normalizes the error relative to the square root of the observed flow.

LSE – Least Squares Error.

LOS - Level of Service. A report card that rates traffic flow from A (excellent) through F (flunks), and compares actual or projected traffic volume with the maximum capacity of the intersection or road in question.

Link - The one-way, linear road segment between two nodes. Links have characteristics associated with them such as capacity and speed limit.

Loop Detector - See: Vehicle Sensors and Detectors.

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M

Macroscopic Simulation - Uses mathematical expressions based on aggregate descriptions of traffic FLOW, rather than individual vehicle movements. Outputs from macroscopic models include speed, flow and density measures.

MAG - Maricopa Association of Governments.

MATLAB - Matrix Laboratory –A technical computing environment for high-performance numeric computation and visualization.

MAXBAND - MAXBAND is a bandwidth optimization program which calculates signal settings on arterials and triangular networks. MAXBAND produces cycle lengths, offsets, speeds, and phased sequences to maximize a weighted sum of bandwidths. The primary advantage of MAXBAND is the freedom to provide a range for the cycle time and speed.

MCDOT - Maricopa County Department of Transportation.

MDI - Model Deployment Initiative.

MDT - Mobile Data Terminal.

Median - The portion of a divided highway or guideway that separates the opposing flows of traffic.

Mesoscopic Simulation - Uses a level of detail in between that of micro- and macroscopic simulations. Usually, results from microscopic models are aggregated for use in the mesoscopic model. This reduces the simulation time needed.

Microscopic Simulation - Uses computer models to simulate vehicle-vehicle interactions, giving continuous or discrete speed and location data for each vehicle. This results in a more realistic representation of how vehicles actually move on a network, but requires significantly more data.

MMDI - Metropolitan Model Deployment Initiative, a project intended to show that additional benefits will arise from integration of ITS components.

Model - An analytical tool (often mathematical) used by transportation planners to assist in making forecasts of land use, economic activity, travel activity and their effects on the quality of resources such as land, air and water.

MOE - Measure of Effectiveness.

MOP - Measure of Performance.

MOTION (Method for the Optimization of Traffic Signals in On-Line controlled Networks) - A prototype system for the automatic control of traffic lights under the global goal of optimized flow conditions and waiting times in a network. MOTION determines a network cycle time mainly according to the traffic volumes at critical intersections. Based on the current average turning movements at intersections, a number of alternative basic signal programs are then calculated. In the second step the O-D pattern and corresponding traffic streams through the network are determined. The system also gives priority to public transportation vehicles by inserting a special stage to shorten or lengthen the green time.

mph - miles per hour.

MPO - Metropolitan Planning Organization The organization designated by the governor and local elected officials as responsible, together with the state, for transportation planning in an urbanized area.

Multimodal - Refers to the availability of multiple transportation options, especially within a system or corridor. A concept embraced in ISTEA, a multimodal approach to transportation planning focuses on the most efficient way of getting people or goods from place to place, be it by truck, train, bicycle, automobile, airplane, bus, boat, foot or even a telecommuting.

MUTCD - Manual on Uniform Traffic Control Devices.

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N

NCHRP - National Cooperative Highway Research Program. A program established by AASHTO to provide a mechanism for a national coordination program of cooperative research employing modern scientific techniques.

NEMA - National Electrical Manufacturers Association.

NEMA TS-1- The first broadly accepted industry defined traffic controller, NEMA TS-1 is based on conformance to standard mechanical and electrical connectors. The architecture is closed to the customer, which does not allow a DOT to change the software / hardware and functionality of the product.

NEMA TS-2- Recognizing the need for a new controller, NEMA published the TS-2 specification in 1992. The system utilizes a serial I/O architecture to provide modularity and expandability for the I/O detectors. The TS-2 architecture remains closed to the integrator, so the inherent limitations of a closed system remain.

Neural Network – A computing technique designed to complete complex tasks quickly and efficiently by combining, in parallel, many simple processing nodes. This technique is relatively new to the transportation modeling arena, but shows much future promise.

NHI - National Highway Institute.

NHS - National Highway System. An approximately 155,000-mile network called for in the Intermodal Surface Transportation Efficiency Act to provide an interconnected system of principal routes to serve major travel destinations and population centers. The NHS is expected to be designated by Congress in 1995.

NHTSA - National Highway Traffic Safety Administration A branch of the U.S. Department of Transportation responsible for overseeing and improving safety and standards in the United States.

NIMC - National Incident Management Coalition. A program created to serve as a focus for consensus building, and for promotion and wider implementation of incident management programs.

NIST - National Institute of Standards and Technology.

NOx - nitrous oxides - These are formed during all high-temperature atmospheric combustion processes in a spontaneous chemical reaction between the nitrogen and oxygen in the air. The health effects can include nose and eye irritations and, with increasing concentration, bronchiololitis and pneumonitis. The presence of NOx is a precursor to O3 formation.

Node - The point in space that represents the endpoint of a link in a simulation model, often at an intersection.

Nonattainment Area - Any geographic region of the United States that the U.S. Environmental Protection Agency (EPA) has designated as not attaining the federal air quality standards for one or more air pollutants, such as ozone and carbon monoxide.

NRC - National Research Council.

NSF - National Science Foundation.

NTCIP - National Transportation Communication for ITS Protocol.

NTI - National Transit Institute.

NTS - National Transportation System. Called for in the Intermodal Surface Transportation Efficiency Act, the NTS to date is a proposal by the U.S. Transportation Secretary to integrate all aspects and modes of the transportation system into a single national system. The National Highway System is expected to be a subset of the larger, multimodal NTS.

NTSB - National Transportation Safety Board An independent agency of the Federal Government (FHWA) created in 1975 whose responsibilities include investigating transportation accidents and conducting studies, and making recommendations on transportation safety measures and practices to government agencies, the transportation industry, and others. Promotes safe transportation in the U.S. through accident investigations, studies, and recommendations.

Index

O

OBC - On-Board Computer. Special purpose microcomputers that are attached to sensors that record vehicle and driver attributes.

O-D - Origin-Destination. An O-D Table is a two-dimensional matrix detailing the demand for travel between two points—the origin and destination nodes.

Off-Peak Period - Non-rush periods of the day when travel activity is generally lower.

ORNL - Oak Ridge National Laboratory.

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P

Passenger Miles - The total number of miles traveled by passengers on transit vehicles; determined by multiplying the number of unlinked passenger trips times the average length of their trips.

PASSER II-80 - PASSER II-80 is a band width optimization program that calculates signal timings on linear arterials. A modified version of Webster's delay equation is used to approximate platoon effects. Outputs include cycle length, phase sequencing, splits, offsets, and band speed that maximize band width in both directions. Advantages are flexibility to vary cycle length and band width and consideration of multiphase operation under a variety of timing strategies. Disadvantages include lack of emissions or fuel consumption data.

PASSER III - PASSER III computes cycle length, phase sequencing, and splits for a pre-timed interchange that minimize average delay per vehicle. PASSER III uses a deterministic, macroscopic time scan optimization.

PATH - Partners for Advanced Transit and Highways. The producers of the world's largest bibliographical database pertaining to Intelligent Transportation Systems.

Peak Spreading – lengthening of the peak hour due to congestion.

PHT - Person hours of travel.

PIAS - Personal Information Access System.

PM - particulate matter - smoke, fly ash, dust, and fumes that are solid and liquid matter in the air. They may settle to the ground or may stay suspended. They may scatter light and carry poisonous gases to the lungs. The EPA has currently revised its NAAQs to require analysis of PM greater than 2.5 microns. Due to the lack of data and studies currently available to support PM 2.5 analysis, only PM greater than 10 microns will be considered in this study.

PMT - Person miles of travel.

Pneumatic Detector – See: Vehicle Sensors and Detectors.

Pneumatic Tubes – See: Vehicle Sensors and Detectors.

Pre-Trip Travel Information - A user service that will provide travelers with information before their departure and before the mode choice is made.

PRUEVIIN - Process for Regional Understanding and Evaluation of Integrated ITS Networks. Planning and traffic simulation; often used for large-scale mesoscopic analysis.

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Q

QUEENSOD – A model for estimating origin-destination traffic demands based on observed link traffic flows turning movements, and link travel times. This model is capable of estimating both static and dynamic O-D.

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R

Radio Determination AVL - Radio determination AVL uses radio signals to measure the distance between a truck and two or more known points; location is calculated by triangulation. Government radio determination systems use one-way radio signals: the Loran-C system transmits from a network of ground towers: and the NavStar Global Positioning system (GPS) uses a network of satellites. Vehicle tracking can be continuous or intermittent. Loran-C is accurate within several thousand feet and GPS within several hundred feet. Location information can be stored onboard or transmitted.

Ramp - An auxiliary roadway used for entering or exiting mainline highway facilities.

RBDS - Radio Broadcast Data System.

RT-TRACS (Real-time Traffic Adaptive Signal Control System) - Developed by PB Farradyne for FHWA. The RT-TRACS control logic assesses the current status of the network with forecasting capabilities, allowing proactive, not reactive, response. The most fundamental requirement of this system is to effectively manage and respond to rapid variations in traffic conditions. RT-TRACS consists of a number of real-time control prototypes that each function optimally under different traffic and geometric conditions. When conditions dictate, RT-TRACS can automatically switch to another strategy. Features of the RT-TRACS design include: both distributed and centralized traffic control; dynamic priority control on selected routes; capability to interact with dynamic traffic assignment to implement proactive control; improved fallback capabilities in case of surveillance system failure; and, effective use of the accumulated experience with real-time control. Five prototypes strategies are currently being developed and evaluated for use in the RT- TRACS program. The FHWA awarded five separate contracts to develop these real-time prototype strategies. The contracts were awarded to the University of Arizona, the University of Minnesota, the University of Massachusetts (Lowell)/ PB Farradyne, Wright State University in Ohio, and the University of Maryland/University of Pittsburgh. Kaman Sciences Corporation is responsible for evaluating these prototypes using the CORSIM simulation model. In late 1997, the FHWA and the University of Arizona teamed to develop and field test one of these prototypes, RHODES, an open architecture version of RT-TRACS that will utilize an alternative database management system and NTCIP protocol. Three of these prototypes, the RHODES prototype from the University of Arizona, OPAC (Optimization Policies for Adaptive Control) from PB Farradyne/ University of Massachusetts (Lowell), and RTACL from the University of Pittsburgh/University of Maryland, are at an advanced state of development. Initial simulation testing showed that these prototype strategies produced statistically valid improvements in traffic throughput and reduced average delay.

RWIS - Road Weather Information System.

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S

SAIC - Science Applications International Corporation.

Saturation Flows -- Simulation models use the saturation flow rate for a system to determine how many vehicles can pass through the system during a given period of time. Saturation flow is defined as the maximum flow rate that can be sustained by traffic from a queue on the approach used by the stream.

SCATS (Sydney Coordinated Traffic Adaptive System) - Developed by the New South Wales Department of Main Roads, SCATS is a dynamic control system with a decentralized architecture. SCATS updates intersection cycle length using the detectors at the stop line. SCATS allows for phase skipping. Offsets between adjacent intersections are predetermined and adjusted with the cycle time and progression speed factors.

SCOOT (Split, Cycle and Offset Optimization Tool) - SCOOT is an off-the-shelf centralized computerized traffic control model developed at the Transportation Road Research Laboratory in the U.K. It is an enhancement over first generation UTCS systems and provides real-time traffic adaptive control. Tests have shown that SCOOT is most effective when demand approaches but is less than capacity, where demand is unpredictable, and when distances between intersections are short. Traffic control systems using SCOOT are prevalent in Australia, Asia, and recently in North America. The three key principles of the SCOOT system which make it different from the TRANSYT model are: it measures the cyclic flow profile in real time as opposed to deriving it from upstream turning movements; it updates an on-line model of queues continuously as opposed to only updating once; and, it makes incremental as opposed to global optimizations to the signal settings. The SCOOT and SCAT traffic models are built on a vertical queue model and thus can not consider the effect of downstream link congestion on the signal output. These models operate fairly well as long as the network is not overly congested. However, they fail to model the effect of downstream congestion on the capacity of upstream intersections during queue spillback. The queuing model is updated from queue measurements from the field.

Second Generation Control - Second generation uses detector information to modify the signal timing plan, but allows time between each change to allow the network to come into equilibrium with the new plan.

Semi Actuated Control - Semi-actuated traffic signal controllers use actuation on all phases except the main phase. This type of control is best suited for intersections with one minor approach and one major, i.e., when one approach is operating at or near saturation and the opposing approaches are operating well below saturation. The major approach is left green unless a vehicle is detected on the minor approach.

SHRP - Strategic Highway Research Program.

SIGOP - Using a macroscopic traffic flow model, SIGOP determines the cycle lengths, splits, and offsets needed to minimize delay for up to 150 intersections.

SIP - State Implementation Plan. Metropolitan areas prepare regional SIPs showing steps they plan to take to meet federal air quality standards (outlined in the Clean Air Act). Several SIPs make up the statewide plan for cleaning up the air, also known as a SIP.

Smart Card - Plastic cards with an embedded integrated circuit chip containing memory and microprocessor.

SMARTEST - Simulation Modelling Applied to Road Transport European Scheme Tests. A comprehensive project conducted by a consortium of European agencies with intent to evaluate and enhance simulation tools for use in the European community.

SOAP - Macroscopic analysis of signal timing plans, primarily for individual intersections. The optimization is based on a performance index that include delay, fuel consumption, and stops.

SOV - Single-Occupant Vehicle. A vehicle with one occupant, the driver, who is sometimes referred to as a "drive alone."

STIP - Statewide Transportation Improvement Program.

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T

Tag Number - A vehicle's license plate number, including state, of a vehicle.

TCC – Traffic Control Center.

TCM - Transportation Control Measure. Strategy to reduce driving or smooth traffic flows in order to cut auto emissions.

TDM - Transportation Demand Management. Low-cost ways to reduce demand by automobiles on the transportation system, such as programs to promote telecommuting, flextime and ridesharing.

TEA - Transportation Enhancement Activities. An ISTEA created funding category. Ten percent of STP monies must be set aside for projects that enhance the compatibility of transportation facilities with their surroundings. Examples of TEA projects include bicycle and pedestrian paths, restoration of rail depots or other historic transportation facilities, acquisition of scenic or open space lands next to travel corridors, and murals or other public art projects.

TEA-21 - Transportation Equity Act for the 21st Century.

Third Generation Control - Third generation control also uses detector information to modify the signal timing plan, but it goes one step further by predicting future traffic volume, and adjusting the signal timing plan earlier than in second generation control.

THOREAU - Traffic and Highway Objects for Research, Analysis & Understanding.

TIC – Traffic Information Center.

TIP - Transportation Improvement Program. This is primarily a spending plan for federal funding expected to flow to the region from all sources for transportation projects of all types.

TM - Transit Management.

TMA -Transportation Management Association. A voluntary group set up by employers or other entities to reduce vehicle trips within certain areas.

TMA - transportation management area. A region subject to certain planning requirements under ISTEA. Any urbanized area with a population of more than 200,000 automatically is a TMA.

TMC - Transportation Management Center or Traffic Management Center.

TMIP - Travel Model Improvement Program.

TMP - Transportation Management Plan. Shows how traffic flows will be smoothed or diverted during construction. A TMP might call for installing ramp meters or upgrading parallel roads; boosting public transit service; aggressively marketing carpooling vanpooling; and mounting a public information campaign.

TMS - Transportation Management System or Traffic Management System.

TOC – Traffic/Transportation Operations Center. The place from which the TOS is run.

TOS - Traffic Operations System.

TracoNet - TracoNet is a distributed intelligence closed loop network control system used for coordinating, controlling and facilitating the flow of vehicular traffic. It can operate in all control modes, including fully actuated. Traffic responsive algorithms based on pattern matching are also available.

TRANSIMS - Transportation Analysis Simulation System. Uses intermodal planning and a region-wide microscopic simulation model.

Transponder - An electronic tag carried by a motor vehicle that has electronically stored information that can be retrieved by a roadside reader.

TRANSYT (Traffic Network Study Tool) - TRANSYT is a macroscopic, deterministic simulation model. TRANSYT-7F is the version of TRANSYT designed for use in the United States.

TRB - Transportation Research Board. Under direction of National Academy of Science's National Research council, it stimulates, correlates and makes known the findings of transportation research.

TRO - Trip Reduction Ordinance. This regulation is to limit the number of SOV users in order to stanch polluting emissions. Aimed at employers, TROs have been enacted by local governments in response to CMP requirements, which vary from county to county.

Trip Table – See: O-D.

TS - Traffic Signal Control System.

TSM - Transportation Systems Management. Low-cost improvements to make the transportation system work more efficiently, such as traffic signal coordination.

TSS - Transportation Sensor System.

Tube Count – A mechanically recorded count of the number of vehicles to pass a certain point on a link. See Also: Vehicle Sensors and Detectors.

Tube Detector – See: Vehicle Sensors and Detectors.

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U

UDOT – Utah Department of Transportation.

U.S. DOT - United States Department of Transportation. The federal cabinet-level agency with responsibility for highways, mass transit, aviation and ports; headed by the secretary of transportation. The DOT includes the Federal Highway Administration and teh Federal Transit Administration, among others. There are also state DOTs.

UTC - Urban Traffic Control.

UTCS – Urban Traffic Control Systems.

UTPS - Urban Transportation Planning System.

UZA - Urbanized Area. An U.S. Bureau of Census-designated area of 50,000 or more inhabitants consisting of a central city or two adjacent cities plus surrounding densely settled territory, but excluding the rural portion of cities.

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Validation - The process of verifying the fundamental relationships forming the basis of a simulation model; or ensuring that the simulation provides theoretically correct results. In other words, can the car-following, lane-changing and gap acceptance rules utilized by the model produce the corresponding capacities, queue sizes, speed distributions and weaving effects. Validation is not usually conducted for each project, and is, for the most part, the responsibility of the model developer.

V/C – Volume-to-Capacity (ratio).

Vehicle Sensors and Detectors - Infrared, inductive loop, microwave, magnetic, doppler radar, pneumatic tube, and others. These devices, either embedded in the roadway, suspended above or adjacent to the roadway, or lain atop the roadway, provide automated detection of vehicles for use in sign activation, signal actuation, incident detection, weigh-in-motion, or volume and/or speed counting.

Verification - The process of determining if the logic that describes the underlying mechanics of the model, as specified by the model designer, is faithfully captured by the computer code. Model verification therefore determines if, independent of the validity of the logic or the theory from which the logic is derived, the corresponding computer program produces the desired outputs (in terms of accuracy, magnitude, and direction). For example, if the model designer specifies that A = B + C, then model verification determines if the computer code computes A as the sum of B and C. Model verification does not attempt to determine whether this relationship adequately captures reality or if A should be equal to something other than the sum of B and C.

VERTIS - Vehicle, Road and Traffic Intelligence Society.

VHT - Vehicle Hours of Travel.

VIN - Vehicle Identification Number. A unique combination of alphanumeric characters affixed to one vehicle in specific locations and formulated by the manufacturer.

VMS - Variable Message Sign.

VMT - Vehicle Miles of Travel.

VNTSC - Volpe National Transportation Center.

vph - Vehicles per Hour.

VRC - Vehicle Roadside Communications.

VTTI - The Virginia Tech Transportation Institute.

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W

WCI - Webster-Cobbe Isolated (signal control).

WIM - Weigh-In-Motion. Measures dynamic axle weight at highway or slower speeds. Weigh-In-Motion refers to various technologies that enable vehicle weights to be determined without the need for a vehicle to physically stop on a scale.

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X

Y

Z

References

1. Information in this glossary was obtained from:
2. Caltrans online glossary: http://transweb.sjsu.edu/index.asp
3. A Compendium of Traffic Model Validation Documentation and Recommendations
4. The Johns Hopkins University Applied Physics Laboratory online CVISN glossary: http://www.jhuapl.edu/cvisn/introcvisn/gloss_98.html
5. LEAP online database. (http://www.path.berkeley.edu/~leap/Acronym.html). Maintained by the California PATH program.
6. Metropolitan Model Deployment Initiative National Evaluation Strategy. V. Alexiadis, M. Carter, A. DeBlasio, V. Inman, B. Perez, C. St-Onge, M. Van Aerde. November 1998. FHWA Publication No. FHWA-JPO-99-041. Accessed on the ITS Electronic Document Library (EDL): http://www.its.fhwa.dot.gov/cyberdocs/welcome.htm, EDL Document Number 6305.
7. Systematic Verification, Validation and Calibration of Traffic Simulation Models. H. Rakha, B. Hellinga, M. Van Aerde, Perez. Transportation Research Board 75th Annual Meeting January 1996
8. TRAFFIC SIGNALS AND CONTROL, RAMP METERING, AND LANE CONTROL SYSTEMS (http://www.path.berkeley.edu/~leap/TTM/Traffic_Control/control.html#Signal Control)
9. Studies of Potential Intelligent Transportation Systems Benefits Using Traffic Simulation Modeling.
10. Many of the acronyms were catalogued by the Jet Propulsion Laboratory for the U. S. Department of Transportation.

APPENDIX B: QUEENSOD

QUEENSOD is a computer program for calculating O-D data based on a combination of observed link flows, turning percentages, and link travel times. QUEENSOD uses the maximum likelihood method of determining O-D demands. This method was first formulated by Willumsen (1978), and Van Zuylen and Willumsen (1980).

While QUEENSOD was originally developed for use with the INTEGRATION simulation model, it can be used as a stand-alone product. It is convenient to use QUEENSOD in conjunction with the INTEGRATION model because the two programs share file formats.

QUEENSOD "…is capable of estimating both static and dynamic Origin-Destination (O-D) traffic demands…[It] implements a customized code to solve the single step formulation. Sample results…indicate that the solution obtained through QUEENS-OD matches [that obtained from solving the full formulation of the problem]" (Paramahamsan, 1999).

"The single step approach [used by QUEENSOD] has been demonstrated to yield very accurate results for small networks, where the actual solution can be verified independently through exhaustive enumeration of all possible solutions" (Paramahamsan, 1999). Though the results obtained from synthetic O-D generation tools such as QUEENSOD can be checked for small networks, large networks have too many variables and too many simultaneous equations to be solved using standard equation solvers. Therefore, while QUEENSOD has the ability to solve networks with more than 1,000 zones and 5,000 links, the results cannot be completely verified. The QUEENSOD Process is outlined in Figure B-1.

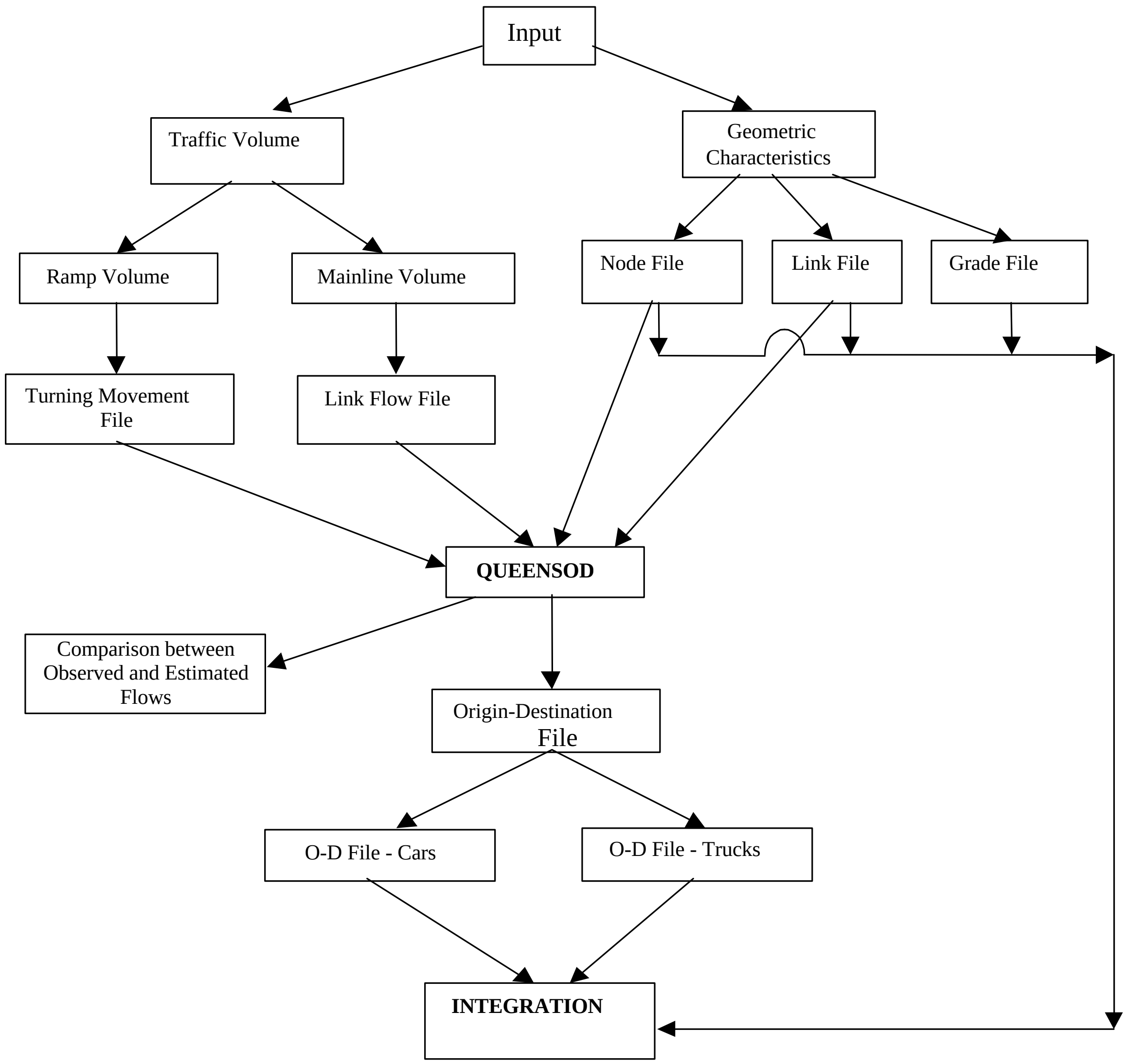

Figure B-1: QUEENSOD Process

APPENDIX C: ITS MEASURES OF EFFECTIVENESS

Table C-1: ITS Measures of Effectiveness
(Turner and Stockton, 1999)

ITS Goal	Related Metric
Increase Transportation System Efficiency and Capacity	Traffic flows/volumes/number of vehicles
	Lane carrying capacity
	Volume to capacity ratio
	Vehicle hours of delay
	Queue lengths
	Number of stops
	Incident-related capacity restrictions
	Average vehicle occupancy
	Use of transit and HOV modes
	Intermodal transfer time
	Infrastructure operating costs
	Vehicle operating costs
Enhance Mobility	Number of trips taken
	Individual travel time
	Individual travel time variability
	Congestion and incident-related delay
	Travel cost
	Vehicle miles traveled (VMT)
	Number of trip end opportunities
	Number of accidents
	Number of security incidents
	Exposure to accidents and incidents
Improve Safety	Number of incidents
	Number of accidents
	Number of injuries
	Number of fatalities
	Time between incident and notification
	Time between notification and response
	Time between response and arrival at scene
	Time between arrival and clearance
	Medical costs
	Property damage
	Insurance costs
Reduce Energy Consumption and Environmental Costs	NOx emissions
	SOx emissions

	CO emissions
	VOC emissions
	Liters of fuel consumed
	Vehicle fuel efficiency
Increase Economic Productivity	Travel time savings
	Operating cost savings
	Administrative and regulatory cost savings
	Manpower savings
	Vehicle maintenance and depreciation
	Information-gathering costs
	Integration of transportation systems
Create an Environment for an ITS Market	ITS sector jobs
	ITS sector output
	ITS sector exports

APPENDIX D: THE PAIRED *T*-TEST

The Paired *t*-test

A recommended modification to the *t* test is the *paired t* test. "Many statistical applications use paired data samples to draw conclusions about the difference between two population means. Data pairs occur very naturally in "before and after" situations, where the same object or item is measured both before and after a treatment…When working with paired data, it is very important to have a definite and uniform method of creating data pairs that clearly utilizes a natural matching of characteristics" (Brase and Brase, 1999). In simulation, it is possible to wield this control. The two case studies presented in Chapter 4 and Chapter 5, for instance, slightly modified the base case for each new test group. Then, the same seed generators were used to generate the traffic as were used in the base case. Therefore, the demand for each instance is the same, but the network they travel on has been modified in some way. The paired test, then, can be used to determine if the changes have any significant impact on the results.

Paired data tests cannot always be used, but there are significant advantages in doing so. For instance, using "…matched or paired data often can reduce the danger of introducing extraneous or uncontrollable factors into tour sample measurements because the matched or paired data have essentially the same characteristics except for the one characteristic that is being measured. Furthermore ,it can be shown that pairing data has the theoretical effect of reducing measurement variability (i.e., variance), which increases the accuracy of statistical conclusions" (Brase and Brase, 1999).

The first thing to consider when evaluating the appropriateness of the paired *t*-test is if there is "…natural pairing between the data in the two samples. Again, data pairs are created from "before and after" situation, or from matching data by using studies of the same object, or by a process of taking measurements of closely matched items" (Brase and Brase, 1999). Sensitivity analyses conducted during traffic simulations fit this description.

Steps of the Paired *t*-test

The first step in conducting the paired *t*-test is to make sure that the data fit the requirements for the Student's *t* test:

- Independent random samples of size n1 and n2, respectively, are drawn from populations that possess means 1 and 2.
- The parent populations are (approximately) normally distributed
- The standard deviations 1 and 2 for the two populations are equal (or approximately equal)

If the criteria are met, the first step of the paired test is to "…take the difference *d* of the data pairs first and look at the mean difference $\bar{d}$. Then we use a test on $\bar{d}$ …Consider a random sample of *n* data pairs. [If] the differences *d* between the first and second members of each data pair are (approximately) normally distributed with population mean μ_{d}…", the *t* values are as shown in Equation 2.

$$t = \frac{\bar{d} - m_d}{s_d / \sqrt{n}} \qquad [2]$$

In Equation 2, $\bar{d}$ is the sample mean of the *d* values, *n* is the number of data pairs, and the sample standard deviation of the *d* values is as shown in Equation 3.

$$s_d = \sqrt{\frac{\sum \left(d - \bar{d}\right)^2}{n-1}} \qquad [3]$$

The *t* values shown in Equation 2 follow a Student's *t* distribution with degrees of freedom *d.f.* = *n*-1.

As before, the null hypothesis is that the means between the two groups are equal, and the alternative hypothesis is that they are not equal. It is important to note that this test must be performed on each different scenario run, and that each one must be compared against the base case.

Table D-1: Table of *t*-statistics

d.f.	*t*-stat
4	2.776
5	2.571
6	2.447
7	2.365
8	2.306
9	2.262
10	2.228
11	2.201
12	2.179
13	2.160
14	2.145
15	2.131
16	2.120
17	2.110
18	2.101

APPENDIX E: VITA

Joshua James Diekmann was born in St. Louis, Missouri in 1974 to James Edward Diekmann and Mary Jo Elizabeth Hagan. He attended High School in Washington State, where he also worked two summers for the Washington State Department of Transportation. Josh spent one year at Whitman College in Walla Walla, Washington, after which time he transferred to the Colorado School of Mines in Golden, Colorado. Josh graduated from the School of Mines with a Bachelor of Science in engineering with a specialty in civil engineering and a minor in environmental engineering. Following graduation, Mr. Diekmann accepted a position with the civil engineering design firm MK Centennial, presently located in Littleton, Colorado. In 1998, he enrolled in the Transportation and Infrastructure Systems Engineering curriculum at Virginia Tech. Following receipt of his masters, he accepted employment with the Transportation Group of the International Team at Booz·Allen & Hamilton in McLean, Virginia.