Technical Report Documentation Page

1. Report No. FHWA/TX-94/1278-2	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle DEVELOPMENT OF ANALYTICAL TOOLS FOR EVALUATING OPERATIONS OF LIGHT-RAIL AT-GRADE WITHIN AN URBAN SIGNAL SYSTEM - INTERIM REPORT 2	5. Report Date July 1994 6. Performing Organization Code
7. Author(s) Steven P. Venglar, Daniel B. Fambro, and Carol H. Walters	8. Performing Organization Report No. Research Report 1278-2
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Study No. 0-1278
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Interim: December 1992 - May 1994 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

Research Study Title: Development of Analytical Tools for Evaluating Operations of Light-Rail At-Grade Within an Urban Signal System

16. Abstract

This research investigated the use of the Federal Highway Administration's NETwork SIMulation (NETSIM) program and JRH Transportation Engineering's TransSim II™ as a tool for agencies interested in planning and developing LRT systems. NETSIM is one of the few available traffic analysis programs with the flexibility to model the operations and mobility impacts of transit. Similarly, TransSim II™ can model the impacts of transit and has been specifically developed for this purpose.

To evaluate NETSIM and TransSim II™ for simulating and providing accurate descriptive measures of performance for LRT and traffic in pretimed and actuated arterial networks, researchers compared outputs from the model with real-world field data from Los Angeles and Long Beach, California and Portland, Oregon. The results indicated that the models could produce moderately accurate measures of stopped delay and percent stops for individual intersections within studied networks. On a system-wide basis, the models produced reasonably reliable, accurate estimates of network travel times and were capable of reproducing most traffic characteristics observed in the field. They also performed well in simulating the control impacts and behavior of LRT in the modeled systems.

17. Key Words Light Rail Transit, Simulation, TransSim II™, NETSIM	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 114	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DEVELOPMENT OF ANALYTICAL TOOLS FOR EVALUATING OPERATIONS OF LIGHT-RAIL AT-GRADE WITHIN AN URBAN SIGNAL SYSTEM

INTERIM REPORT 2

by

Steven P. Venglar
Assistant Research Scientist

Daniel B. Fambro, P.E.
Associate Research Engineer

and

Carol H. Walters, P.E.
Research Engineer

Research Report 1278-2
Research Study Number 0-1278
Research Study Title: Development of Analytical Tools For Evaluating Operations of Light-Rail At-Grade within An Urban Signal System

Sponsored by the
Texas Department of Transportation
In Cooperation with
U.S. Department of Transportation
Federal Highway Administration

July 1994

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

IMPLEMENTATION STATEMENT

The following report is the second interim report for project 1278. This report contains the evaluation of two computer programs used for modeling LRT in urban networks. One of the programs evaluated was the Federal Highway Administration's NETSIM, and the second was a program known as TransSim II^{TM}, which is a proprietary program made available by JRH Transportation Engineering. Both programs were evaluated independently for their ability to evaluate automobile and LRT performance in several field study environments. This report presents the results of the tests conducted with both programs and points to the role of each in the final product of the research, a tool for analyzing LRT placement and operations alternatives.

The completed research, of which this interim report forms a part, will provide engineers with a methodology and computerized procedure for assessing the impacts of an LRT system on a signalized urban arterial street network. By analyzing various configurations of roadway and trackage geometrics and signalization alternatives, the engineer can make decisions for the optimum LRT placement and signal operations in an efficient and organized fashion.

DISCLAIMER

ACKNOWLEDGMENTS

This report was prepared as the second interim report for the research study entitled "Development of Analytical Tools for Evaluating Operations of Light-Rail At-Grade within an Urban Signal System." The research was conducted by the Texas Transportation Institute (TTI) and sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). Ed Collins, Jim Cotton, and G. Curtis Herrick served as the TxDOT project directors for the research. Carol H. Walters, P.E. # 51154 (Texas), Daniel B. Fambro, P.E. # 47535 (Texas), and Steven P. Venglar of TTI served respectively as study co-supervisors and research assistant.

The authors wish to thank the following individuals for serving on the advisory panel (steering committee) for this project.

Mildred E. Cox	City of Dallas
Donald R. Garrison	TxDOT, Houston District
David G. Gerard	City of Austin
John P. Kelly	TxDOT, San Antonio District
Rich Krisak	Dallas Area Rapid Transit (DART)
Ernie Martinez	Capital Metro, Austin
Jim Robertson	Capital Metro, Austin
John Sedlak	METRO, Houston

The authors would also like to thank the following individuals for their significant contributions as members of the technical committee for this project.

Paul N. Bay	BRW, Inc.
Richard A. Berry	Deshazo, Starek, & Tang
Owen P. Curtis	JHK & Associates
David G. Gerard	City of Austin
James R. Hanks	JRH Transportation Engineers
J. Douglas Hunt	University of Calgary, Canada
Kenneth R. Marshall	Barton-Aschman, Associates, Inc.
Kenneth W. Ogden	Monash University, Australia
Robert N. Wunderlich	Barton-Aschman, Associates, Inc.

The data collection for this report was an effort involving the collaboration of many individuals. In Los Angeles, California, meetings with Linda Meadow, system safety manager for the Los Angeles County Metropolitan Transportation Authority, and James Curry, project manager for TEAMETRO, resulted in the selection of study networks. Brian Gallagher, transportation engineer with the City of Los Angeles, provided assistance in collecting information about the Los Angeles networks; and James P. B. Chen, senior traffic engineer with the City of

Long Beach, and Larry Bass, traffic signal coordinator with the City of Long Beach, provided information about the LRT and traffic system in downtown Long Beach. Jesse Guzman and Adolfo Garcia of Texas A&M University provided valuable assistance throughout the data collection.

In Portland, Oregon, a meeting with William Kloos, signal systems manager for the city, resulted in the selection of study networks and the collection of information about the operations of LRT in Portland. Kent Lall, a professor of civil engineering with Portland State University, served as a contact for the data collection and recruited Virinchi Garimella, Selvarat Ramachandran, and Muralidharan Janakiraman to assist in the effort. Bruce Robinson of Kittelson & Associates, Inc., provided office space from which the data collection was managed, and Robert Keech of Traffic Smithy provided traffic count information for the study networks. Additional assistance was provided by Vince Williams of Car Corner in establishing a vantage point for part of the data collection.

JRH Transportation Engineering of Eugene, Oregon, provided a beta-test version of TransSim II^{TM}, an LRT simulation program, for evaluation as part of the project. Continuous and helpful support was provided by Thomas Bauer of JRH in coding the data and providing prompt responses to questions and concerns.

Greg Krueger of the Texas Transportation Institute provided valuable assistance in coding data sets for the models reviewed for this project. Mr. Krueger generously made time available throughout the modeling process, cooperated extensively in the model adjustment process and analyzed coding and software problems.

Table of Contents

Table of Contents (continued)

List of Figures

List of Tables

Summary

As the engineering and planning communities continue their progress toward managed and integrated transportation systems, transit will play an increasing role. Light rail transit (LRT) has already been selected and implemented by 15 United States cities as a rail transit alternative. As new or expanded systems are planned and designed, it is essential that engineers are able to make the best decisions for LRT placement and operations. This research investigates the use of the Federal Highway Administration's NETwork SIMulation (NETSIM) program and JRH Transportation Engineering's TransSim II^{TM} as tools for agencies interested in planning and developing LRT systems. NETSIM is one of the few available traffic analysis programs with the flexibility to model the operations and mobility impacts of transit. Similarly, TransSim II^{TM} can model the impacts of transit and was specifically developed for this purpose.

To evaluate NETSIM and TransSim II^{TM} for simulating and providing accurate descriptive measures of performance for LRT and traffic in pretimed and actuated arterial networks, researchers compared outputs from the models with real-world field data from Los Angeles and Long Beach, California and Portland, Oregon. The results indicated that the models could produce moderately accurate measures of stopped delay and percent stops for individual intersections within studied networks. On a system-wide basis, the models produced reasonably reliable, accurate estimates of network travel times and could reproduce most traffic characteristics observed in the field. The models performed well in simulating the control impacts and behavior of LRT in the modeled systems. As with traffic, the modeled system-wide travel times were representative of the field data and the individual intersection measures from the models were assessed as moderate predictors of the field MOEs.

INTRODUCTION

Congestion in freeway and arterial street networks is an increasing problem in urban areas throughout the country. In an effort to abate the excess fuel consumption, automobile emissions, and delays to road users brought about by congestion, cities are pursuing rail transit alternatives. In Texas, for instance, Houston has examined and is presently developing commuter rail, and Dallas is presently constructing the Dallas Area Rapid Transit light rail transit line. Among the rail transit alternatives of commuter rail, heavy rail, and light rail, light rail is the cheapest and most flexible due to its ability to operate at grade and even in mixed operations with street traffic.

When in the process of planning a future light rail transit (LRT) system, or even for examining operational alternatives for an existing LRT system, it is essential that tools be available to assess the impacts of transit on the existing transportation system. These effects are described by measures of effectiveness (MOEs), which include delay to motorists and transit riders, fuel consumption, emissions, and overall mobility. With such information, it is possible to select the best alternatives for implementation of LRT. To produce the necessary database of MOEs, models that simulate the LRT system operations are used. The models can range from mathematical procedures to computer simulation. To efficiently process the necessary information and maintain records of the myriad variables describing the interaction between drivers, vehicles, and the roadway, researchers used computer simulation.

For traffic engineering applications, the Federal Highway Administration's NETSIM (NETwork SIMulator) is perhaps the most flexible computer simulator. NETSIM is capable of simulating networks under control strategies ranging from sign control to fully actuated signal control. The model can provide MOEs for a variety of traffic scenarios and can simulate LRT in urban environments using a variety of methods. Proprietary software has also been developed to determine the network impacts of LRT. JRH Transportation Engineering's TransSim II™ is one such program capable of simulating LRT using a variety of control and priority schemes for transit and providing MOEs for network traffic.

PROBLEM STATEMENT

As LRT becomes an increasingly popular transit alternative, there arises a need in the planning and development stages to make informed decisions about the optimum signal system operation. Integrating the LRT system into the existing urban signal system has created a need to better analyze the effects of the LRT system on the traffic signalization as well as the effects of the signalization on train operations. Research has been undertaken to develop analytical tools to optimize and simulate the operations of signal systems in a network, but as yet no definitive method exists for the inclusion of light rail at-grade crossings within such a network.

Following the development of a method for computing LRT impacts, any shortcomings in the procedure can lead to a failure of the planned system. Therefore, it is essential that the model produce accurate and reliable results. Model calibration and validation help ensure that the model produce accurate and reliable results. Model calibration and validation help ensure that the model outputs accurately represent the effects of the planned LRT system. For this report, calibration consists of adjusting NETSIM and TransSim II^{TM} model inputs and default parameters to model the true data from field observation as accurately as possible. The validation procedure statistically tests and assesses the ability of the model to replicate the real world conditions.

RESEARCH OBJECTIVES

The objective of this research was to determine the applicability of the Federal Highway Administration's NETSIM and JRH Transportation Engineering's TransSim II^{TM} for modeling LRT in urban arterial street networks.

The objective was achieved through the four tasks listed below:

1. Review the literature concerning LRT operations and the use of computer models to model LRT and network operations;
2. Perform data collection to provide a field LRT network environment that could be modeled and compared to NETSIM and TransSim II^{TM};
3. Calibrate NETSIM and TransSim II^{TM} for the field network; and
4. Evaluate the models through statistical testing of model MOEs against field MOEs.

The objectives for this research form a part of the overall objectives of the TxDOT research project entitled *Development of Analytical Tools for Evaluating the Operations of Light-Rail At-Grade Within An Urban Signal System*.

ORGANIZATION

This report has been divided into five chapters. Chapter 1 provides an introduction to the need for a model to simulate LRT in urban environments, discusses the requirement of model accuracy, and defines the objective of the research. Chapter 2 contains a discussion of background information, including a review of the literature regarding LRT environments, operational characteristics, and MOE calculations. Furthermore, it discusses attempts to model LRT environments and the NETSIM and TransSim II^{TM} models. Chapter 3 contains a discussion of the basic work plan used to accomplish the objectives of this research. Included is the procedure used to collect and reduce the field data for later representation in the models. Chapter 4 presents the results of the research, including the calibration procedure used to adjust the models, the output obtained from the calibrated models, and the results of the statistical procedures used to assess the accuracy of NETSIM and TransSim II^{TM} in modeling LRT in arterial networks. Chapter 5 presents the conclusions from this research and the recommendations for further use of NETSIM and TransSim II^{TM} for modeling LRT.

BACKGROUND

This chapter presents background information on model validation, the definition and characteristics of LRT systems, and NETSIM and TransSim II^{TM}. Attention focuses on the features and characteristics of the LRT environment considered for inclusion in the model.

MODEL VALIDATION

Four prerequisites have been set forth to determine whether or not a situation can be modeled validly (*1*):

1. It must be possible to observe and measure the situation being modeled;
2. The modeled situation must remain structurally constant over time;
3. The situation being modeled must exhibit a constancy across variations in conditions not specified in the model; and
4. It must be possible to collect ample data with which to make predictive tests of the model.

The first criterion was met by the observation of existing urban arterial networks with LRT systems. Researchers collected data describing system traffic patterns, network geometrics, and signal operations. Further, field MOEs were measured and recorded as descriptors of system performance.

Secondly, traffic operations, by their nature, are reasonably predictable and consistent, especially in pretimed operation. Signal timings vary only by set time of day plans, weekday traffic patterns are generally known, and system disruptors, such as accidents, do not occur with undue frequency. When unusual conditions do exist, their causes are easily traced and the conditions manifest themselves in a fashion, such as excessive queues, apparent to the observer.

Thirdly, even the most complex models are a simplification or reduction of a real-world entity or event. Though it is understood that the model cannot include all the features of the modeled situation, it is necessary that conditions not specified in the model either remain constant or have inconsequential impact on the modeled situation. Obviously, if factors in the modeled situation are not, or cannot be, accounted for in the model and impact the system, the predictive ability of the model and its reliability are in jeopardy.

Finally, the modeled system must lend itself to observation in such a manner that one may collect adequate data to describe and test the model. For this LRT investigation, researchers sought the assistance of traffic engineers in cities where LRT is currently operating in obtaining the data necessary to model the system. In addition, a data collection trip was undertaken to observe the system and record data describing its operation.

SIMULATION

Simulation is a powerful and widely used technique for the analysis and study of complex systems. Simulation can be chosen rather than mathematic or analytical models for a variety of reasons, including the stochastic nature of the problem, the complexity of problem formulation, and the myriad interactions that adequately describe the problem under investigation. Simulation has a number of significant advantages as an analytical device as well as distinct disadvantages. It provides a means of addressing particularly complex analytical problems which may not be susceptible to direct analytical treatment. The analyst is permitted to focus on specific portions of an overall problem using simulation and experimentation with new ideas that have yet to be put into practice. Simulation avoids the very real risk of failure implicit in any extensive program of field experimentation and is generally considerably quicker, more flexible, and less expensive than other forms of complex, analytical evaluation.

A simulation model created to simulate a system is still essentially a simplification of a real-world situation. The results obtained from such a model are only as good as its capacity to reflect a particular real-world situation. Additional factors, including the starting conditions of the simulation, the length of the period being simulated, and the accuracy of the model itself all impact the quality of the model output (*2*).

CONSIDERATIONS FOR MODELING LRT

The model inputs and embedded parameters for simulation of LRT in an urban street system include the location of the transit line with respect to the roadway, the environment in which LRT will run, general aspects of LRT operations, traffic control devices, possible priority schemes for transit, and a means of quantifying the impact of LRT on the traffic system.

Crossing Configurations

Four major at-grade configurations exist for LRT-roadway intersections: isolated crossings, isolated crossings with a nearby traffic control device, crossings where LRT is adjacent to a parallel street, and crossings for LRT median operation (*3*). For each type of crossing, there are modeling concerns such as the presence and handling of turning vehicles, the need to prevent cross street vehicles from encroaching on the LRT tracks (intersection spillback), the degree of priority needed for LRVs, the optimal signal timing, and the effects of altering the signal timing for an LRV when the signal is timed for arterial progression.

The LRT Physical Environment

LRT right-of-way and environment describe the purpose and exclusivity of the corridor in which the LRT line will be located. The land on which the line is or will be constructed may be devoted entirely to the transit facility and its appurtenances, it may be shared with a freight rail line, or it may even be in the right-of-way of a municipal street. Within the corridors, varying at-grade LRT track placements have been utilized in cities around the country. Despite this diversity, five general classes of track locations define and classify a vast majority of these placements. Ranging from least to greatest interaction with automobile traffic, these locations are grade separation, exclusive right-of-way, side of street, median of street, and mixed traffic. Grade separation is included in this discussion since there are many predominantly at-grade LRT lines that are grade separated at intersections where a high degree of automobile congestion exists. This issue has been addressed for LRT (*4*). An additional environmental factor is the type of urban area through which the LRV will run. Categories for differentiation of area type can be downtown areas, areas with tight street grids, and areas with widely spaced arterial crossings.

LRT Operations

To ensure accurate representation of the LRV within the model, it is necessary to provide accurate information about the vehicle's features and operations. The list here includes vehicle characteristics, headways (the average time between LRV arrivals), dwell time (the time required for passenger boarding and alighting), operating speed (depending on the environment), and time factors at roadway crossings (including blockage time, clearance time, and lost time).

Traffic Control Devices

Pursuing the discussion of LRT roadway crossings, another topic to be addressed is the type of control present at the crossing. The crossing may exhibit crossbucks only, flashing lights with crossbucks, flashing lights with gates and crossbucks, or standard traffic control devices (*3*). Each control option has different blockage, clearance, and lost times, and all differences must be accounted for as accurately as possible within the model.

Control Strategy

In addition to the reproduction of the physical aspects and features of the modeled environment, it is also necessary to incorporate the control strategy found in the network. Where LRVs and automobiles are considered equally, no modifications are required; however, where transit is given special treatment, signal priority for the LRV must be considered in the model.

Signal priority is an attempt to minimize or eliminate LRV delay by temporarily altering the traffic signal phase so that an approaching LRV receives a green phase when it arrives at the intersection. Piper et al. (*5*) provides an extensive discussion on priority techniques. The traffic signal priority treatments outlined in that report were subdivided into passive and active priority treatments. Passive priority treatments use anticipated public transit operations to determine the required priority treatment to be implemented. The following list shows several treatments that fall into this category:

1. Reduced cycle time,
2. Priority movement repetition in the cycle,
3. Green allocation weighted towards the priority movement,
4. Phasing design, and
5. Linking of signals for LRT progression.

Active priority treatments improve upon one basic weakness in passive priority treatments, and that is their ability to sense the presence of the public transit vehicle and select the most suitable priority technique. Common active priority techniques are listed below:

1. Phase extension;
2. Phase early start;
3. Special phase;
4. Phase suppression;
5. Priority phase sequences;
6. Compensation; and
7. Flexible window stretching.

The microprocessor traffic signal controller is one means of implementing a flexible and low-cost system of controlling LRVs and providing preemption at signalized intersections. Before discussing the preemption of traffic signal controllers, it is first necessary to understand the nature of traffic controllers. Reference (*6*) summarizes the preemption capabilities of a number of currently used traffic signal controllers and identifies shortcomings in the preemption logic of these controllers. Although this reference deals with preemption in terms of railroad preemption, the information provided can be useful when discussing preemption for LRT trains.

There are two general types of actuated traffic signal controllers available: Type 170 models and units based on the National Electrical Manufacturers Association (NEMA) standard. Type 170 controllers can theoretically be operated in a variety of ways. NEMA, on the other hand, is limited to the factory-set configurations and capabilities. All controllers reviewed in this document provide the same basic preemption sequencing (*6*):

1. Entry into preemption;
2. Termination of the phase in operation;
3. Track clearance phase;
4. Hold interval; and
5. Return to normal operation.

Impact of LRT on Traffic System

Assessment of the effects of an LRT system on an arterial network and the impacts of different LRT operating scenarios can be determined by the examination of MOEs. MOEs quantify the impacts of LRT on other roadway users, including other transit vehicles, and can be used to reflect the Level of Service (LOS) of the roadway network. Some MOEs that can be used include delay to automobile occupants, delay to LRT users, "person-delay" at intersections, the volume to capacity ratio for the intersection, queue lengths, number of stops, and the travel times on adjacent streets. MOEs are also the gauges that indicate the impact of the LRT system on an areawide signal system. When utilized as indicators, these MOEs delineate the LOS of the roadway and its crossings. LOS, however, has been criticized as a criteria in evaluating LRT impacts because it does not consider the volume of people being carried by transit. A principal concern is the need to determine the impact of preferential control of the LRT on the overall system performance. Studies have shown that signal priority generally results in some loss in intersection capacity. This loss is a function of the LRT frequency and the priority strategy used.

It should be noted that the use of delay has been discouraged by Bates and Lee (*7*) for the following reasons: (1) no way to account for rail preemption in delay; (2) although over-capacity is definable, over-delay is not; and (3) delay due to auto traffic differs from delay due to rail. The volume-to-capacity ratio, a ratio of the demand to the supply of roadway capacity, is suggested (*7*) rather than average vehicular delay for the definition of level-of-service.

Another MOE for LRT impact quantification is the length of the automobile queue accumulated during the passage of an LRV. Bates and Lee (*7*) state that while the "LOS identifies the average operating conditions over the peak period, the worst-case queue length indicates the impacts of a specific though-transient condition."

Impact on Areawide Signal System

Presumably the most efficient means of modeling an arterial network is with pre-existing microcomputer software. Existing, proposed, or hypothetical arterial networks can be created and optimized using programs such as TRANSYT and/or PASSER II. This optimized network and all of its attributes can then be used as the input to a system simulator, such as NETSIM or TransSim II^{TM}, to develop a control case of the network that, based on "runs" of the system, has an associated arterial level of service and quantified MOEs. The LRT system is then added to the network and the output is compared to the control case. The differences are due to the presence of the LRV, and these differences can be computed for various LRT operating scenarios.

Problems exist, however, in the applicability of the system simulation software to the LRT placement scenario. Though LRV characteristics can be entered as inputs and tracks can be modeled by exclusive roadways or busways, the reliability and compatibility of the LRT placement in the simulator is questionable. Further, the addition of priority schemes for LRT is difficult, if not impossible, within the limitations of the existing and available simulation software.

NETSIM

The NETSIM network simulation model (*8*) performs a microscopic simulation of traffic flow in an urban street network. The traffic engineer and researcher can apply the model as an operational tool for the purpose of evaluating alternative network control and traffic management strategies. NETSIM allows the designer to simulate the performance of traffic under a number of alternative control strategies.

The model is based on a microscopic simulation of individual vehicle trajectories as they move through a street network. It has the capacity to treat all major forms of traffic control encountered in the central areas of American cities. It includes a set of "default" values for most input parameters, precluding the need for detailed calibration if such data has not been assembled.

The model is designed primarily to serve as a vehicle for testing relatively complex network control strategies under conditions of heavy traffic flow. It is particularly appropriate to the analysis of dynamically-controlled traffic signal systems based upon real-time surveillance of network traffic movements. It may also be used, however, to address a variety of other simpler problems, including the effectiveness of conventional traffic engineering measures (e.g., parking and turn controls, channelization, one-way street systems, etc.), bus priority systems, and a full range of standard fixed-time and vehicle-actuated signal control strategies.

Modeling the Physical Environment Using NETSIM

The street network is defined in terms of a series of interconnected links and nodes. An urban street network is broken down into a set of uni-directional links and nodes. One link would represent a particular direction of travel along a single street between two adjacent intersections. Each link may contain up to five moving lanes. Provision is also made for mid-block "source/sink" nodes representing entrances to parking lots, shopping centers, or minor streets not represented on the full network. Input into the model is achieved through the use of "cards," each of which is used to designate a particular type of input. Some general categories of card type include data set descriptor, run control, output format and frequency, link name, link characteristic, link permitted movement, node signal timing and approach, node permitted movement by signal phase, and end of input delimiter cards. Special bus cards can be used to simulate bus lanes and routes, bus stations and station locations, and bus headways and dwell times. For advanced NETSIM simulation, the default values used in the model to describe such traffic environment parameters as start-up lost time and queue discharge headway can be modified using special input cards.

Past Application of NETSIM in LRT Modeling

NETSIM was used (*9*) to evaluate the relationship between an intersection crossing volume and the average automobile delay at an isolated crossing. In NETSIM, the LRT was modeled as a single lane roadway, and the grade crossing as a two-phase, fully actuated intersection. The LRV's arrivals were modeled as buses operating on the track using specified headways. The model, however, gave unconditional priority to the LRT vehicles and made no allowances for nearby signals and progression (*9*).

Simulation of DART's North Central Light Rail Line was accomplished using a modified version of NETSIM (*10*). The original software did not readily accommodate the complex, frequently changing signal sequences found in the "window" limited priority scheme proposed for the DART line. Restrictions in NETSIM that limited the signal transition flexibility were identified and their influence on the simulation was mitigated. NETSIM was used, in conjunction with TRANSYT-7F and the HCS (Highway Capacity Software), to identify the delay impacts of LRT and the presence, if any, of residual queues after LRV passage.

An attempt was made in 1979 (*11*) to validate NETSIM as a simulation model for an urban arterial street. NETSIM was evaluated for its ability to reproduce actual observed MOEs and to develop a methodology to determine optimal signal timings for a linear signal system. Attempts at reproducing observed MOEs were not successful, nor were attempts to estimate MOE changes for different signal timing alternatives. It was concluded that it was not possible to validate NETSIM for use as a computer program for improving signal timing in a linear system of signals.

TRANSSIM II^{TM}

TransSim II^{TM} is a program developed by JRH Transportation Engineering of Eugene, Oregon. Having identified the shortcomings mentioned in current software for modeling LRT, JRH proceeded to develop a program specifically designed for modeling LRT or bus transit in urban networks. The program is microscopic with respect to LRT (or bus) behavior and movement within the modeled system and macroscopic with respect to traffic performance. The computation of MOEs for traffic is accomplished within TransSim II^{TM} using a methodology similar to that found in the TRANSYT program.

Inputs to the program include features of the roadway environment (e.g., geometrics, traffic volumes, and signal phasing) and information about the transit route (e.g., including stations and intersections). Operating speeds and station dwell times can vary to better simulate realistic transit operations. The user enters data in a pull-down menu format under the entries of system data, route data, link data, and signal data. A variety of types and degrees of priority are available and easily selected by the user, facilitating the evaluation of alternative control strategies for the networks.

Modeling the Physical Environment Using TransSim II^{TM}

As with NETSIM, the networks are best conceptualized as nodes (intersections) and links (directional roadways). The physical and traffic operational features of the network are defined through link data, including traffic volumes and intersection spacing. The data describing the LRT route includes the number and location of stations within the system and the manner in which the LRT interacts with each station and intersection. Unlike NETSIM, links in TransSim II^{TM} are organized as movements that move concurrently during a given signal designation. Movements which have exclusive lanes or bays, move in a unique set of phases, or have left turns that move under permitted phasing and occupy shared lanes must be coded as separate links. TransSim II^{TM} uses the NEMA standard dual-ring numbering system for all traffic signal phases. Additional information coded into the model includes general system-wide data, such as LRT operational parameters and traffic system constants.

STUDY DESIGN

This chapter describes the locations selected for the field data collection, the development of the plan to acquire the necessary data in the study cities, the data elements themselves, procedures used to assemble the data in final form and, finally, coding all the information into NETSIM and TransSim II^{TM}.

SELECTION OF STUDY CITIES

The criteria for study site selection for the project were the following:

1. Cities similar to Texas cities in their land use and transportation system;
2. Cities with LRT that has been operating long enough to have the LRT incorporated into the daily transportation operation of the city;
3. Extensive system that travels through a variety of urban environments and, if possible, has LRT in varying locations with respect to the roadway; and
4. Cities with varying control strategies for LRT.

Since the current research required data for both pretimed and actuated networks with LRT in a variety of environments, two cities were chosen for the data collection. The sites for pretimed data collection were Los Angeles and Long Beach, California (the Metro Blue Line), and Portland, Oregon (the MAX LRT line), was chosen as the actuated site. Cooperation of representatives in both the transit agency and the city traffic engineer's office in both areas ensured the quality and success of the data collection effort.

DATA COLLECTION PLAN

For each modeled network under investigation, two separate sets of data were collected. The first set was used to calibrate NETSIM and TransSim II^{TM} for use with LRT, and the second set was used to statistically test and validate the model's ability to recreate the modeled environment.

Design of the Data Collection Plan

Inputs. Since the data was specifically being collected for input to NETSIM and TransSim II^{TM}, the data to be collected was defined by the data requirements of the models. Networks are broken down into links and nodes, which can be respectively conceptualized as uni-directional roadways joining two intersections and the intersections themselves. The following list summarizes the input data requirements of the models. It was anticipated that some of this information could be obtained from the city traffic departments and the city transit agency:

1. Network geometry by link: length in feet, grade in percent, capacity in vehicles/hour;
2. Operational data by link: number of travel lanes, target speed, queue discharge rate, start-up delay, pedestrian volume, lane use;

3. Turning movements by link: number or percent of vehicles proceeding straight or turning at the downstream end of a link;
4. Signal controls by intersection: signal offset in seconds, phase length in seconds, and control for each approach during each phase; and
5. Flow rates by source link: peak hour volume that is emitted from each source node in number of vehicles.

Embedded Parameters in NETSIM. NETSIM uses a number of embedded parameters to assign characteristics to the vehicles in the network. The fact that changing embedded parameters and/or NETSIM features, such as driver characteristic, impacted vehicle handling in the network became important in calibrating the model to recreate the field data. NETSIM uses fourteen embedded parameters (*8*), including such factors as distributions for gap acceptance and turning speed. It was unlikely that sufficient data could be provided by a data collection effort to field adjust all fourteen parameters, but the data collection team collected or estimated such data where possible and appropriate.

Output. Output given by the NETSIM model includes link-specific output and summary network output (*8*). Table 1 lists the link and general output provided by the model.

Table 1. NETSIM Outputs by Link and Network

OUTPUT	LINK	NETWORK
Link Identification	X	
Vehicle Miles Traveled (VMT)	X	X
Vehicle Trips (number of vehicles discharged)	X	X
Moving Time (accumulated in veh-min)	X	
Total Delay (total travel time - ideal travel time)	X	
M/T Ratio (moving time/travel time)	X	X
Total Time (veh-minutes)	X	
Travel Time/Vehicle (in seconds)	X	
Average Speed	X	X
Average Occupancy (average number of vehicles)	X	X
Stops/Vehicle (percent stopping at least once)	X	X
Average Saturation Percentage (occupancy/capacity)	X	
Cycle Failure (queue clearance failures)	X	
Stop Delay (delay due to red signal)	X	X
Total Queue Delay (not attain target speed)	X	X
Queue Delay/Vehicle (queue delay/vehicle trips)	X	X
Delay/Vehicle-Mile		X
Travel Time/Vehicle-Mile		X
Stop Delay/Vehicle		X
Delay/Vehicle		X
Total Delay		X

The output generated by the TransSim II™ model includes comprehensive LRT performance measures, comprehensive traffic performance measures, link specific output, LRT location information by simulation time, and the time of LRT checkout at each signal. The MOEs provided for the LRT include travel time, dwell time, average speed, stop line delay, time-to-green delay, and non-station delay. MOEs for traffic include v/c ratio, uniform delay, random delay, total delay, average delay, and maximum queue. Additional output of the program can be used to determine the location of the LRT at any time during the simulation, the arrival and departure behavior of the model (similar to the TRANSYT program), and the time of checkout after the LRT leaves each signalized intersection. These latter data elements lend themselves to examination for understanding the methodology used in the program and debugging any coding errors.

Limits of Data Collection

Though it would have been desirable to collect field data to compare with all the output MOEs provided by NETSIM and TransSim II™, such a data collection would have required a massive and exhaustive effort. Realistic limitations of time, money, and personnel restricted the quantity of data that could be collected. In addition to measuring MOEs in the field, researchers had to collect the input data for the models.

The available resources for the collection effort were two video cameras, three persons for data collection, one or two rental cars, and approximately one week each in the cities of Los Angeles/Long Beach, California, and Portland, Oregon.

City contacts were made in the Los Angeles and Portland areas to identify available input or MOE data. To provide a reasonably sized network that was within the processing limits of NETSIM and the collection limits of the data collection team, each study area was limited to a maximum of eight or ten intersections paralleling the LRT line and a network width of two intersections (three including the LRT-roadway intersection). The operations at the one or, at most, two major intersections were recorded by the available video cameras (one camera per approach paralleling the LRT line). Travel time runs were conducted along the arterials paralleling the LRT line. Researchers averaged the data from these runs, and it was possible to obtain link-specific travel times and total travel times along networks from the assembled travel time data. From the video at one intersection in each network, researchers computed stopped delay per vehicle and percent stops by visible approach.

Format of Data Collection

The information necessary for input into the NETSIM and TransSim II™ models was easily formatted by the completion of *Highway Capacity Manual* Input Worksheet, page 9-75 (*12*). It was important for each sheet to be completed in full for each intersection in the model, including an accurate representation of the number of approach lanes, lane usage, lane widths, and turn bay presence in the Volume and Geometrics Diagram.

Additional input information included the following:

1. The signal offsets between intersections, which were noted on the HCM worksheet and referenced to the upstream intersection;
2. The link lengths, measured from the stop bar at one intersection to the stop bar at the downstream intersection. These measurements were also to be made at the intersections of roadways with LRT lines; and
3. Frequency of LRV arrivals (headways), type of signal control implemented when LRV arrives at the intersection, location of stations, average dwell times.

Potential Sources of Required Data

To minimize the quantity of data to be collected, the city traffic engineer's office and the transit agencies in the study cities were contacted for access to any of the following data, if collected and available:

City Traffic Department

1. Length in feet from the stop bar of one intersection to the stop bar of the downstream intersection for every intersection and roadway link in the network to be studied. Lengths included distances to the stop bars at LRT-roadway intersections;
2. Capacity estimates of all through and turning lanes in the network;
3. Presence, location and degree of significant grades;
4. Number and width of travel lanes and turn bays for every intersection approach in the studied network;
5. Target speed - comfortable maximum driver speed on the arterials in the network;
6. Estimates of queue discharge rate and start-up delay;
7. Pedestrian volumes - light, moderate, heavy - at all network intersections;
8. Volumes (through, turning left, and turning right) for every approach to every intersection in the study network;
9. Phase length in seconds and type of control for each approach during each phase;
10. Signal offsets for every network intersection;
11. Special signal phasing used when LRT is detected, if present; and
12. Any available MOEs - average intersection delay, number of stops, travel times - for the intersections or roadways in the studied networks.

Transit Agency

1. Frequency of LRV arrivals (scheduled headways);
2. LRT signals and signal control used at all LRT-roadway intersections in the studied network;
3. Location of stations in the network;
4. Average dwell times for the LRV at each station; and
5. Average blockage time when LRV passes each intersection.

Data to be Collected in the Field Study

1. Data made available by the city traffic engineer's office and the transit agency;
2. Input data required but not available through the city or transit agency;
3. Travel time runs in the studied networks, two data sets at each site, multiple runs for each data set, and
4. Video record of major arterials in the network for later single intersection MOE analysis.

DATA COLLECTION

The field data for both the Los Angeles/Long Beach and Portland networks consisted of network description data, travel time information collected using a portable computer and video tapes of at least one major intersection within each of the study networks. Network 1 was designated along Washington Boulevard in Los Angeles from Flower to Los Angeles; Network 2 was designated along Washington Boulevard from Los Angeles to Alameda; Network 3 was designated along Pacific Avenue in Long Beach from First to Eighth; Network 4 was located in Portland, Oregon along Holladay from MLK to 13th; and Network 5 was located along Burnside in Portland from 102nd to 122nd.

Collection of Network Geometric, Volume, and Signal Data

To accurately provide a description of the modeled environment for inclusion in the model, researchers required reliable information as to the geometric description of the network roadways, LRT locations, and intersections; traffic volumes at each network entry point and turning percentages (left, through, right) for each approach to each intersection in the network; and signal timings and permitted movements by signal phase. The primary source for this information was the city traffic engineer's office in each of the study cities. Scale drawings of the roadway-LRT network as well as distances to cross street intersections adjacent to the LRT line were provided. For all networks, signal timing information was obtained from photocopies of timing plans used in the field. For the network in Long Beach, an output file from TRANSYT, a flexible, computerized optimization program, provided all signal timing data. This output also provided the traffic counts and turning percentages for this network.

In Los Angeles, intersection traffic counts by movement and approach were provided for most intersections in the study networks from data collected by the city. The data collection team conducted additional traffic counts during the analysis time periods to fill the few gaps that were present in the data provided by the city. Turning count data for some intersections in Portland was provided gratis by Traffic Smithy. The data collection team took additional traffic counts to complete the data sets.

Collection of Field Data MOEs

The travel time information was collected using a computer program developed by the Texas Transportation Institute (*13*). Using a portable computer inside a floating car probe vehicle, the program was run and recorded the absolute time, from beginning of the travel time run, to each intersection in the network. If stops were encountered, a separate keystroke recorded the time of the stop, the time the vehicle started in motion, and the time the intersection was reached. For non-stop intersections, a simple keystroke pressed when the vehicle entered the intersection recorded the time. Two sets of travel time runs were conducted for each location. Data collectors used the first set for calibrating the model to produce travel times similar to the field results, and the second set was used to statistically compare the calibrated model results to the field data. The data from all travel time runs was stored on disk for later reduction.

Data collectors used the video tapes for collecting intersection delay and percent stop information for later comparison to model results. Within Network 1, the video tape was made at the intersection of Washington and Flower and the approaches visible in the camera eye were the NB and EB approaches. Within Network 2, the video tape recorded the intersection of Central and Washington, and the NB and EB approaches were in the camera eye. In Network 3, video was made at two intersections. At First and Pacific, the video recorded the NB and SB approaches. At Broadway and Pacific, the video recorded the NB and SB approaches. In Network 4, the MLK SB approach of MLK and Holladay was recorded and in Network 5, the NB approach of 122nd Avenue at 122nd and Burnside was recorded. Each video tape consisted of two hours of intersection operation. The first hour of tape was used for collecting data for calibrating the model, and the second hour was used for statistical comparison to calibrated model results.

DATA REDUCTION

The travel time data files contained on disk were printed out, and the collectors calculated travel times between intersections from the computer's internal time clock, which was started anew for each travel time run. A spreadsheet was used to create tables of travel time runs for the five networks. Each column contained travel times for an individual run, and each row represented the roadway link between intersections. Averages were computed across runs to calculate the mean travel time between each intersection in each network. Columnar averages were computed to calculate the mean directional travel times within each of the three networks. Standard deviations were also computed, by direction, for the travel times between links and along each network.

Individual intersection stopped delay and percent stops data were collected from the video tapes made for each network. Again, the data from the tapes was broken down into two subcomponents. One half, or one hour, was used for the calibration, and the other half was used in the statistical comparison of the calibrated model to the field data. The data from all of the video tapes was entered into ten different spreadsheets, one for each of the studied approaches at the six intersections where video data was collected. The standard form of the spreadsheet included entries for number of vehicles, stopped delay, and number and percent stops per minute.

Each of the eight spreadsheets was then examined for the development of an analysis interval by which to summarize the collected data. A five minute interval was selected as a balance between the need for reasonably consistent volumes among intervals and the need for a sample size of intervals that could be compared to the output of the model. One exception was the intersection of Central and Washington, which exhibited stopped delay per minute that cycled in three minute intervals. To maintain consistency among intervals indicative of the delay observed in the field, a six-minute interval was selected for this intersection. For each approach to each intersection, the data was tabulated, and an overall mean and standard deviation were computed for stopped delay and percent stops for the summarized five or six minute interval. Researchers then tabulated the mean and standard deviations by intersection and approach into two tables, one for calibration and one for later comparison to the calibrated model (see Appendix A).

CODING THE MODELED ENVIRONMENT IN NETSIM

The described geometric, traffic volume, and signal timing information was input into the model through the use of files containing series of cards, each card containing information about a particular feature of the modeled environment. In the pre-calibration stage, all default values were entered as model inputs on the appropriate cards. To clarify this procedure, the following section describes the function of each card used in modeling pretimed networks in NETSIM. Researchers used special card types to model the LRT in NETSIM as a bus route, and these cards are also discussed.

Card Types

Run Control Data. Card types 00 through 05 describe the network and indicate how long the model will simulate the modeled system and in what increments of time. This structuring allows the analyst to vary signal operations, some geometric conditions, and volumes. The final card, 05, designates the frequency of output desired from the model and whether or not the analyst desires to produce graphics files for later review of the simulation.

Network Description Cards. Card type 11 is used to describe the links, or roadway segments, that constitute the urban network. Specified on this card are the nodes, or intersections, joined by the link; the link length; the lengths of any turn pockets; the number of through lanes and the number of lanes in turn pockets; channelization codes (i.e., left turn only, etc.); nodes receiving through and turning traffic; mean start-up lost time; mean queue discharge headway; free flow speed; right-turn-on-red code; and pedestrian code.

Card type 21 specifies surface street-turning movements. For each link, the permitted movements and percent of traffic turning through, left or right is indicated.

Signal Control Cards. A card type 35 must exist for each node controlled on a pretimed basis. The approaches to the node are specified in clockwise order and up to 12 separate signal intervals can be indicated. Corresponding to each card 35 is a card 36, which specifies the control code for each approach link for each signal interval specified on card 35. The control code can vary from 0 to 9, with the following meaning attached:

0. Amber;
1. Green ball;
2. Red ball;
3. Red with right green arrow;
4. Red with left green arrow;
5. STOP sign;
6. Red with green diagonal;
7. Green through with no left turns;
8. Green arrows with no through; and
9. Green through and right, no left turn.

Traffic volumes. Traffic is entered into the network via entry nodes and links. The volume generated at each entry node is specified on card type 50. Along with the flow rate in vehicles per hour, percent trucks and percent carpools composing the traffic stream can be specified.

Delimiters for Separating Model and Time Period Data. Card type 170 marks the end of the input stream. This card is then followed by data for another network during the same time period, input records for global networking, or a card type 210, which marks the end of the data for the current time period. Card type 210 closes the input file unless the final time period has not been reached.

Special Considerations

Modeling LRT. LRT can be modeled in NETSIM using bus routes. The location of the route is specified similarly to the normal roadway links described earlier, but no traffic volume is entered for these links. Rather, bus routing is established using card type 187 and bus headways are specified using card type 189. Stations can be included using card type 185, which physically locates the stations in the network, and card type 188, which indicates the order in which the LRT will reach each station. One can even specify mean dwell times at stations and their distribution with card types 186 and 150, respectively. The length and acceleration properties of the LRT vehicle can be input, rather than those of the bus, using card type 58; however, the maximum vehicle length that one can enter is 125 feet, while dual car LRT trains can be up to 175 feet in length.

Model Calibration Cards. Card type 11, one of the network descriptor cards, has three entries which are important in model calibration. The entries are the mean start-up lost time, mean queue discharge headway, and free flow speed. If the mean start-up lost time or queue discharge headway were lower, the vehicles that were stopped at one intersection will reach the downstream intersection sooner. It is essential that both of these values match the field observed values. If the mean values from the field differ from the defaults in the model, the observed means can be entered in the appropriate column of card 11. Not only can the mean values change, but their distributions can change as well. Any noticeable differences between model and field distributions can be brought into agreement by changing the start-up lost time distribution or mean queue discharge headway distribution in the model using card type 149. Free flow speed, which can be changed on card type 11, can also impact the time that platoons arrive at a downstream intersection since the higher the free flow speed entered, the higher the average speed along the link. Free flow speeds also follow a distribution, and this distribution can be changed using card type 147.

Other cards can be used to adjust other model parameters. The possible changes can impact turning speeds, lane switching, spillback probabilities, amber phase response, left-turn gap acceptance, pedestrian delay, short and long term events, parking, and a host of other parameters. Sufficient data will probably not be available to adjust for those parameters in the above list, and the default values within NETSIM will be utilized.

CODING THE MODELED ENVIRONMENT IN TRANSSIM II™

Researchers entered the geometric, traffic volume, signal timing, and LRT information necessary for input into TransSim II™ using the pull-down menu driven data entry format of the program. The program main screen displays five menu options; File, Edit, Schedule, Run, and Result and Graphics (*14*). The data was entered using the Edit and Schedule menus. The Edit menu displayed the headings System Data, Route Data, Link Data and Phase Data. This menu is the primary vehicle for entering data into the program. The Schedule menu was used to enter the LRT schedule and the standard deviation of the LRT generation in the modeled system.

Data Files

System Data. Information provided under this entry included the acceleration and deceleration of the LRT, the minimum distance headway for LRVs, the minimum walk time for system signals, the start-up lost time, the type of arrivals in the system (uniform or random) and the number of left-turn sneakers per phase. This menu is also the location where the random number seed for stochastic variance was entered for multiple runs of program data sets.

Route Data. The route length, number of stations, specification of speed limited zones, and number of signals along the route are all specified under the Route Data entry. For each station, one enters a label, forward and reverse station location, passenger service time, and scheduled headway. Each signal description includes an intersection label, location in the forward and reverse train directions, phases associated with LRT movement, a priority level for the LRT (a code specifying a particular priority type at the intersection which can be easily changed to determine the impacts associated with different operations strategies), the time for LRT clearance, the minimum phase length, and the location of LRT detectors in the system.

Link Data. For every intersection in the modeled network the link data specifies the phase associated with movement on the link, the link length, the free flow speed, the saturation flow rate, the existing traffic volume, any midblock entry volumes and shared links/lanes. Included on this entry is whether or not permitted turns are present and the opposing link and number of opposing lanes.

Phase Data. The main Phase Data entry screen allows the user to input the cycle length and offset for the intersection and specify up to two overlaps at the intersections. An indication is also given on this menu as to the recall state of each of the eight NEMA phases. Submenus are used to enter the features of the individual phases, such as whether the phase is on recall (none, minimum or maximum), whether or not the phase is a coordinated and/or exclusive phase, the yield point or maximum green, the yellow plus red time, the minimum phase green, a pedestrian clearance time, and the minimum gap for actuated phases.

RESULTS

This chapter presents the results of the analyses conducted to calibrate NETSIM and validate NETSIM and TransSim II™ using statistical comparison of calibrated model output to the field validation data.

NETSIM

Calibration

Calibration was performed to ensure that the model reproduced field operations as accurately as possible. This step is a necessary part of any modeling effort and provides credibility to the model output.

Modeling LRT in NETSIM. Researchers modeled each of the three pretimed networks in the Los Angeles/Long Beach area in NETSIM using two different conventions. The first convention included a physical representation of the LRT line, including right of way in the median of the through arterial, transit stops, LRT vehicles at scheduled headways, and vehicle characteristics. The second convention included only the traffic environment of roadway links, motor vehicle volumes and traffic signal operations. Since no direct conflict between the LRT and vehicles occurs in the pretimed systems (the LRVs only pass through the intersection during parallel street green, and vehicular lefts are only allowed during non-LRT protected green arrow designations), it was possible to model the traffic environment without the physical inclusion of the LRT in the model. This tradeoff also meant that no MOEs, such as LRV delay, were available in the model for LRT in the no-LRT simulations. Under both conventions, researchers entered the roadway geometrics, traffic volumes, and signal timings and offsets from field data as accurately as possible within the data entry structure of the NETSIM model.

The decision to model the system without LRT included was made to alleviate some difficulties with coding NETSIM to accurately reproduce the physical environment with light rail included. The limitations of NETSIM that produced the difficulties included the fact that if left-turn bays are present on a link, the lane to the left of the bay may not be used as a moving link. This restriction meant that one link could not be used for the through lanes on the arterial parallel to the LRT line and the LRT line itself, since the LRT line for all of the networks was located in the median of the arterial street.

To overcome this limitation, the arterial was separated into three separate links, one directional through link for arterial traffic in each direction and an additional link for the LRT. Several additional difficulties were encountered in implementing this "solution." The first difficulty occurred because the minimum link length allowed by the NETSIM model is 50 feet. Accordingly, the arterial lanes were separated in the model from the LRT line by a nominal 26 feet (50 feet minimum minus two lane widths) rather than being adjacent to one another, as in the field. The second difficulty developed in dealing with left turns on the arterials and cross streets. For all three networks, the cross streets experienced one phase of green, with left turns permitted through acceptable gaps in the opposing traffic stream. Since the intersection was essentially broken into three intersections in the model, with the left-turning vehicles making their maneuver from a 50-foot link made necessary by including the LRT between the arterial lanes, no space existed for the inclusion of left turn storage space on the cross streets. The cross street left-turning vehicles effectively blocked the left lane to through traffic. In addition, cross street vehicles and vehicles making left turns from the arterials were required to travel 100 feet in the model that was, in the real environment, only the width of the LRT right of way and two traffic lanes. Figures 1, 2, and 3 show an example of the coding conventions. Figure 1 shows the Long Beach network existing field conditions. Figures 2 and 3 show the coded links and nodes for this network with and without LRT, respectively.

For traffic actuated Networks 4 and 5, the LRT had to be detected to implement the LRT phase; accordingly, only the "with LRT" convention was used to code these networks. The use of multiple nodes to represent a single intersection was continued into the actuated scenarios to include LRT in the median of the arterial and to provide enough phases to accommodate traffic as well as LRVs.

In Network 4, the LRT runs in two-way operation to one side of a one-way street. The signals operate with through phases on recall and left turns across the LRT tracks are actuated. Essentially, the one-way street is a pretimed coordinated system running a 70 second cycle length for traffic. During the detection of an approaching LRV, the conflicting phases are terminated after a minimum green is provided and non-conflicting phases are given green until the LRV clears the intersection and/or is timed out. Pedestrian calls are inhibited during an LRV detection, and after the minimum walk times and clearances are provided, a walk indication will not appear again until the LRV checks out or is timed out. If the coordinated controller is "knocked out" of synchronization by the LRV presence, the controller will re-synchronize itself by dwelling (up to a given maximum) in a designated high demand phase during one or more cycles until resynchronization is achieved.

This behavior could not be closely replicated in NETSIM without designating separate nodes for the LRT and the vehicular traffic. In this manner, the nodes for traffic could be timed with the given signal settings from the field and the LRT nodes could be coded with the minimums for cross street traffic and the average blockage times for the LRVs. The LRT nodes would then dwell in cross street green and the LRVs, when detected, would call for the green but would not violate cross street vehicular or pedestrian minimums. This system behavior replicated as closely as possible the field conditions with two exceptions: (1) the 50 foot minimum link length existed between the traffic and LRT nodes, allowing traffic to queue in the interior and (2) the presence of an approaching LRV did not affect the controller for traffic. Thus, the controller at the traffic node did not display a red signal indication to movements conflicting with the LRT based on the presence of the LRV; this red was encountered when the vehicle reached the LRT node. Also, the traffic node, not being linked to the LRT, could not be "knocked out" of synchronization and forced into a situation where it had to dwell in a specified phase to "resync" itself.

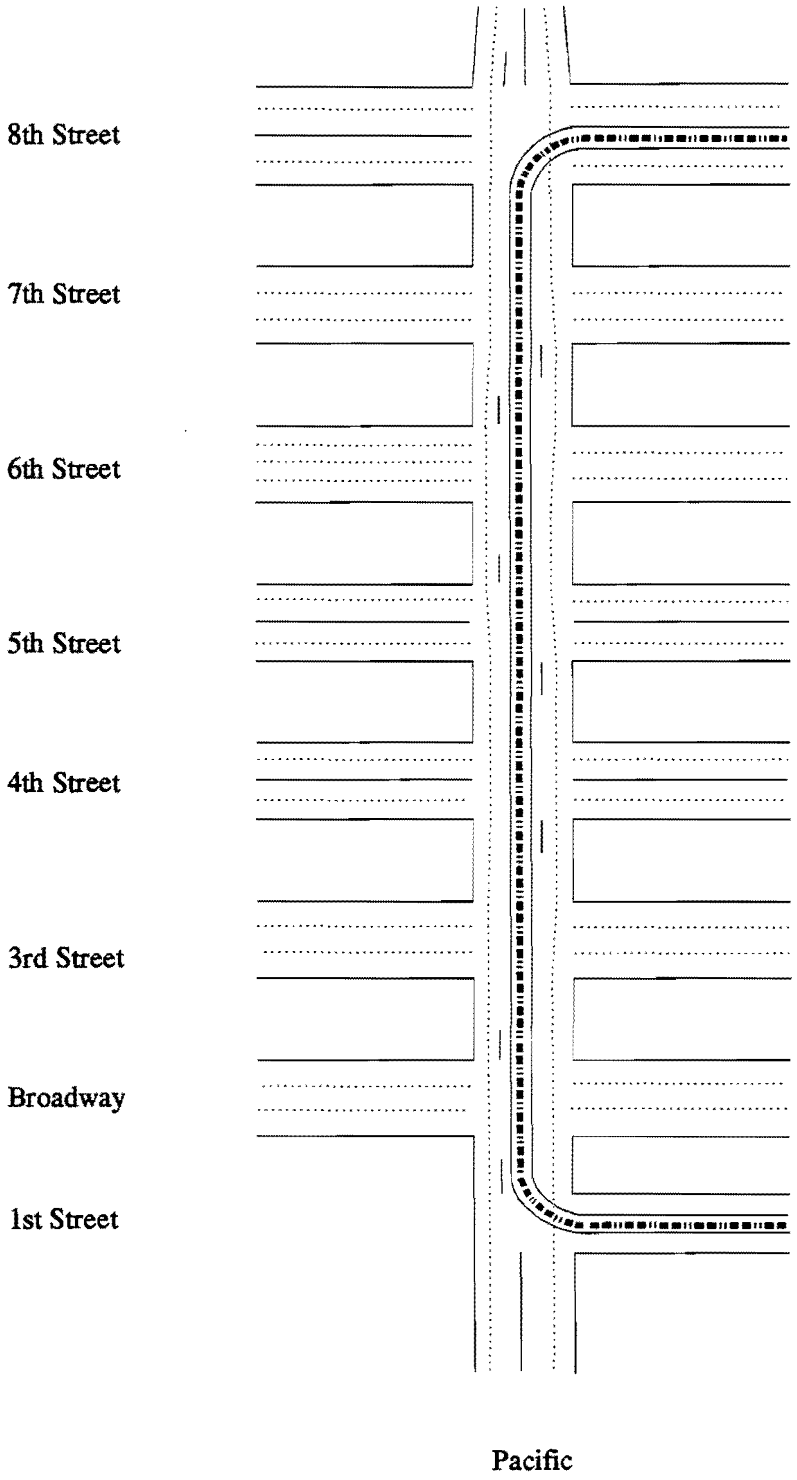

Figure 1. Long Beach LRT and Arterial Street System Along Pacific Avenue

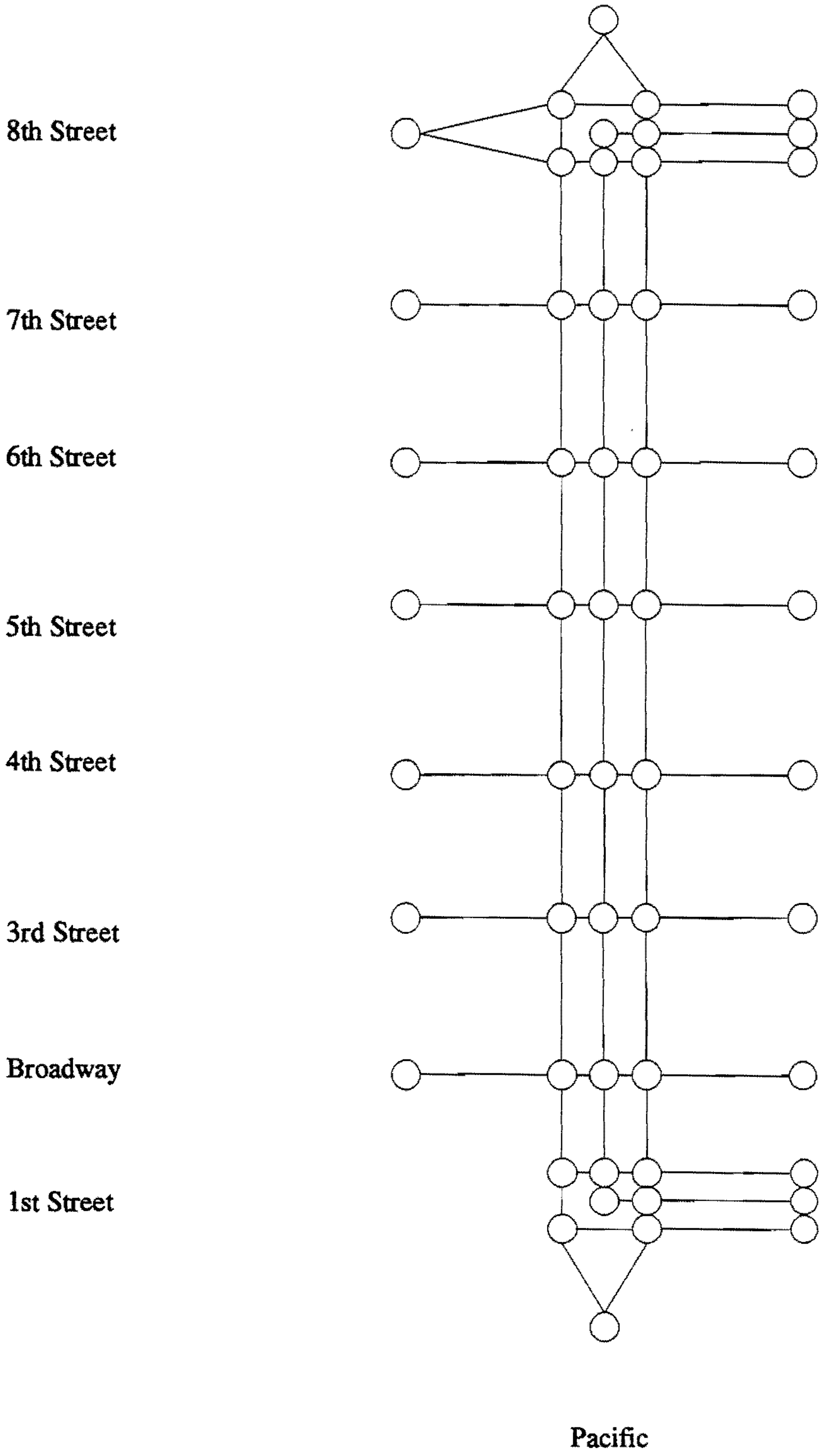

Figure 2. Model Link-Node Representation of Pacific Avenue - with LRT

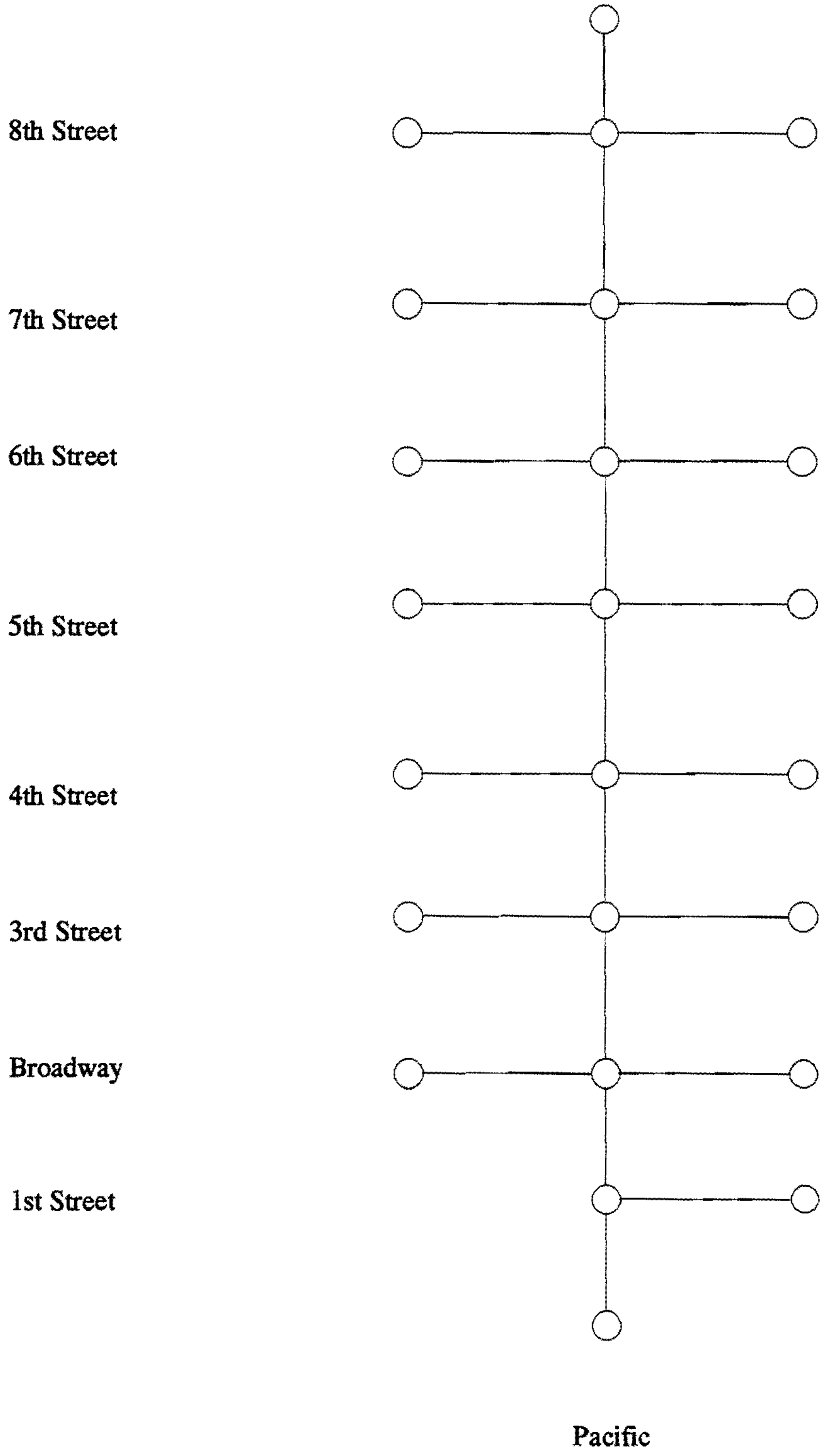

Figure 3. Model Link-Node Representation of Pacific Avenue - without LRT

Network 5 along Burnside Avenue in Portland consists of fully actuated intersections and LRT in the median of the street. As with Network 4, the traffic nodes were separated from the LRT nodes. In this case, the lack of available phases for the LRT when all eight NEMA phases were used to control traffic necessitated the separation. Each intersection was coded as three nodes, one for the LRT and two for traffic, one on either side of the LRT. Again, the traffic nodes were coded from field signal settings and the LRT nodes were coded with cross street vehicular and pedestrian minimum greens. The behavior of this modeling arrangement was the equivalent of the field condition with one exception; the traffic nodes were not directly affected (in terms of timing control) by the presence of an LRV. Vehicles were given the green at the traffic nodes based on demand and actuations, and were allowed to proceed on green as normal. The vehicles had to stop for the LRV as they reached the LRT node, allowing two or three cars to advance from the traffic node to the LRT node that, in the field, would have to wait at the traffic signal. The fact that this type of movement was limited and that the vehicles were still not permitted to cross the tracks during LRV passage seemed to minimize the impact of this non-field condition.

Reduction of Pre-Calibrated Model Output. For both the LRT and no-LRT conventions, researchers ran NETSIM six times, with different random number seeds, to obtain data sets equivalent in size to the calibration data set and exhibiting random variability. The data taken from the NETSIM output files was the parallel to the calibration data collected in the field, with directional travel times along the arterial paralleling the LRT line for each network, and stopped delay and percent stop data taken for each of the eight approaches for which this type of calibration data was collected in the field.

The travel time data was tabulated for the two conventions of model runs in the same fashion as the original calibration data (see Appendix B, Tables B-1 through B-3). Mean travel times were calculated by link and a mean travel time and standard deviation by directional network length were computed. The stopped delay and percent stops were averaged across runs, and then summarized in Table 2. The data is also presented graphically in Figures 4 and 5 for stopped delay and percent stops, respectively.

Comparison of Pre-Calibrated Model Output to Field Data. Researchers developed a travel time comparison table to compare the travel time by link and the average directional travel times within each network to the same quantities generated by the LRT and non-LRT model simulations (see Appendix B, Table B-4). Examination of Table 2 indicated several important considerations. Primarily, travel time comparisons between the model and the calibration data showed the same general relationships, except for the east to west direction of Network 2 and the fact that the model seemed to overpredict the travel times in Network 3. Also, the LRT and non-LRT conventions showed the same general pattern, whether it was overpredicting or underpredicting calibration travel times. No differences were apparent between the two conventions. Overall, investigation was called for to determine the cause of discrepancies between the model and calibration data MOEs and to make adjustments to the model, where possible, to bring the model output into agreement with the observed field calibration data.

Table 2. Uncalibrated Model Intersection MOEs

	Mean Stopped Delay			Mean Percent Stops		
	Calibration Data	Model w/ LRT	Model w/o LRT	Calibration Data	Model w/ LRT	Model w/o LRT
Flower & Washington						
EB Approach	3.16	21.95	6.98	13	87	22
NB Approach	24.71	38.52	10.05	73	100	47
Central & Washington						
EB Approach	8.67	5.3	10.22	25	30	40
NB Approach	23.16	6.9	7.12	88	17	21
First & Pacific						
NB Approach	9.43	0	0.08	58	0	4
SB Approach	6.85	2.78	4.62	42	21	29
Broadway & Pacific						
NB Approach	16.13	8.22	6.3	68	32	31
SB Approach	19.91	19.67	19.92	66	56	55
MLK & Holladay						
SB Approach	6.19	3.2		27.36	21.4	
122nd & Burnside						
NB Approach	32.42	31.48		72.35	78.6	

Comparisons were made in tabular and graphical format for the stopped delay and percent stops data. Both comparisons pointed to the fact that little consistent similarity could be discerned between calibration data and model stopped delay or percent stops for either convention. There was general consistency between the LRT and non-LRT model results except for the intersection of Flower and Washington, but this consistency unfortunately did not extend into the comparison with the calibration data.

Calibration Procedure. The capability exists within NETSIM to alter mean start-up lost times, mean queue discharge headways, the distribution of these two parameters, and the free flow speed, or desired speed of unimpeded flow, to calibrate the model to the field conditions. Default values for each of these variables is used by the model if alternative values are not specified.

The model defaults for mean start-up lost time, queue discharge headway, and free flow speed are 2.5 seconds, 2.2 seconds, and 35 miles per hour, respectively. For each vehicle, the program uses the randomly assigned driver characteristic (1 = passive, 10 = aggressive) to select a multiplier from the distributions, shown in Table 3, to be multiplied by the mean start-up lost time or queue discharge headway to determine the specific value for that vehicle.

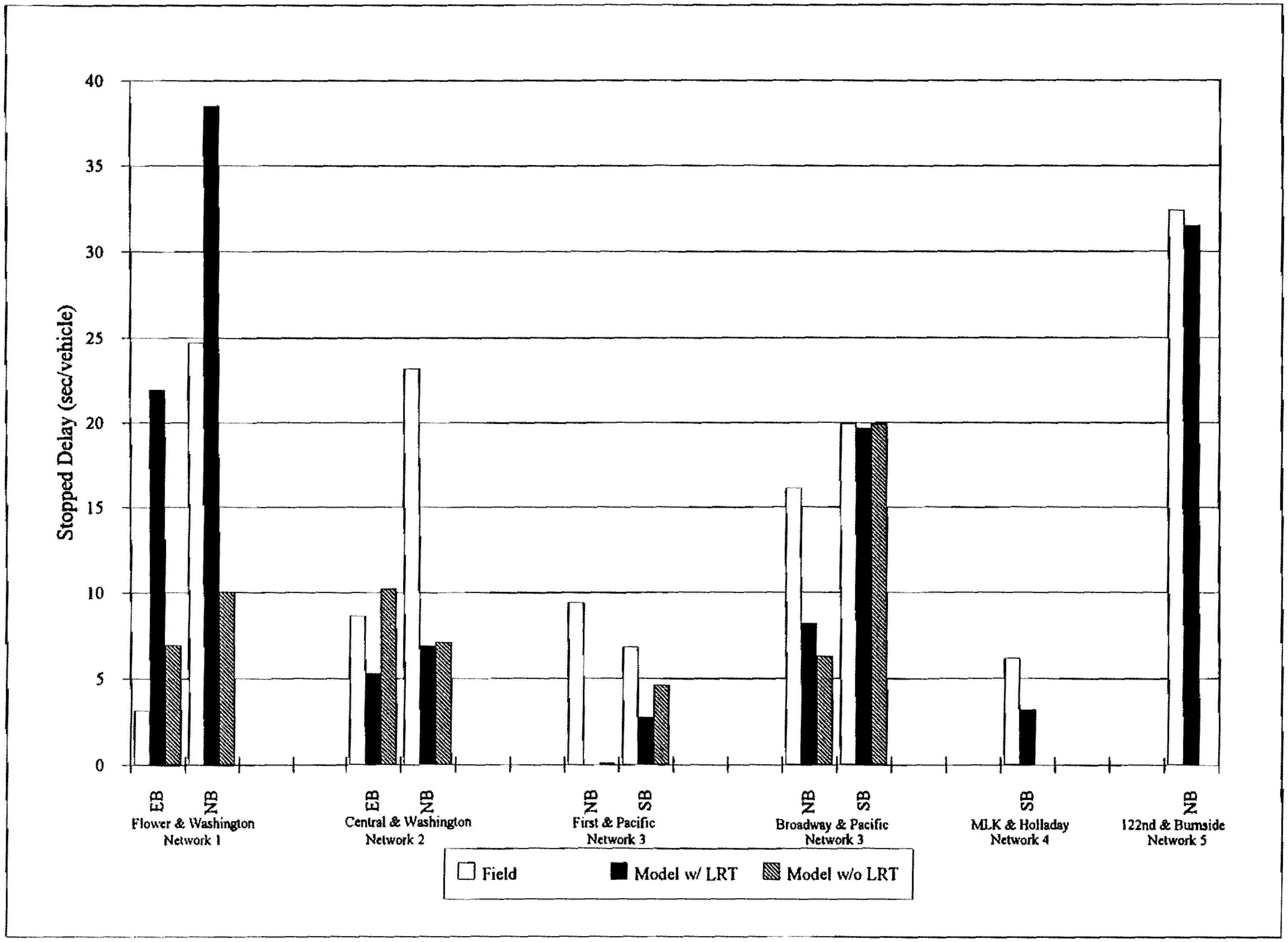

Figure 4. Uncalibrated Model Stopped Delay by Intersection

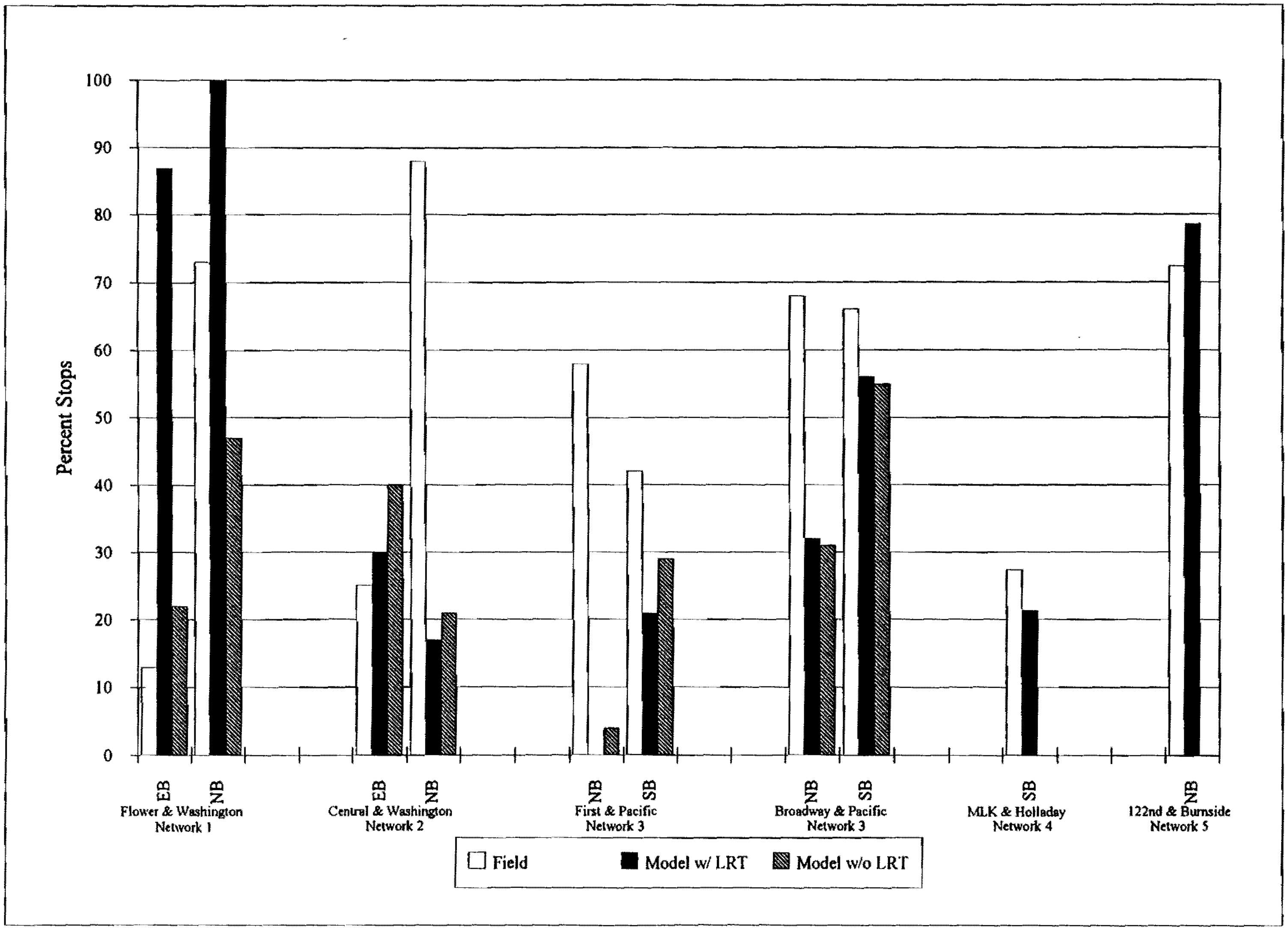

Figure 5. Uncalibrated Model Percent Stops by Intersection

The video for each network was used as a data collection source for determining the mean start-up lost time, mean queue discharge rate, and the distributions of both. For all networks, field-based average values were computed for the calibrated start-up lost time and queue discharge headway. Researchers obtained distributions for each of these parameters by collecting fifty field measurements of each, arranging the measurements in descending order, and then pairing the measurements in groups of five. The average of each group of five was computed, divided by the already calculated mean to obtain a percent, and then multiplied by 100 to produce ten new multipliers for creating the distribution of start-up lost times and queue discharge headways.

The field-measured mean start-up lost time and mean queue discharge headway were input on card type 11 in NETSIM. Researchers input the new distributions on separate optional input cards, both of type 149. The new mean and distributions were entered for both the LRT and non-LRT simulations. Table 3 shows the default and modified start-up lost time and queue discharge headway distributions.

An initial investigation of the effects of free flow speed, or desired unimpeded link speed, was conducted using the non-LRT Network 3 data set. This set was selected to remove any unpredictable LRT influences from the simulation and because of increased data availability from the network-wide vantage point of the video for this network. With all other parameters and random numbers remaining the same, the free flow speed was altered from 25 to 55 miles per hour in 10 mph increments. Table 4 shows the results of the variation.

Table 3. NETSIM Start-up Lost Time and Queue Discharge Headway Distributions

			Driver Characteristic, K									
	Network	Avg.	1	2	3	4	5	6	7	8	9	10
Lost Time	Default	2.5	218	140	125	118	102	86	78	63	47	23
Headway	Default	2.2	170	120	120	110	100	100	90	70	70	50
Lost Time	1	1.88	145	124	114	105	101	96	92	83	74	66
Headway	1	1.97	155	125	114	107	98	93	86	81	73	68
Lost Time	2	1.88	145	124	114	105	101	96	92	83	74	66
Headway	2	1.91	140	122	114	110	105	96	88	81	76	68
Lost Time	3	2.08	146	130	115	108	100	94	86	81	74	66
Headway	3	2.06	148	121	111	105	100	94	90	80	78	73
Lost Time	4	1.72	152	124	115	106	98	89	82	82	79	73
Headway	4	2.16	147	119	110	105	100	95	91	87	79	67
Lost Time	5	1.83	144	126	106	102	98	93	88	86	82	75
Headway	5	2.03	130	115	112	107	104	99	93	88	80	72

Table 4. Free Flow Speed Calibration Comparison - Network 3

Link	Field	Free Flow Speed				Effect
		25	35	45	55	
1. 1st to Broadway	19	24.6	19.9	16	16.3	decrease
2. Broadway to 3rd	12.67	18	11.9	16	12.5	decrease, increase
3. 3rd to 4th	10.67	16.7	14.6	16.5	17.8	varies
4. 4th to 5th	9.17	10.5	10.2	10.8	9.6	varies
5. 5th to 6th	37.5	42.8	45.9	46.4	45.3	decrease
6. 6th to 7th	12	13.9	15.6	13.4	14.8	varies
7. 7th to 8th	15.17	8.7	8.8	7.4	6.8	varies
TOTAL	116.18	135.2	126.9	126.5	123.1	decrease
1. 8th to 7th	42.5	39.4	22.5	20.3	19.3	decrease
2. 7th to 6th	18.33	69.5	37.3	14.9	35	varies
3. 6th to 5th	11	19.8	18.8	18.3	26.6	decrease, increase
4. 5th to 4th	10.17	10	11	8.6	9.2	none
5. 4th to 3rd	44.67	21.2	20.5	15.3	13.3	none
6. 3rd to Broadway	17.5	49.3	30.8	35.8	35.1	none
7. Broadway to 1st	15.33	12.8	9.9	13.1	11	none
TOTAL	159.5	222	150.8	126.3	149.5	decrease, increase
First & Pacific:						
NB Approach						
Delay	9.43	0	0	0	0	none
Percent Stops	58	0	0	0	0	none
SB Approach						
Delay	6.85	3.4	2.78	4.1	3.2	none
Percent Stops	42	32	21	30	21	varies
Broadway & Pacific:						
NB Approach	16.13	10.8	8.22	4.8	4.9	decrease
Delay	68	45	32	24	18	decrease
Percent Stops						
SB Approach	19.91	35	19.67	24.9	22.4	decrease, increase
Delay	66	66	56	73	70	decrease, increase
Percent Stops						

Due to the inconclusive nature of the results of the speed variation, further investigation was made into the definition of and factors impacting free flow speed on each link. The free flow speed is defined as the speed attained by traffic in the absence of any impedance due to other vehicles, pedestrians, or control devices (*8*). Though conceptually this value could be estimated by the mid-block speed within each network, the realistic speed of vehicles in each of the networks was impacted by other vehicles, acceleration and deceleration due to traffic signals, and other features of the roadway environment. Further review of the output from the speed variation test showed that as speeds on a link were adjusted to better fit the calibration data for travel time, the intersection MOEs — stopped delay and percent stops — improved with respect to the calibration data as well.

Based on the conjectural nature of the free flow speed definition, the improvement in intersection MOEs with calibration for travel time, and the fact that both start-up lost time and queue discharge headway had been fixed to field-observed values, researchers made the decision to utilize input link free flow speed as a means of adjusting the traffic stream in the model. As with start-up lost time and queue discharge headway, the free flow speed is multiplied by a coefficient to determine the free flow speed of each vehicle. Examination of the traffic stream in the model's graphic output and investigation into the dispersion of platoons in the model showed that NETSIM tends to disperse, or "spread out," the platoon more than vehicles in the modeled environment. The effects of the dispersion would vary depending on the time in each intersection's cycle when portions of the steadily dispersing platoon arrived at the successive downstream intersections, creating the variable travel time effects of speed found in Table 4. To reduce the rate of dispersion, researchers made the free flow speeds for all vehicles on each link uniform by adjusting the multiplier for the free flow speed distribution to unity.

Mean free flow speed was calibrated in the model by comparing the directional travel times produced by the model to those found in the field calibration data set. The free flow speed on all links was adjusted using the same speed value in an iterative process until the travel time results from the model compared favorably to the calibration data. The determined free flow speeds for each network corresponded to the speed at which unimpeded drivers would feel comfortable (usually the speed limit plus approximately one standard deviation of field speeds) on the roadway link.

Selection of Appropriate Test Statistics

The selection of appropriate tests for assessing the accuracy of the calibrated model was dependent on a number of considerations, including the small sample size of the validation travel time data sets, the variability of this data, and the ability of the calibrated model to accurately reproduce and report link and system-wide MOEs.

Due to time and resource limitations during the data collection, researchers made only twelve travel time runs within each network. As described earlier, the data was then divided into two groups: six runs for calibration data and six runs for validation. Both groups, when analyzed, showed high variability in their individual link travel times but relatively consistent travel times by direction in the network as a whole. When the networks were modeled, it was not possible to calibrate the link variables to consistently reproduce measured link travel times; however, it was possible to calibrate the directional travel time in the overall network. Accordingly, and mainly due to the high variability and low sample size of the validation data, it was decided to judge the accuracy of link travel times by establishing a minimum percentage and range for the modeled link travel times to agree with the validation travel times. Eighty percent of the mean link travel times within plus or minus 20 percent of the validation mean was selected as an acceptable criteria for modeling accuracy. Additionally, researchers performed a correlation analysis to assess the quality of the relationship between the validation data and the modeled individual link travel times.

Validation data total travel times by direction, on the other hand, showed consistency and a standard deviation that, for all data collection runs, was less than 25 percent of the mean (See Appendix B, Table B-5). These overall travel times were also represented accurately in the model. The Studentized t-test was selected to test whether or not the validation network travel times and the modeled network travel times were equal. All tests were conducted at the 95 percent confidence level.

Though calibration of travel times on each link also improved the percent stops and stopped delay MOEs in comparison to the calibration data, no other model adjustments could be directly made to predictably alter these MOEs for more favorable comparison to the validation data. It was decided to assess the modeled accuracy of these MOEs by correlation analysis. Also, a regression analysis was performed by pairing the modeled MOEs and validation data MOEs as X and Y coordinates, respectively. If the slope of the resulting line equalled unity, then the modeled MOEs accurately predicted the validation data MOEs. A two-tailed t-test with a confidence level of 95 percent was used to judge whether or not the slope of the regression line equalled unity.

Validation

The calibrated model input data sets for each modeled network were run ten times. This number of runs was selected so that output would be available for comparison and pairing with each element of the individual intersection stopped delay and percent stops data in the validation data set. In terms of individual link travel times, the selection of ten runs implied comparison of the six validation values for each link to ten modeled values for each link. And, since the travel times from the model output were average statistics for all vehicles traveling the link during the selected run time of 15 minutes, the actual number of modeled vehicles represented by each modeled link travel time was a nominal 200 vehicles for all networks. Not only was the model data set significantly larger than the validation data set, but the data was also inherently more stable (with lower variance).

Travel Time Analysis. Validation travel time data and the modeled travel times for the LRT and non-LRT modeling scenarios can be found in Tables B-5, B-6 and B-7 of Appendix B, respectively. A comparison of the individual link and directional network travel times, including the calculated difference and percent difference between modeled values and validation values, is presented in Appendix B, Table B-8. Table 5 summarizes the pertinent statistics from the latter table.

Table 5. Summary Statistics for Link Travel Time Comparison

		Model w/ LRT		Model w/o LRT	
	Total Number of Links	Range of Percent Difference	Links within ±20 Percent	Range of Percent Difference	Links within ±20 Percent
Network 1:					
EB	6	-53 to 47	3	-29 to 93	3
WB	6	-31 to 111	3	-20 to 129	5
Network 2:					
EB	9	-42 to 73	5	-39 to 44	4
WB	9	8 to 123	1	2 to 128	4
Network 3:					
NB	7	-57 to 27	3	-64 to 34	2
SB	7	-56 to 47	1	-79 to 104	3
Network 4:					
EB	6	-24 to 51	2		
Network 5:					
WB	4	-13 to 20	3		
EB	4	-21 to 38	2		
TOTAL	58		23		21

As indicated in Table 5, 23 of the 58 links, or 40 percent, in the "with LRT" simulation matched the validation data within plus or minus 20 percent. For the simulation "without LRT," 21 of the 44 links, or 48 percent, matched the validation data within plus or minus 20 percent. Neither simulation reached the 80 percent of link travel times within the plus or minus 20 percent criteria that was established. Experience with the model pointed to greater platoon dispersion in the model than was present in the field traffic stream as the major cause of the discrepancy between model and validation data link travel times.

Researchers chose not to conclude that individual link travel times could not be modeled accurately since such a conclusion would be based on only six runs of highly variable validation data. Rather, Figures 6 and 7 were constructed to illustrate the travel time progression, by link, in the LRT and non-LRT simulations, respectively. Review of the figures showed that where travel times were greater in the validation data, they were also greater in the model with good consistency — the peaks of the model matched closely with the peaks of the validation data.

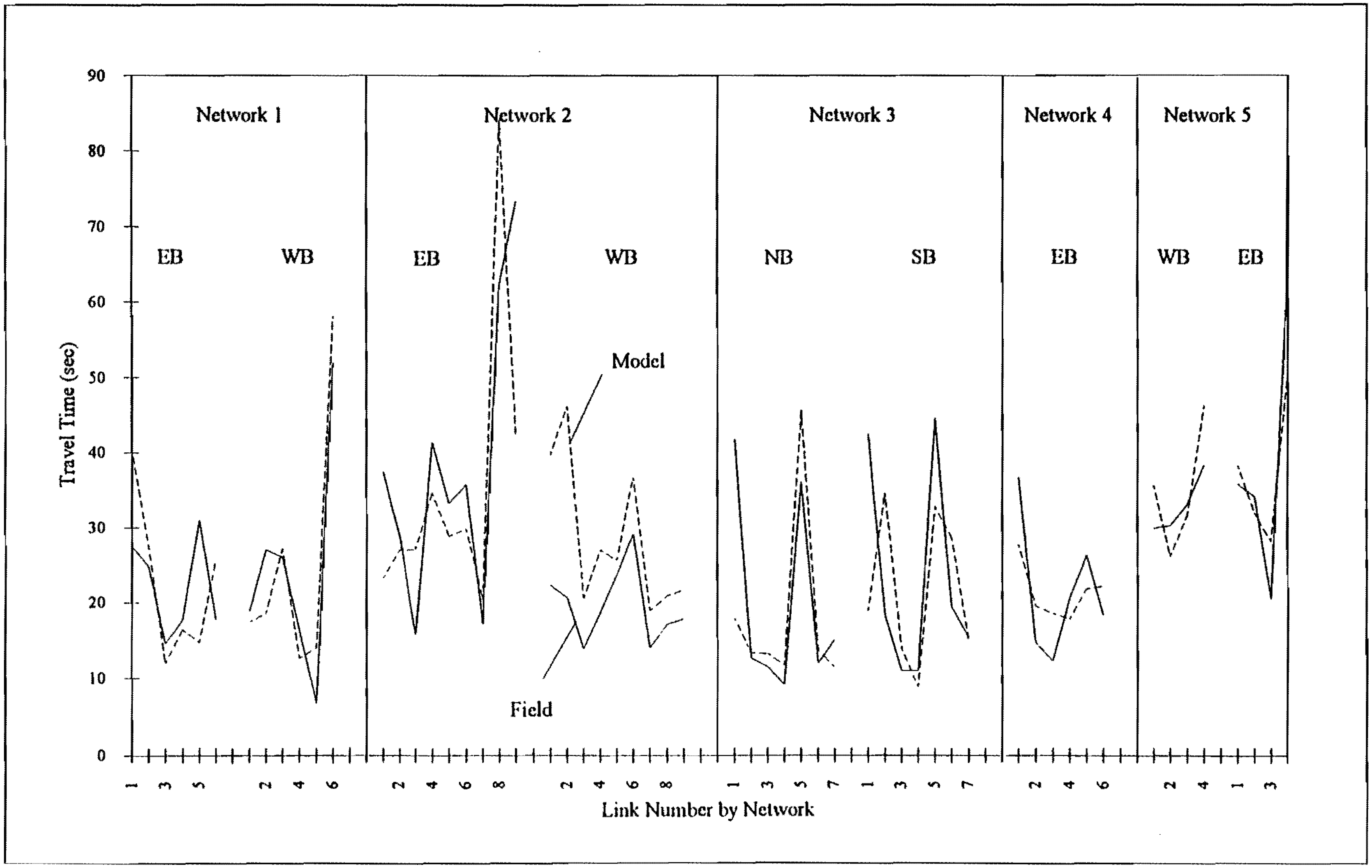

Figure 6. Calibrated Model Link Travel Time Comparison to Validation Data - with LRT

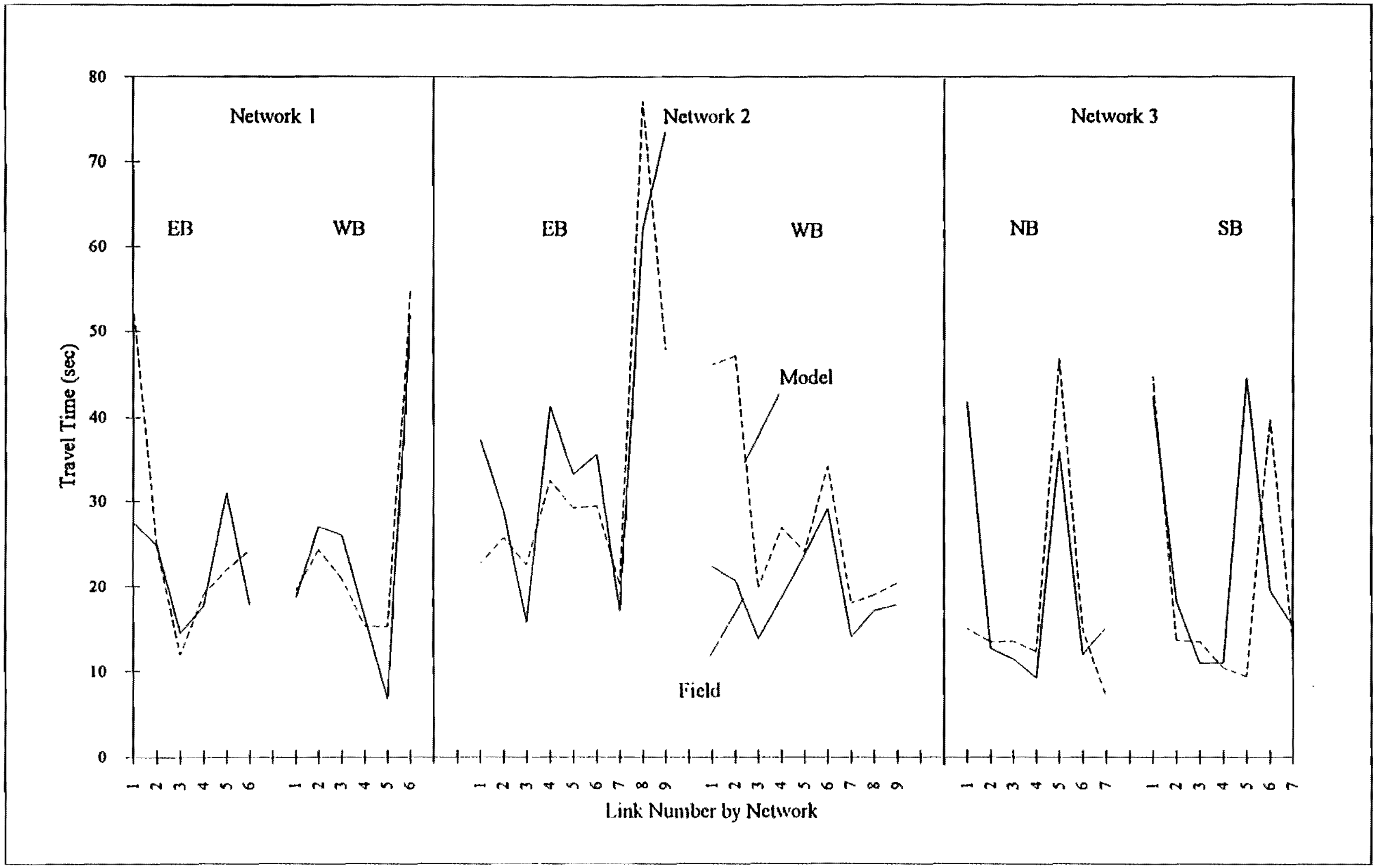

Figure 7. Calibrated Model Link Travel Time Comparison to Validation Data - without LRT

Two correlation analyses (one for the LRT simulation and one for the non-LRT simulation) were performed on all travel times, and the data were paired by link for the model and the validation field data. The resulting coefficient of correlation, r, was 0.72 for the LRT simulation and 0.66 for the non-LRT simulation. Such results indicated a moderate correlation between the link travel times in the model and these same quantities in the validation data. Thus, while the modeled link travel time results did not meet the percentile criteria of acceptance, the model link travel times were representative of the travel time behavior of the validation values, as shown in Figures 6 and 7.

Since the directional travel times for the validation data showed greater consistency, or less variance with respect to the mean, than the individual link travel times, researchers selected a Studentized t-test to determine whether or not the mean travel times by direction in each network from the model and the validation data were equal. Fifteen t-tests were performed; nine for the with-LRT simulation and six for the without-LRT simulation. Before a t-test was performed, an F-test was performed to determine whether or not the variances were from the same population (i.e., to determine whether or not the variances could be pooled). If the result of this test was positive, the standard t statistic was computed. If the result was negative, researchers performed a form of the t-test for unequal variances, known as the Smith-Satterthwaite test. Table 6 shows the test results. The F-test was performed at the 95 percent confidence level.

Table 6. Determination of Equal Variances for Validation and Model Data

	F - Model w/LRT	F- Model w/o LRT	Confidence Level		Result*	
			w/ LRT	w/o LRT	w/ LRT	w/o LRT
Network 1:						
EB	7.32	16.04	0.995	>0.999	-	-
WB	221.06	187.33	>0.999	>0.999	-	-
Network 2:						
EB	141.68	739.84	>0.999	>0.999	-	-
WB	2.94	5.73	0.876	0.966	+	-
Network 3:						
NB	34.74	238.19	>0.999	>0.999	-	-
SB	5.49	44.18	0.986	>0.999	-	-
Network 4:						
EB	5.04		0.982		-	
Network 5:						
WB	5.38		0.985		-	
EB	8.83		0.997		-	

* + indicates equal variances, - indicates non-equal variances

Knowing the result of the equal variances test, researchers selected the correct t-test for determining whether or not the validation and simulation data mean directional travel times were equal. The null hypothesis of all tests was that the two means were equal, and the alternative hypothesis was that the two means were not equal. Table 7 displays the results of this analysis. The tests were performed at the 95 percent confidence level. For both the LRT and non-LRT simulations, all directional travel time hypothesis tests failed to reject the null hypothesis, except for the WB direction of Network 2. Researchers believed this one exception to be caused by strong progression effects that could be calibrated on a link-by-link basis with model calibration adjustments, but not on a system-wide basis as well. Essentially, the platoon dispersion and downstream signal arrival times did not coincide appropriately, on a network progression basis, with the green window provided on the arterial. The strength of any conclusion based on this analysis is somewhat limited by the small sample size of the validation data. Thus, the overall analysis of directional travel times indicated that, with one exception, no evidence showed that the modeled directional travel times were different from validation data directional travel times at the 95 percent confidence level.

LRT Travel Time Analysis. Priority for the LRT made the travel times for LRVs in Networks 4 and 5 vary from the travel times for traffic. NETSIM was calibrated for transit in a similar fashion as the calibration for traffic. To validate field travel times for transit, measurements were made of the LRT travel time through the actuated networks and compared to the same values from the model. Figure 8 shows the link travel time comparison for Networks 4 and 5, Table 8 highlights the link travel time comparison, and Table 9 displays the results of the directional travel time comparison.

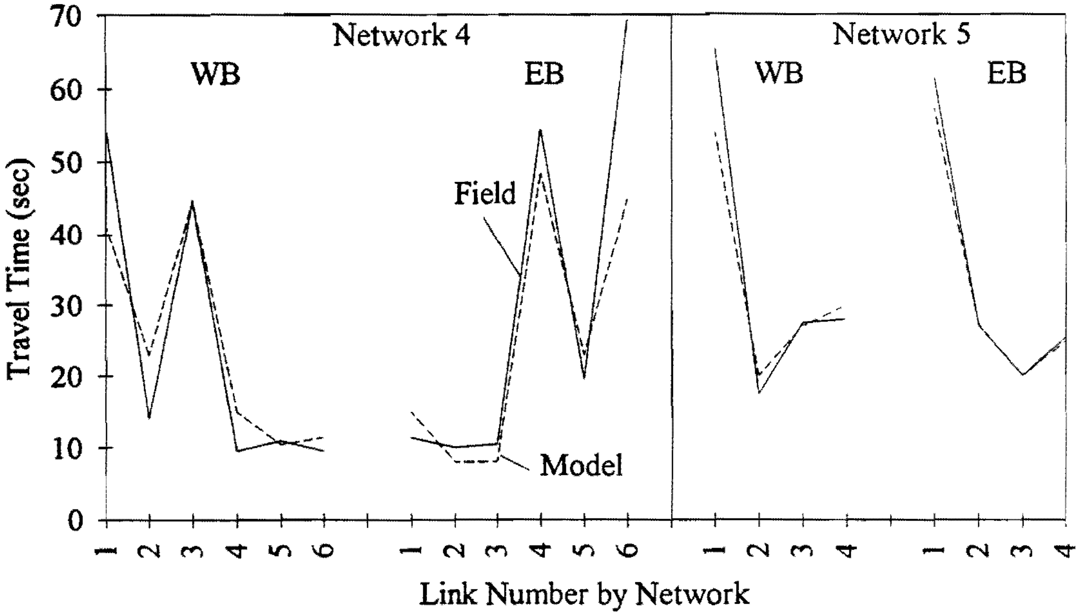

Figure 8. Calibrated Model LRT Travel Time Comparison to Validation Data

Table 7. Network Directional Travel Time Comparison Using the t-Test

	Validation Data		Model Data		Test*	ν	t'	Confidence Level	Result
	Mean	s^2	Mean	s^2					
Model w/LRT									
Network 1:									
EB	133.2	269.8	136.4	36.84	≠	5.831	0.459	0.334	not reject
WB	146.7	857.9	147.9	3.881	≠	5.027	0.100	0.076	not reject
Network 2:									
EB	344.8	5394	317.1	38.07	≠	5.042	0.923	0.601	not reject
WB	177.3	13.1	257.2	38.32	=	14	5.28	>0.999	reject
Network 3:									
NB	138.3	713.1	127.1	20.52	≠	5.173	1.018	0.645	not reject
SB	162.3	1048	152.43	191.0	≠	6.113	0.709	0.495	not reject
Network 4:									
EB	128.86	177.2	127.9	35.16	≠	6.212	0.167	0.127	not reject
Network 5:									
WB	131.86	177.2	139.9	32.95	≠	6.135	1.403	0.790	not reject
EB	154.43	614.0	149.2	69.56	≠	5.688	0.500	0.362	not reject
Model w/o LRT									
Network 1:									
EB	133.2	269.8	154.7	16.81	≠	5.377	3.148	0.975	not reject
WB	146.7	857.9	150.0	4.580	≠	5.032	0.276	0.206	not reject
Network 2:									
EB	344.8	5394	307.0	7.29	≠	5.008	1.260	0.737	not reject
WB	177.3	13.07	255.6	74.65	≠	13.02	25.21	>0.999	reject
Network 3:									
NB	138.3	713.1	123.1	2.993	≠	5.025	1.393	0.777	not reject
SB	162.3	1048	144.9	23.72	≠	5.136	1.308	0.752	not reject

* ≠ represents t-test with unequal variances, = represents t-test with equal variances

Table 8. Calibrated Model LRT Travel Time Comparison to Validation Data

	Total Number of Links	Range of Percent Difference	Links Within ± 20 Percent
Network 4:			
WB	6	-24 to 64	2
EB	6	-35 to 30	3
Network 5:			
WB	4	-17 to 14	4
EB	4	-6 to 1	4
TOTAL	20		13

Table 9. LRT Directional Travel Time Comparison Using the t-Test

	Validation Data		Model Data		t	Confidence Level	Result
	Mean	s^2	Mean	s^2			
Network 4:							
WB	143.5	4.950	145.95	3.369	0.8968	0.6091	not reject
EB	175.5	19.09	147.4	5.516	5.2774	0.9996	reject
Network 5:							
WB	138.5	19.09	131.0	8.434	1.0194	0.6679	not reject
EB	134.0	11.31	129.5	10.12	0.5672	0.4169	not reject

As demonstrated in Tables 8 and 9, the model accurately reproduced a majority of the individual link travel times within the plus or minus 20 percent criteria. Thirteen of the 20 links, or 65 percent, were within acceptable limits. And, as with the directional travel times for traffic, the directional travel times for LRT in the model were not rejected at the 95 percent confidence level in mean comparison testing with the validation data. One exception was the EB direction in Network 4, which in the field exhibited a greater travel time than in the model. The probable cause of the discrepancy was unusually long dwell times in this direction during the field data collection that, when translated into a mean and standard deviation for the model, could produce unrealistically low dwell times (researchers entered the known mean and standard deviation in the model, but took the field data during a time period of uncharacteristically high dwell).

Individual Intersection MOE Analysis. Individual intersection stopped delay and percent stops output from the calibrated model compared much more favorably with its comparison field data than the original, uncalibrated model. The MOE information, presented in Table 10 and graphically in Figures 9 and 10, was also subjected to numerical analysis in an effort to quantify its degree of accuracy. The ten individual validation measurements for each approach and each of the two MOEs were paired with their complementary data from the model. The paired data points were plotted, and a correlation coefficient was computed for both MOEs for the with and without LRT scenarios. Figures 11 through 14 show these scatterplots. A one-to-one sloped line was added to each figure to indicate that the ideal model output would produce a unity slope when plotted in such a fashion. The correlation coefficient, r, was also included on the figures.

A regression analysis was also performed on the relationship between the plotted model output versus validation field data. For each of the four figures, a least squares best fit line was computed. The slope coefficient, $\square_1$, was calculated along with the standard error of $\square_1$. A t-statistic was computed to test whether or not the slope of each regression line equalled one at the 95 percent confidence level. If the slope equaled one, it would indicate that the model was a good predictor of the stopped delay or percent stops MOE being analyzed. Table 11 shows the results of this analysis. All four model versus validation field data regression lines were rejected; however, Figures 11 through 14 do indicate the moderately strong positive correlation between model and validation data stopped delay and the moderate positive correlation between model and validation data percent stops. Thus, while the model did not produce individual intersection MOEs that could be accepted at the 95 percent level, it was shown that moderately strong relationships existed between the individual intersection MOEs and their counterparts from the validation data.

Table 10. Calibrated Model Intersection MOEs

	Mean Stopped Delay			Mean Percent Stops		
	Validation Data	Model w/ LRT	Model w/o LRT	Validation Data	Model w/ LRT	Model w/o LRT
Flower & Washington						
EB Approach	2.27	4.47	5.8	13	12	17
NB Approach	29.99	16.74	18.93	83	77	93
Central & Washington						
EB Approach	6.13	5.22	5.62	24	38	40
NB Approach	21.28	32.62	19.36	80	68	40
First & Pacific						
NB Approach	10	6.37	6.2	56	78	76
SB Approach	7.36	5.32	5.28	45	29	29
Broadway & Pacific						
NB Approach	16.19	5.03	5.18	71	20	18
SB Approach	20.86	18.28	30.62	68	51	76
MLK & Holladay						
SB Approach	6.01	5.61		28	33.4	
122nd & Burnside						
NB Approach	31.41	25.53		73	74	

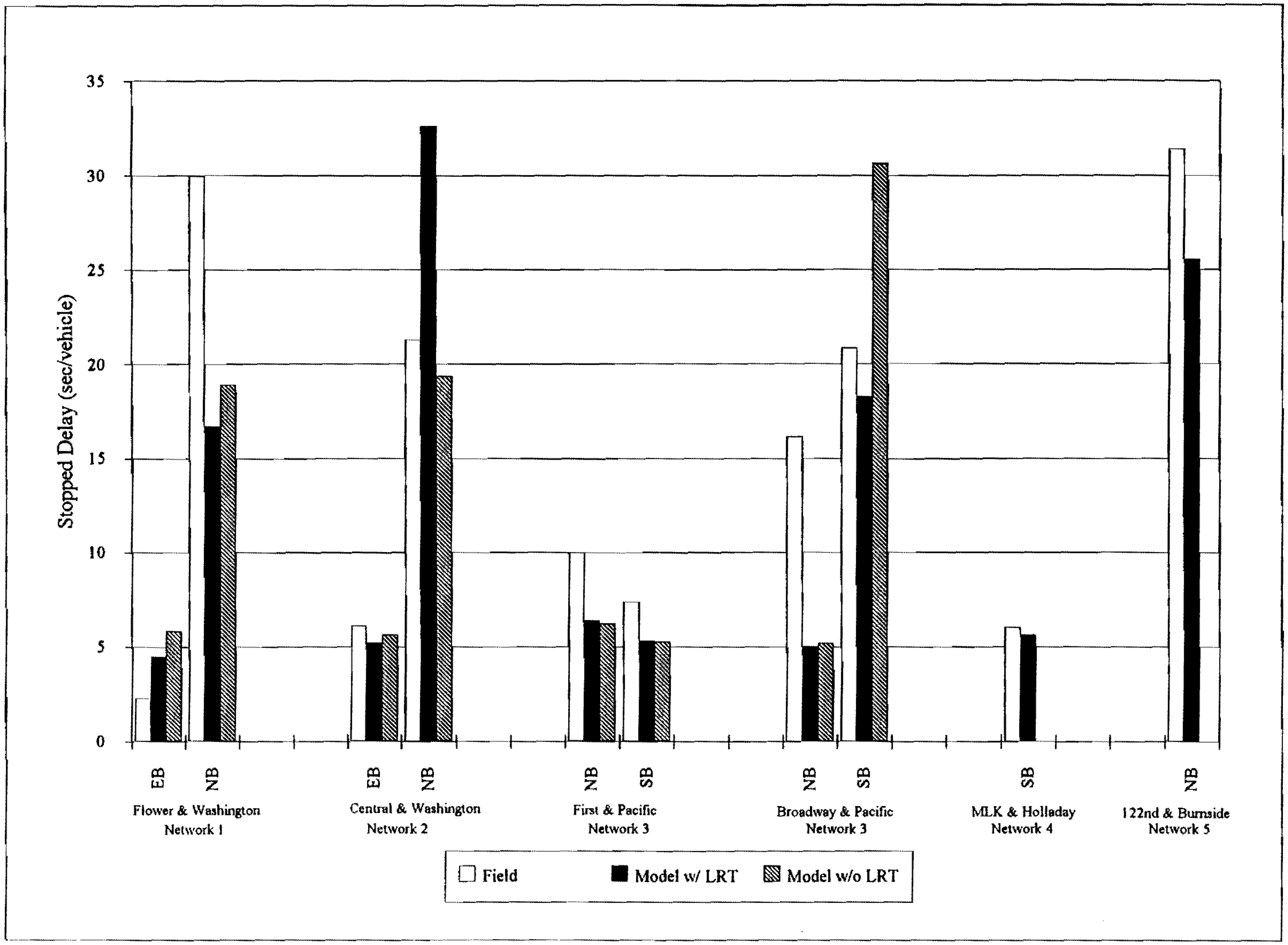

Figure 9. Calibrated Model Stopped Delay by Intersection

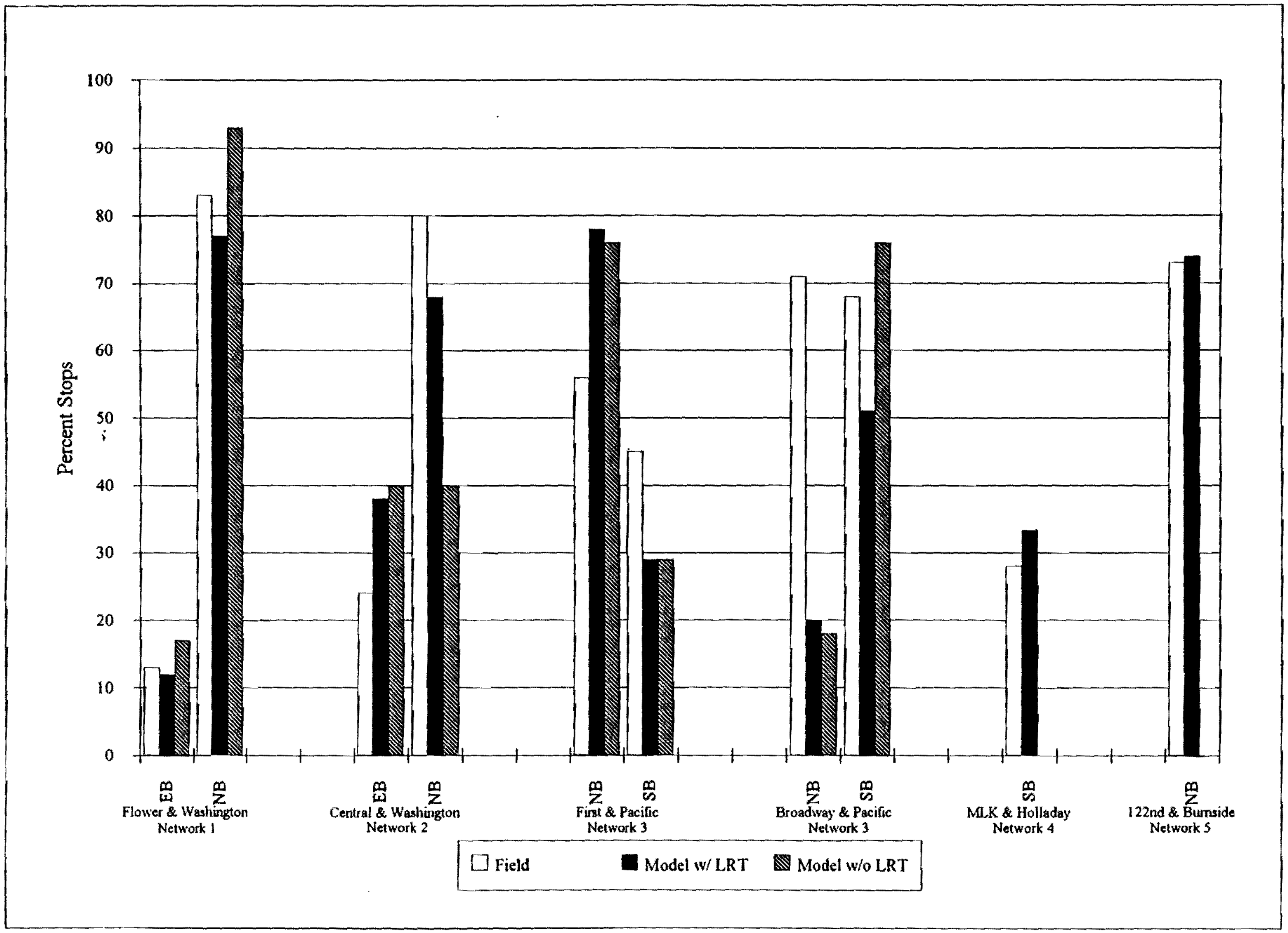

Figure 10. Calibrated Model Percent Stops by Intersection

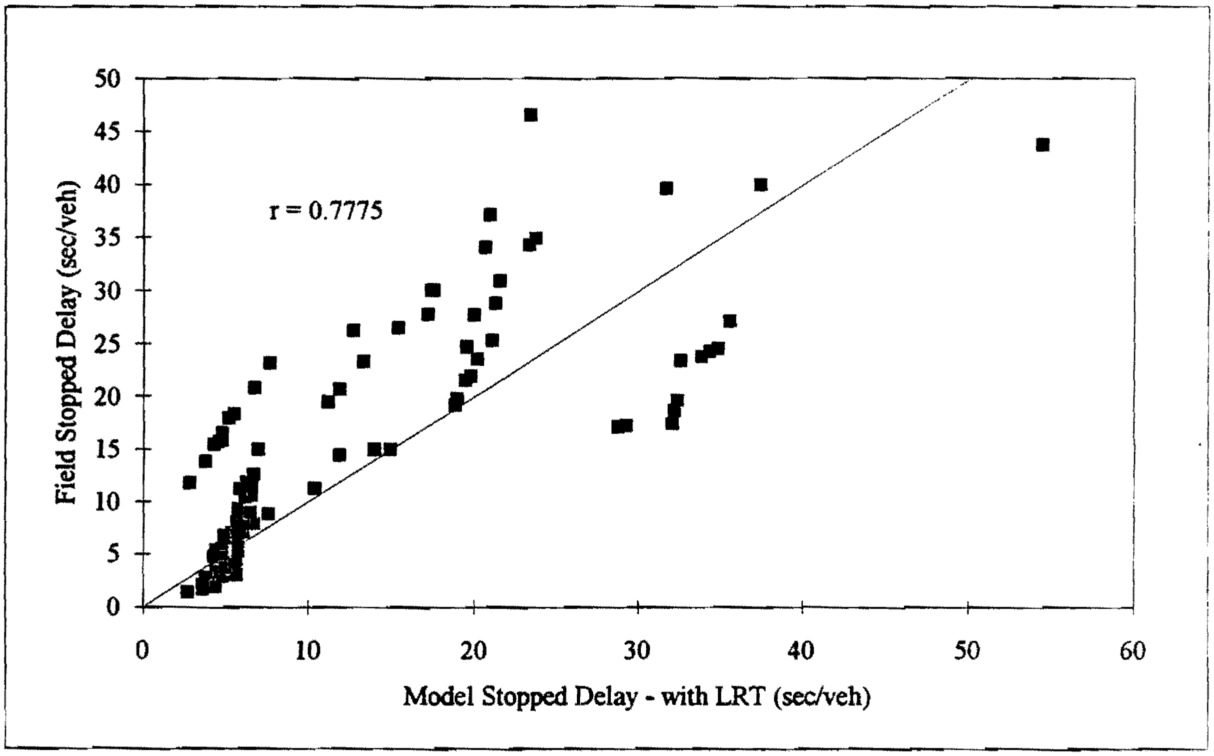

Figure 11. Model Versus Validation Data Stopped Delay - with LRT

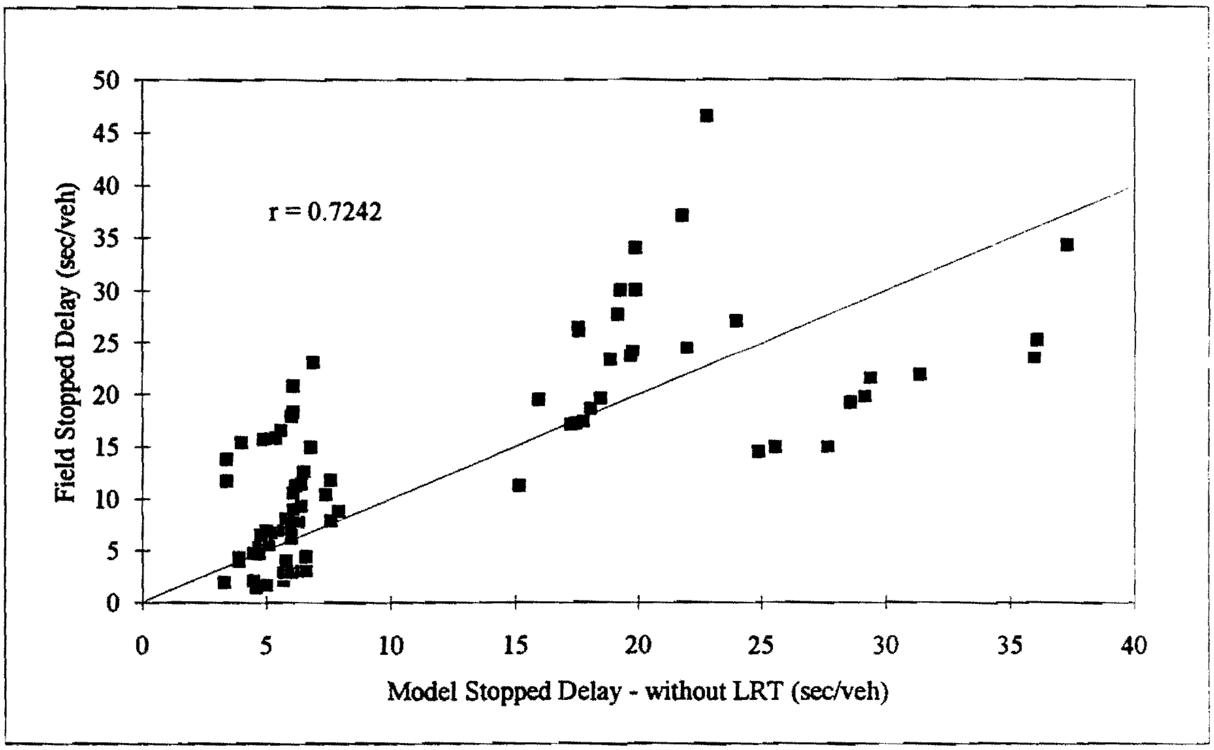

Figure 12. Model Versus Validation Data Stopped Delay - without LRT

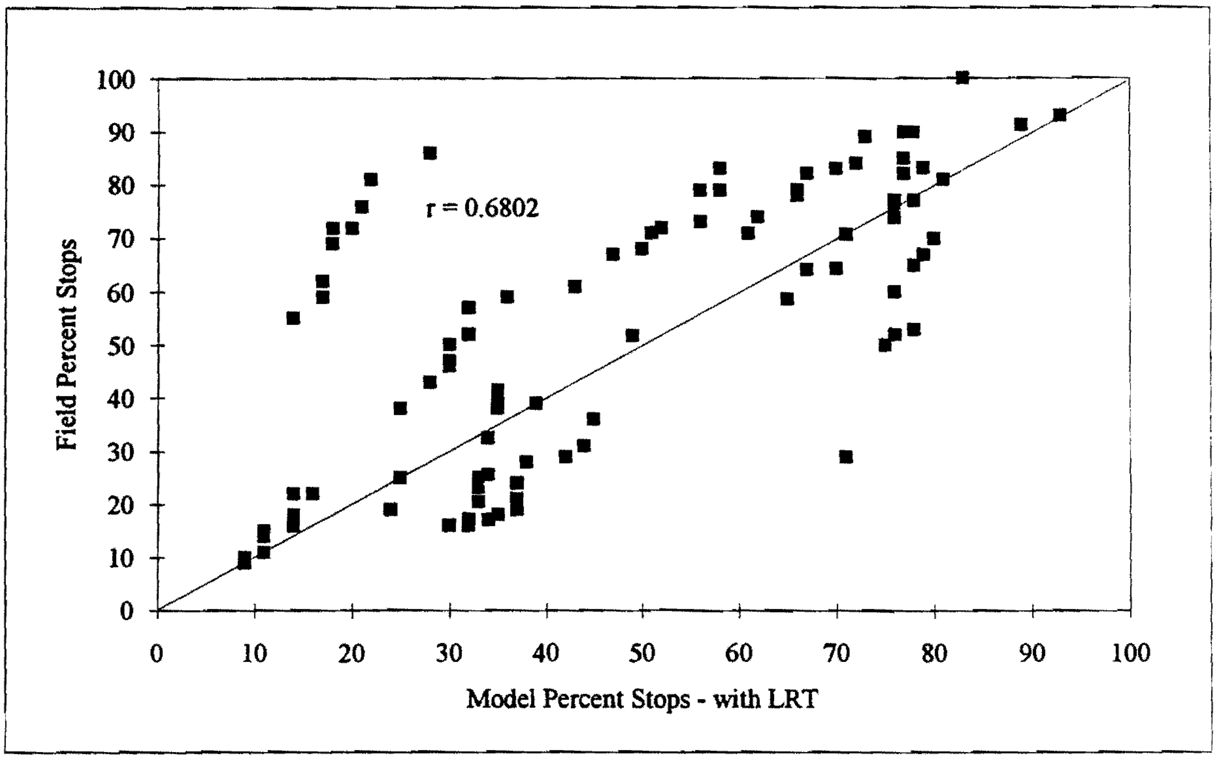

Figure 13. Model Versus Validation Data Percent Stops - with LRT

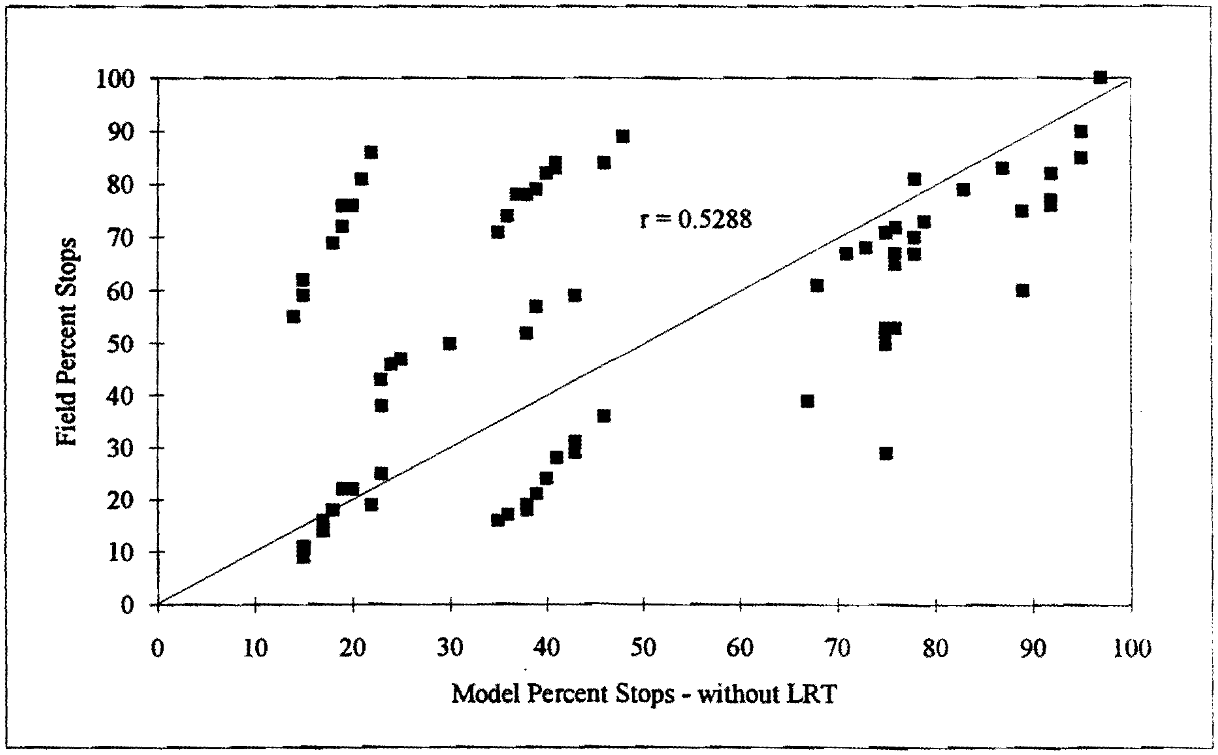

Figure 14. Model Versus Validation Data Percent Stops - without LRT

Table 11. Regression Analysis of Model Output Versus Validation Data

		Slope, β_1	Standard Error, S_b	t	Confidence Level
Stopped Delay	w/LRT	0.7945	0.06491	3.17	0.998
	w/o LRT	0.7588	0.08182	2.95	0.996
Percent Stops	w/LRT	0.7234	0.07875	3.51	>0.999
	w/o LRT	0.4912	0.08929	5.70	>0.999

Summary of Model Performance. The features of the traffic environment must be specified in order for the user to properly utilize the NETSIM model. Among these features are the topology of the roadway system, roadway geometrics, channelization, motorist behavior, traffic control devices, traffic volumes, turning movements, transportation modes, and specifications for transit systems (*8*).

For each of the pretimed networks, the required input data was readily processed for entry into the model. Once the necessary information was assembled, the physical features of the roadway environment, the traffic volumes and turning percentages, and the traffic signal data were easily input into NETSIM in the model's card type format. The few exceptions to this rule included the fact that any links to the left of left-turn bays cannot be moving links — making it impossible in this scenario to directly model median running LRT — and the fact that links in the model have a minimum length of fifty feet. Modeling the median running (or side of street running) LRT given the constraint of the minimum link length requirement produced a network that not only was more complex to model, but also one which required cross street vehicles and arterial street left-turning vehicles to travel distances not present in the modeled environment. To assess the impact of this change in the modeled system, two conventions were used to perform the simulation using NETSIM - one with LRT and one without LRT. The system including LRT required additional inputs not present in the non-LRT system; among them, LRT vehicle acceleration, occupancy, and length characteristics, links and routes for LRT, transit station location information, and mean dwell times and distributions for dwell times; however, since LRT was included in this convention, MOEs for transit were included in the summary output provided by the model. Such transit information as bus trips, person minutes spent on transit, and bus travel times were available in the output.

The coordinated actuated (Network 4) and fully actuated (Network 5) networks used the same LRT node format as the pretimed networks. Since the LRT and traffic nodes were separated, the approach of LRVs did not directly impact signal control at the traffic nodes. While vehicles conflicting with the LRT still received green time in the presence of an LRV, the vehicles were not able to advance across the "tracks" at the LRT node. This coding allowed reasonably accurate modeling of field traffic, LRV, and controller behavior (with the exception of dwell in the coordinated phases) found in the field in Network 4. Coordinated phase dwell was used to "resync" controllers in the field that were unsynchronized by the priority of the approaching LRV, giving extra green to the coordinated cross street phases. Since dwell could not be replicated in the model, some green time found in the field for the cross streets was not reproduced in the model.

Calibration of the model consisted of using field observed means and distributions of start-up lost time and queue discharge headway rather than NETSIM default values for these parameters and repeated link "free flow" speed adjustments to coordinate downstream arrivals in the model with patterns observed in the field. Researchers monitored improvement caused by changes to the model by comparing the modeled output to a calibration field data set. Changes were easily noted since components of the summary output provided by NETSIM were directly comparable to observed calibration field data MOEs. The primary cause of discrepancies between the model and the calibration field data appeared to involve the queue discharge and platoon dispersion behavior in the model. NETSIM tended to "spread out" the platoon earlier and to a greater extent than observed behavior in the field. Some tools to control the dispersion of the traffic stream in the model, including the opportunity to change the free flow speed distribution, were available.

Following calibration, the model was run to produce a simulation data set for comparison to the second part of the field data set, the validation field data. Three categories of comparisons were made: individual link travel times, network directional travel times, and individual intersection MOEs. Analysis showed that about 40 percent of modeled links displayed travel times within plus or minus 20 percent of the validation field data. Correlation analysis showed a moderately strong correlation between validation field and model data. Network directional travel time analysis showed that most system-wide travel times were easily accepted at the 95 percent confidence level. Modeled travel times for LRT were acceptable for a majority of links and most directions. Individual intersection MOEs for the calibrated model were much improved over the uncalibrated model. Correlation analysis indicated a moderately strong correlation between validation field data and model stopped delay, as well as a moderate correlation between validation field data and model percent stops. The with-LRT convention seemed to produce results that were aligned more closely with the validation data than the without-LRT convention.

The graphics component (GTRAF) included in the TRAF software proved to be an invaluable asset throughout the investigation. Both the static and animated graphics supplied by the model assisted in describing how the input data was accepted by the model, in finding coding errors in the input data sets, and in clarifying the queue discharge behavior of the model.

TRANSSIM II™

Calibration

Following the entry of the input geometric, traffic volume, and signal timing data, few adjustments were required in order to run the model. Several of the inputs, including entries for LRV acceleration and deceleration, start-up lost time, average speeds for LRVs and automobiles, and the standard deviation of LRV entry into the modeled system, enabled adjustment of the model's environment parameters to field conditions. The one model parameter that did require adjustment through iterative runs of the program was the location of the detector that notified the downstream intersection of an approaching LRV in the priority networks (Networks 4 and 5). This distance was nominally the braking distance of the LRV plus any remaining distance required to produce the time equivalent of the minimum phase duration on the cross street.

Modeling LRT in TransSim II™. A number of information elements were required to accurately model LRT in TransSim II™. Because the program is microscopic with respect to LRV behavior (i.e., the LRVs are tracked through the system and directly detected to receive priority calls), any physical or control elements that impacted the LRV had to be identified and entered. This information included:

1. The location of the intersection along the LRT route;
2. The location of notification, commitment, and checkout detectors;
3. The automobile phase associated with train movement through the intersection;
4. Time-to-green when a call is placed at a notification detector;
5. Minimum phase durations for phases that could be shortened during priority calls;
6. The location and service times of stations along the route;
7. Scheduled headways for LRVs in the system;
8. The speed through the system, which could be changed along the route if variable speeds were found in the field;
9. LRV acceleration and deceleration rates; and,
10. The type of priority and control found in the field environment, which could be varied from intersection to intersection.

In the pretimed, non-priority networks, some of this input information was not applicable to the field scenario being simulated. For all networks, the above inputs for the LRV and the traffic, and phasing input information was easily entered and required no adjustment (with the exception of detector placements mentioned above) before the final simulation runs of the program were made. Thus, LRT descriptive information was easily entered into the model and the calibration step for TransSim II™ was expeditiously completed.

Selection of Appropriate Test Statistics

Because the outputs from TransSim II™ and NETSIM were compared to the same field data, it was necessary to use the same MOEs as the basis of the comparison. The standard MOE for link behavior was the automobile link travel time and the LRT link travel time; the MOE for system behavior was the directional travel time for both automobiles and LRVs; and the MOEs for individual intersection performance were the stopped delay and percent stops at a minimum of one intersection in each network.

It was necessary to convert MOEs in the output of TransSim II™ to MOEs that could be compared directly to the field data. Total delay at each approach to modeled intersections was a primary output of TransSim II™. Researchers converted this delay quantity to a travel time by adding the computed delay to the time it took for a vehicle travelling along the approach link to reach the intersection from the upstream intersection (distance divided by free flow speed). The calculated link travel times were easily accumulated to produce directional travel times. For individual intersection approaches, the total delay output by the model was divided by the conversion from total delay to stopped delay, 1.3, to produce the model estimate of intersection stopped delay. As TransSim II^{TM} did not output percent stops information, researchers did not use this component of the field data in this analysis.

In the interest of preserving a uniform base of comparison, and for similar reasons as those discussed for the NETSIM data, researchers used the same statistics to compare TransSim II^{TM} output to the field data as they used to compare NETSIM output to the field data. After the conversion of the output to a form comparable to the field data, the statistical analysis began. Link travel times for both automobiles and LRVs were compared and the criteria for acceptable individual link output was within plus or minus 20 percent of the field data. Model automobile and LRV directional travel times were compared to their field counterparts using t-tests to determine whether or not the model and field means were equal at the 95 percent confidence interval. Finally, individual intersection stopped delay from the model was analyzed using a correlation coefficient with the field data and a plot was made of the model and field stopped delays. A one-to-one slope of the resulting line would indicate that the model was a perfect predictor of field stopped delay. Researchers assessed the quality of the model representation of field stopped delay using a regression line for the plotted data and statistically comparing the line to the unity slope line.

Validation

TransSim II^{TM} was run ten times for each of the five networks using different random number seeds. This procedure was facilitated by a multiple run output selection provided in the model. As found with NETSIM earlier, the model output tended to be more stable (of lower variance) than the field data for travel times and comparable to the field data for individual intersection MOEs.

Travel Time Analysis. Appendix B, Table B-5 shows the validation data used in the travel time analysis. The results of the TransSim II^{TM} runs are found in Appendix C, Table C-1. The comparison table, including the algebraic difference and percent difference for link travel times, can be found in Appendix C, Table C-2. Summary statistics of the analysis are found in Table 12.

As shown in Table 12, 22 of the 58 links, or 38 percent, matched the validation data within plus or minus 20 percent. Though the model data did not reach the criteria of 80 percent of the link travel times within plus or minus 20 percent, the model appeared to over- or under-predict randomly. The macroscopic nature of the traffic model in TransSim II^{TM} did not inhibit its ability to predict link travel times in the modeled networks. Macroscopic modeling is limited, however, in near- and over-saturated conditions as queues can cause interferences with upstream intersections and vehicles can be delayed for more than one cycle at an intersection. Figure 15 was constructed to illustrate the mean link travel time similarities between the model and field data.

Table 12. Summary Statistics for Link Travel Time Comparison

		Model w/ LRT	
	Total Number of Links	Range of Percent Difference	Links within ±20 Percent
Network 1:			
EB	6	-45 to 34	3
WB	6	-45 to 182	2
Network 2:			
EB	9	-41 to 20	3
WB	9	-5 to 71	5
Network 3:			
NB	7	-55 to 47	1
SB	7	-74 to 49	0
Network 4:			
EB	6	-29 to 43	3
Network 5:			
WB	4	-9 to 15	4
EB	4	-34 to 65	1
TOTAL	58		22

The directional travel times from the model were compared to the field data using the Studentized t-test. Due to the small sample sizes of directional travel time means and the degree of variance of the field data, an F-test was performed on the variances of the field and modeled data sets to determine whether or not the variances were equal. If researchers judged the variances to be equal, the standard t-test was used. If not equal, a form of the t-test known as the Smith-Satterthwaite test was used. The results of the F-test for equal variances is found in Table 13 and Table 14 shows the results of the directional travel time comparison.

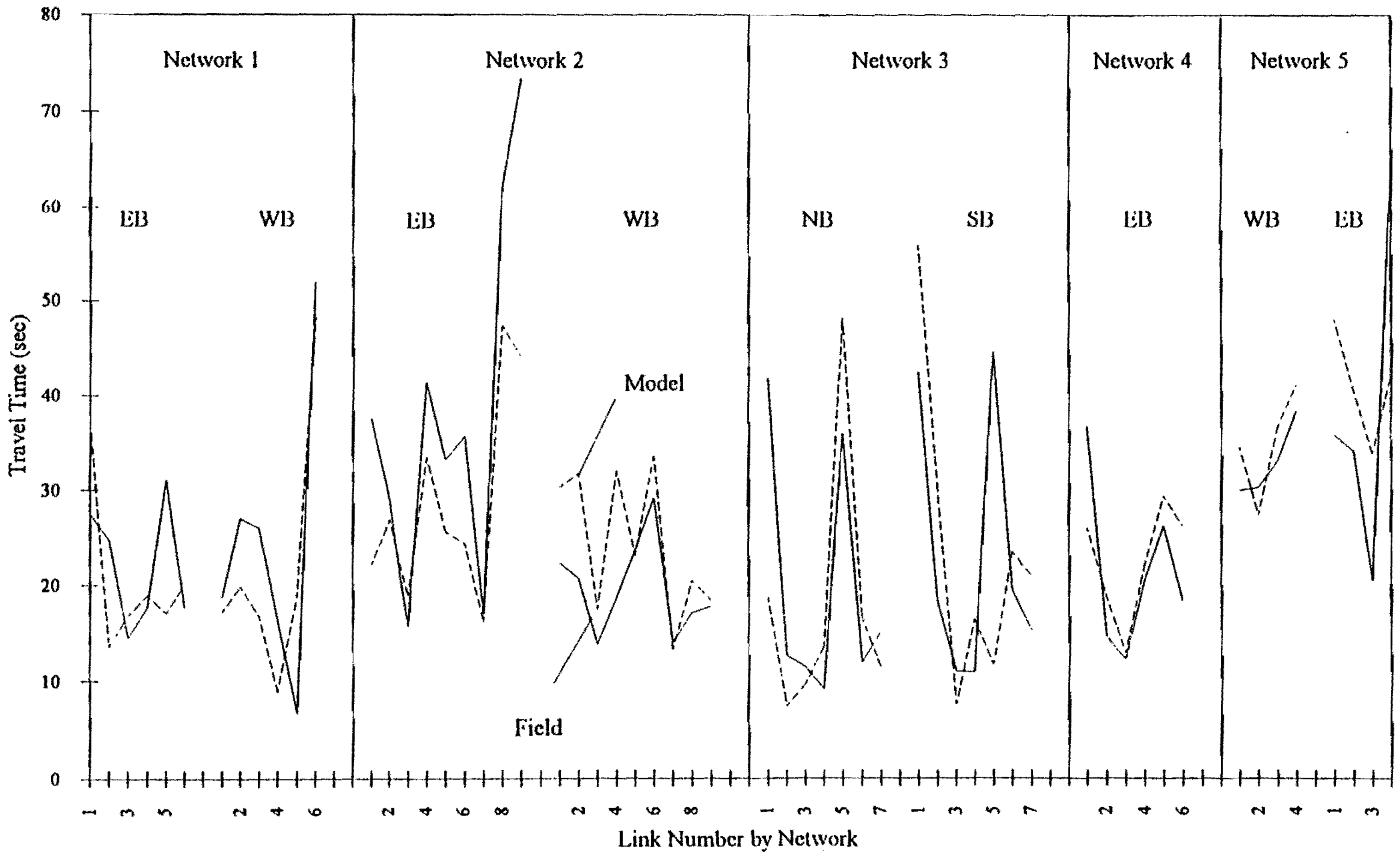

Figure 15. TransSim II™ Link Travel Time Comparison to Validation Data

Table 13. Determination of Equal Variances for Validation and Model Data

	F - Model w/LRT	Confidence Level	Result*
		w/ LRT	w/ LRT
Network 1:			
EB	48.82	>0.999	-
WB	185.59	>0.999	-
Network 2:			
EB	1307.4	>0.999	-
WB	25.14	>0.999	-
Network 3:			
NB	2.66	0.9041	+
SB	2.41	0.8810	+
Network 4:			
EB	1.06	0.4978	+
Network 5:			
WB	33.49	>0.999	-
EB	36.89	>0.999	-

* + indicates equal variances, - indicates non-equal variances

Table 13 shows that the variances of directional travel time in Networks 3 and 4 were close enough to their field counterparts to use the standard t-test. For the remaining networks, the Smith-Satterthwaite form of the t-test was used.

Table 14 shows the results of the t-testing between the field and modeled directional travel times. All of the t-tests were performed at the 95 percent confidence interval and used the same null and alternative hypotheses; the null hypothesis was that the field and modeled means were equal, and the alternative hypothesis indicated the contrary. With one exception, all t-tests failed to reject the null hypothesis. Essentially, the modeled and field directional travel times were equivalent at the 95 percent confidence level. The one exception was the westbound direction of Network 2. Familiarity with the model and field conditions pointed to strong progression effects in the field that could not be accounted for in the model as the cause of this discrepancy. Also, the unusually low variance of the field travel time for this direction indicated that the t-test would have a narrow confidence interval, even at the 95 percent confidence level.

Table 14. Network Directional Travel Time Comparison Using the t-Test

	Validation Data		Model Data		Test*	ν	t'	Confidence Level	Result
	Mean	s^2	Mean	s^2					
Model w/LRT									
Network 1:									
EB	133.2	269.8	123.21	5.52	≠	5.123	1.4807	0.8012	not reject
WB	146.7	857.9	129.76	4.62	≠	5.032	1.4144	0.7836	not reject
Network 2:									
EB	344.8	5394	259.00	4.12	≠	5.005	2.8609	0.9646	not reject
WB	177.3	13.1	220.27	0.52	≠	5.239	28.7405	>0.999	reject
Network 3:									
NB	138.3	713.1	125.48	267.6	=	14	0.0582	0.0456	not reject
SB	162.3	1048	166.17	434.7	=	14	0.0115	0.0090	not reject
Network 4:									
EB	128.86	177.2	135.61	187.7	=	14	0.0722	0.0565	not reject
Network 5:									
WB	131.86	177.2	139.82	5.29	≠	5.179	1.4518	0.7937	not reject
EB	154.43	614.0	164.59	16.65	≠	5.163	0.9963	0.6351	not reject

* ≠ represents t-test with unequal variances, = represents t-test with equal variances

LRT Travel Time Analysis. LRT travel time in Networks 4 and 5 consisted of LRV travel time at ideal speed plus time delayed at signals in the network, LRV acceleration and deceleration at signals and stations, and the dwell times at stations to service passengers. This information was taken from the TransSim II™ output by adding the LRT delay at each intersection to the ideal travel time along transit links and, for links with stations, also adding the time for passenger service and time lost during deceleration and acceleration. Table 15 highlights the link travel time comparison, Table 16 shows the results of the directional travel time comparison, and Figure 16 presents the travel times by link in graphical format.

Table 15. Calibrated Model LRT Travel Time Comparison to Validation Data

	Total Number of Links	Range of Percent Difference	Links Within ± 20 Percent
Network 4:			
WB	6	-39 to 65	2
EB	6	-36 to 14	3
Network 5:			
WB	4	-28 to 63	1
EB	4	-9 to 38	2
TOTAL	20		8

Table 16. LRT Directional Travel Time Comparison Using the t-Test

	Validation Data		Model Data		t	Confidence Level	Result
	Mean	s2	Mean	s2			
Network 4:							
WB	143.5	4.950	138.75	12.10	0.5387	0.3981	not reject
EB	175.5	19.09	131.89	20.73	2.7370	0.9791	reject
Network 5:							
WB	138.5	19.09	144.44	9.32	0.7441	0.5261	not reject
EB	134.0	11.31	146.71	10.84	1.5071	0.8373	not reject

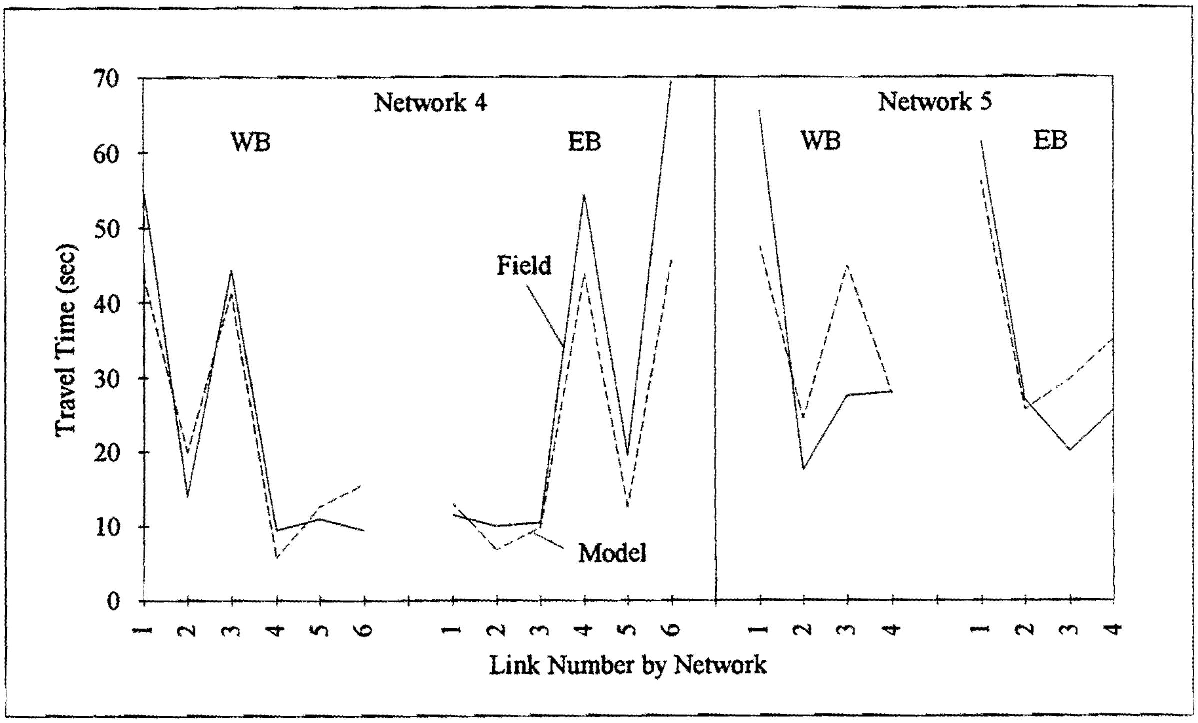

Figure 16. TransSim II™ LRT Travel Time Comparison to Validation Data

As shown in Table 15, eight of the 20 modeled LRT links, or 40 percent, matched their field counterparts within plus or minus 20 percent. In the directional travel time comparison, three of the four system travel times were not rejected at the 95 percent confidence interval. The one exception was the eastbound direction in Network 4, which in the field demonstrated unusually high station dwell times during the field data collection. Figure 16 above shows the model and field LRT travel times through Networks 4 and 5 and the similarity in LRT behavior between the two.

Individual Intersection MOE Analysis. The individual intersection MOE analysis for TransSim II™ consisted of comparing the field stopped delay at selected intersection approaches in each network to the stopped delay (computed as total delay divided by a 1.3 conversion factor) generated by the model. The analysis results are presented in Table 17 and graphically in Figure 17. Researchers compared the stopped delays by pairing the complementary delay values from the model and field and graphing the result, found in Figure 18. A unity slope line was included on the figure to indicate the result if the model was a perfect predictor of field stopped delay. Also included is the correlation coefficient for the paired data elements, interpreted as the strength of the relationship between the model and field data sets (0 = no relationship, 1 = positive linear relationship). A regression line was computed for the relationship between the field and modeled data. Using a 95 percent confidence level t-test, researchers compared the slope of this line to the unity slope. Though this comparison of slopes was rejected, the moderate predictive capabilities of TransSim II™ for individual intersection stopped delay are demonstrated in Figure 18.

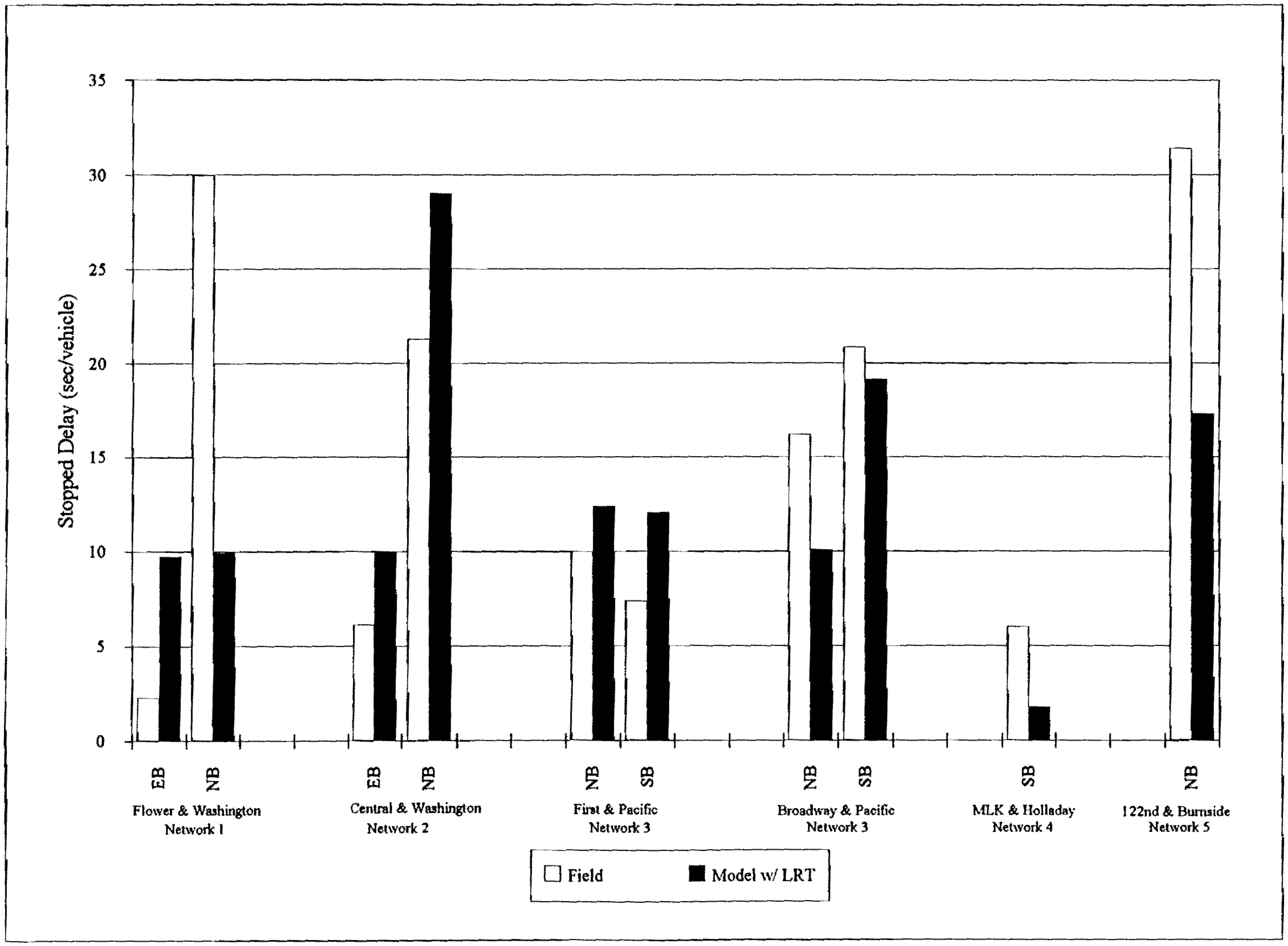

Figure 17. TransSim II^{TM} and Field Stopped Delay by Intersection

Table 17. TransSim II^{TM} and Field Intersection MOE

	Mean Stopped Delay	
	Validation Data	Model w/ LRT
Flower & Washington		
EB Approach	2.27	9.74
NB Approach	29.99	9.91
Central & Washington		
EB Approach	6.13	9.95
NB Approach	21.28	29.01
First & Pacific		
NB Approach	10	12.38
SB Approach	7.36	12.04
Broadway & Pacific		
NB Approach	16.19	10.07
SB Approach	20.86	19.12
MLK & Holladay		
SB Approach	6.01	1.78
122nd & Burnside		
NB Approach	31.41	17.29

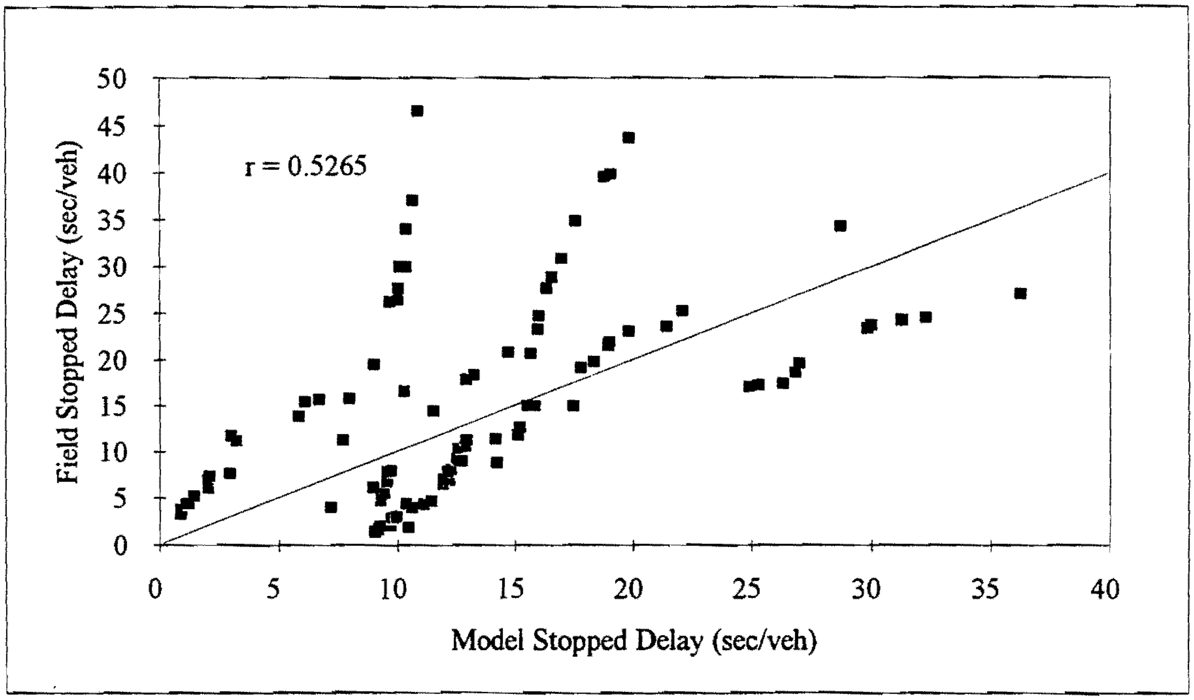

Figure 18. TransSim II^{TM} Versus Field Data Stopped Delay

Summary of Model Performance. The pull-down menu format of TransSim II^{TM} provided an understandable, organized, and efficient means of data entry. Input information, such as traffic volumes entered under their related roadway links and signal phase information under the appropriate intersection number, was logically located in sub-menus. No unusual configuration was necessary for the five modeled networks, and the means of specifying signal control type was facilitated by simply selecting the priority level (a defined code with a variety of control types possible for selection at each intersection) for the intersection. The selection of a priority level for transit and the entry of subsequent control and phasing information for this priority level were the main differences in coding between the pretimed, non-priority networks (1, 2, and 3) and the semi-actuated and fully actuated priority networks (4 and 5, respectively).

Following data entry and detector calibration for the priority networks, researchers made the final TransSim II^{TM} runs. The output ten runs formed the data set that was statistically compared to the field validation data. Automobile travel time comparisons demonstrated that individual link travel times were moderately replicated by the model and that system directional travel times were well represented by the model. Similarly, travel times for LRT were modeled successfully for major directions and with moderate success for individual system links. Researchers modeled individual intersection stopped delay with moderate success using TransSim II$^{TM.}$

The format of the output files proved as clear and concise as the data entry format. Different types of information were located in files with different extensions so that the desired information could be found and viewed exclusively. Files with the LRT extension contained information and MOEs pertaining to LRT performance by LRV and by signal; files with the STA extension displayed dwell times for each station; files with a PRE extension showed the time that detectors registered priority calls for transit, the time priority was initiated, and the time the LRV "checked out" of the intersection; and files with the TRF extension provided traffic MOEs for each modeled intersection in the network. Specific output can also be requested for any modeled link to identify behavior of vehicles on the link or for any LRV to display the speed and location of the LRV at every second during the simulation. Graphic output was also available for the simulation. The graphics could be viewed for an individual intersection or for the entire transit corridor being modeled. Inspection of the graphics for each intersection showed the simulation time, signal status for each approach, queue buildup during red indications, presence of LRVs, and priority calls and recovery periods attributable to transit. The system-wide view afforded by the graphics helped identify coding errors and contributed to an understanding of LRT treatment in the model.

CONCLUSIONS AND RECOMMENDATIONS

This final chapter contains the major conclusions and recommendations of this research, which was conducted to evaluate NETSIM and TransSim II™ for modeling LRT in urban arterial street networks. To date, little research has been done to develop a procedure or tool for evaluating the transportation network impacts of LRT implementation or operational changes in an existing LRT system. The conclusions of this research, as stated below, identify the strengths and limitations of NETSIM and TransSim II™ as tools for assessing the impacts of LRT on pretimed, semi-actuated and fully actuated networks.

CONCLUSIONS

Travel time and individual intersection stopped delay and percent stops data were collected from five networks with LRT systems as measures of the modeling performance of NETSIM and TransSim II™. Through calibrating and validating the models, the following points were emphasized as summary conclusions of this research:

1. The design of the data collection of field descriptive parameters and MOEs around the input and output requirements and capabilities of the models proved conducive to an efficient field data collection. The designed plan served as a framework or guide, the individual elements of which were filled in through the organized effort of the data collectors. The use of video equipment was especially helpful since the permanent "file" was referred to time and again during the calibration process, even after all field input and MOE data was collected.

2. Restrictions in the source code of NETSIM required complex input coding for inclusion of LRT in the model; however, the model output that included LRT did not vary greatly from the output that was coded only for automobile traffic (pretimed Networks 1, 2, and 3). This coding did allow for obtaining LRT operations MOEs from the model as well as the traffic descriptive MOEs.

3. Parameters in NETSIM that could be adjusted to calibrate the model to field conditions included start-up lost time, queue discharge headway, free flow speed, and the distributions of each. Other potential adjustments included distributions for eight other parameters, including turning speeds and gap acceptance, but the data collection for such calibration was not possible within the limited data collection time. Most large-scale model adjustments were accomplished most effectively by altering free flow speed, and these adjustments were made to remove some of the effects of platoon dispersion, which was greater in the model than in the field.

   Aside from the initial data entry of some field descriptive parameters, only one other adjustment (detector placement) was necessary before final output data sets could be generated from TransSim II™.

4. The performance of the calibrated model was assessed by comparison of link travel times, network directional travel times, and individual intersection MOEs to field observed values. NETSIM and TransSim II^{TM} were able to replicate the general trends of link travel times, but were only able to reproduce roughly 50 percent of link travel times within plus or minus 20 percent.

   For NETSIM, the nine network directional travel times for the with-LRT simulation and the six directional travel times for the without-LRT simulation were not rejected at the 95 percent level, with the exception of one direction of one network. This discrepancy was attributed to progression effects in the field that could not be recreated in the model due to its platoon dispersion. In TransSim II^{TM}, the nine directional travel times were accepted at the 95 percent confidence level, with the exception of one direction in one of the networks. Again, strong platoon progression effects in the field that could not be wholly represented in the model caused the discrepancy.

   Individual intersection model stopped delay and percent stops output from NETSIM correlated with their field counterparts in a moderate and strong relationship, respectively. TransSim II^{TM} was a moderate predictor of individual intersection stopped delay. For this LRT modeling investigation, both models proved more accurate in replicating system-wide field measures than individual approach or intersection measures; however, the models could reproduce the underlying relationships which produced the individual approach and intersection measures.

5. Based on the results of this research, researchers concluded that both models could simulate the systems and control behavior of the LRT networks under study. The model outputs were more representative of field data for system-wide measures of effectiveness than for MOEs at individual intersections. As in all applications, the user should be aware of the limitations of the software and should calibrate and validate the model to ensure credible results.

RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the results and conclusions of this study, the following recommendations were made for using NETSIM and TransSim II^{TM} to model LRT:

1. If it is only necessary to obtain impacts of a pretimed signalization scheme on traffic, the system should be coded in NETSIM without the LRT included. Only if it is necessary to obtain MOEs for LRT or transit riders should the effort to code LRT in the system be undertaken. In systems where LRT detection influences signal operations, one should include transit in the modeled system.

2. The minimum link length requirement or the restriction that lanes to the left of left-turn bays not be moving lanes should be removed so that transit can be modeled in realistic arterial environments.

   Additionally, and for purposes of calibrating NETSIM to known field traffic stream behavior, another parameter should be available to the NETSIM user to directly control the degree of platoon dispersion in the model.

3. Prior to future analyses involving NETSIM and/or TransSim II™, one should calibrate and validate the model. Only through aligning the model to the existing or anticipated conditions can credible results be obtained from the model. The calibration step also familiarizes the user with the limitations of the software and identifies the reliability of the MOEs provided by the model.

4. This research has simulated LRT in non-priority pretimed networks and full priority semi-actuated and fully actuated networks. There are other types of priority between these extremes and a variety of means to recover green on cross streets that was given up during priority calls. One should investigate and simulate these additional priority types using NETSIM and TransSim II™ to determine the best simulation configuration and format for each model. It is anticipated that the results of such testing would be similar to the results of this research.

REFERENCES

1. J. S. Hodges and J. A. Dewar. *Is It You or Your Model Talking? A Framework for Model Validation,* RAND, Santa Monica, CA, 1992.

2. W. L. Winston. *Operations Research Applications and Algorithms*, PWS-Kent Publishing Company, Boston, MA, 1991.

3. R. A. Berry. Estimating Level of Service of Streets with At-Grade Light Rail Crossings. In *ITE 1987 Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, DC, August 1987, pp. 167-172.

4. ITE Committee 6Y-37. *Guidelines for Design of Light Rail Grade Crossings*, ITE, Washington, DC, 1992, pp. 1-64.

5. J. Piper and P. R. Cornwell. Design for Public Transport. In *Proceedings,* 12th Australian Transport Research Forum, Sydney, Australia, 1987, pp. 214-228.

6. P. S. Marshall and W. D. Berg. Evaluation of Railroad Preemption Capabilities of Traffic Signal Controllers. In *Transportation Research Record 1254,* TRB, National Research Council, Washington, DC, 1989, pp. 44-49.

7. M. Bates and L. Lee. At-Grade or Not At-Grade: The Early Traffic Question in Light Rail Transit Route Planning. In *Light Rail Transit: New System Successes at Affordable Prices, TRB Special Report 221*, TRB, National Research Council, Washington, DC, 1982, pp. 351-367.

8. *TRAF User Reference Guide, Publication No. FHWA-RO-92-060.* Federal Highway Administration, Office of Safety and Traffic Operations R&D, U.S. Department of Transportation, McLean, VA, May, 1992.

9. B. Rymer, J. C. Cline, and T. Urbanik. *Delay at Isolated Light Rail Transit Grade Crossings.* Texas Transportation Institute Report 339-10, Texas State Department of Highways and Public Transportation, Austin, TX, 1987.

10. P. Luedtke, S. Smith, H. Lieu, and A. Kanaan. Simulating DART's North Central Light Rail Line Using TRAF-NETSIM. In *63rd Annual Meeting Compendium of Technical Papers,* Institute of Transportation Engineers, Washington, DC, September, 1993, pp. 60-64.

11. B. A. Hillson. *Validation and Practical Application of the UTCS-1 Network Simulation Model on an Urban Arterial Street.* Joint Highway Research Project by the Engineering Experiment Station, Purdue University and the Indiana State Highway Commission, West Lafayette, IN, 1979.

12. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, DC, 1985.

13. J. Koothrappally. *FLOATCAR User Reference Guide*. Texas Transportation Institute, College Station, TX, 1992.

14. JRH Transportation Engineering. *TransSim II™ Data Input Instructions.* JRH Transportation Engineering, Eugene, OR, 1993.

APPENDIX A:

INDIVIDUAL INTERSECTION STOPPED DELAY AND PERCENT STOPS - CALIBRATION DATA AND VALIDATION DATA

Table A-1. First and Pacific

NB Approach, 5 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	8.65	0.50	26
	2	4.29	0.38	21
	3	11.11	0.63	27
	4	7.50	0.50	14
CALIBRATION DATA	5	6.52	0.48	23
	6	18.33	0.89	18
	7	5.87	0.65	23
	8	15.00	0.43	21
	9	9.44	0.59	27
	10	7.80	0.68	25
	11	9.17	0.61	18
	Mean	9.43	0.58	
	Std. Dev.	4.10	0.14	
	12	15.00	0.67	24
	13	12.63	0.53	19
	14	7.03	0.50	32
	15	9.00	0.70	30
VALIDATION DATA	16	7.86	0.52	21
	17	6.18	0.29	17
	18	11.25	0.65	20
	19	11.43	0.67	21
	20	10.59	0.53	17
	21	15.00	0.81	21
	22	4.00	0.33	15
	Mean	10.00	0.56	
	Std. Dev.	3.55	0.16	

Table A-2. First and Pacific

SB Approach, 5 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	7.20	0.44	25
	2	4.62	0.35	26
	3	9.29	0.33	21
	4	10.71	0.61	28
CALIBRATION	5	4.29	0.39	28
DATA	6	9.00	0.45	20
	7	6.77	0.58	31
	8	2.73	0.18	22
	9	10.65	0.52	31
	10	6.32	0.47	19
	11	3.75	0.30	20
	Mean	6.85	0.42	
	Std. Dev.	2.80	0.13	
	12	6.50	0.43	30
	13	4.29	0.25	28
	14	1.88	0.19	16
	15	13.24	0.59	17
VALIDATION	16	9.29	0.52	21
DATA	17	10.38	0.38	13
	18	11.79	0.57	14
	19	6.92	0.46	13
	20	3.95	0.47	19
	21	4.69	0.50	16
	22	8.08	0.54	13
	Mean	7.36	0.45	
	Std. Dev.	3.56	0.13	

Table A-3. Broadway and Pacific

NB Approach, 5 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	11.91	0.65	34
	2	18.75	0.72	36
	3	18.64	0.64	33
	4	13.00	0.60	30
CALIBRATION DATA	5	10.50	0.80	20
	6	17.31	0.69	26
	7	9.13	0.65	23
	8	19.14	0.59	29
	9	21.38	0.75	40
	10	20.63	0.69	32
	11	13.18	0.67	33
	12	20.00	0.67	24
	Mean	16.13	0.68	
	Std. Dev.	4.30	0.06	
	13	16.58	0.76	38
	14	18.33	0.69	45
	15	15.69	0.62	65
	16	17.87	0.72	47
VALIDATION DATA	17	23.10	0.86	50
	18	13.82	0.55	38
	19	15.41	0.59	37
	20	11.72	0.72	32
	21	15.81	0.76	37
	22	20.81	0.81	31
	23	12.16	0.81	37
	24	12.93	0.59	29
	Mean	16.19	0.71	
	Std. Dev.	3.44	0.10	

Table A-4. Broadway and Pacific

SB Approach, 5 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	10.83	0.67	18
	2	21.14	0.59	22
	3	20.83	0.61	18
	4	18.75	0.80	20
CALIBRATION DATA	5	13.00	0.50	30
	6	21.25	0.58	24
	7	30.60	0.84	25
	8	20.87	0.48	23
	9	12.39	0.52	23
	10	22.17	0.78	23
	11	29.00	0.80	15
	12	18.13	0.71	24
	Mean	19.91	0.66	
	Std. Dev.	6.02	0.13	
	13	14.46	0.39	28
	14	19.80	0.72	25
	15	21.52	0.83	23
	16	21.88	0.67	24
VALIDATION DATA	17	15.00	0.61	23
	18	19.20	0.68	25
	19	25.26	0.79	19
	20	34.29	0.79	14
	21	23.57	0.71	14
	22	15.00	0.73	22
	23	30.00	0.73	15
	24	10.31	0.56	16
	Mean	20.86	0.68	
	Std. Dev.	6.85	0.12	

Table A-5. Central and Washington

EB Approach, 6 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
CALIBRATION DATA	1	14.00	0.37	75
	2	5.07	0.16	74
	3	5.48	0.22	63
	4	10.71	0.31	70
	5	11.07	0.31	84
	6	10.26	0.21	76
	7	4.09	0.24	55
	8	8.08	0.18	65
	9	12.05	0.30	66
	10	5.94	0.19	53
	Mean	8.67	0.25	
	Std. Dev.	3.40	0.07	
VALIDATION DATA	11	4.74	0.16	57
	12	8.84	0.36	56
	13	7.92	0.29	72
	14	7.77	0.21	56
	15	2.03	0.17	59
	16	5.34	0.24	59
	17	5.53	0.18	76
	18	7.02	0.31	62
	19	6.75	0.28	40
	20	5.37	0.19	67
	Mean	6.13	0.24	
	Std. Dev.	1.96	0.07	

Table A-6. Central and Washington

NB Approach, 6 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	23.64	0.85	99
	2	31.32	1.00	91
	3	25.00	0.92	93
	4	26.42	0.88	88
CALIBRATION DATA	5	24.15	0.84	82
	6	17.53	0.88	89
	7	17.25	0.88	80
	8	18.70	0.91	77
	9	21.61	0.85	84
	10	26.01	0.85	79
	Mean	23.16	0.88	
	Std. Dev.	4.46	0.05	
	11	24.52	0.89	93
	12	24.25	0.84	73
	13	23.72	0.82	74
	14	19.62	0.83	78
VALIDATION DATA	15	27.07	0.84	82
	16	17.23	0.78	74
	17	23.36	0.79	70
	18	17.39	0.71	69
	19	17.08	0.78	65
	20	18.62	0.74	58
	Mean	21.28	0.80	
	Std. Dev.	3.68	0.05	

Table A-7. Flower and Washington

EB Approach, 5 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	2.47	0.11	73
	2	3.00	0.04	70
	3	3.70	0.22	73
	4	2.50	0.08	60
CALIBRATION	5	3.68	0.16	57
DATA	6	1.18	0.08	51
	7	1.30	0.09	81
	8	4.29	0.18	56
	9	2.95	0.14	56
	10	4.18	0.10	61
	11	3.62	0.10	58
	12	5.08	0.23	65
	Mean	3.16	0.13	
	Std. Dev.	1.17	0.06	
	13	0.32	0.02	47
	14	2.80	0.10	59
	15	2.11	0.09	57
	16	0.00	0.00	53
VALIDATION	17	2.88	0.15	52
DATA	18	3.06	0.18	49
	19	1.39	0.11	54
	20	1.67	0.16	45
	21	4.39	0.15	41
	22	2.78	0.22	54
	23	2.84	0.14	37
	24	3.06	0.22	49
	Mean	2.27	0.13	
	Std. Dev.	1.25	0.07	

Table A-8. Flower and Washington

NB Approach, 5 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	25.50	0.87	30
	2	26.13	0.81	31
	3	6.43	0.57	28
	4	30.68	0.91	22
CALIBRATION DATA	5	17.05	0.73	22
	6	35.25	0.80	20
	7	16.80	0.72	25
	8	15.00	0.72	29
	9	39.55	0.55	11
	10	15.00	0.57	30
	11	22.11	0.84	19
	12	47.05	0.68	22
	Mean	24.71	0.73	
	Std. Dev.	11.75	0.12	
	13	19.50	0.90	20
	14	30.00	0.85	20
	15	37.06	0.76	17
	16	11.25	0.75	16
VALIDATION DATA	17	34.04	0.77	26
	18	30.00	0.85	13
	19	27.69	1.00	13
	20	26.47	0.82	17
	21	46.50	0.60	10
	22	26.25	0.90	20
	23	40.00	1.00	6
	24	31.07	0.79	14
	Mean	29.99	0.83	
	Std. Dev.	9.21	0.11	

Table A-9. MLK and Holladay

SB Approach, 6 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	1.94	15.05	93
	2	3.61	18.99	79
	3	5.92	29.58	71
	4	4.05	22.00	100
CALIBRATION	5	7.21	34.35	131
DATA	6	3.68	19.30	114
	7	6.19	22.94	109
	8	8.44	37.50	160
	9	8.94	32.69	156
	10	11.91	41.22	131
	Mean	6.19	27.36	
	Std. Dev.	3.02	8.89	
	11	7.64	41.40	157
	12	6.06	23.18	151
	13	4.29	15.97	119
	14	6.96	38.12	181
VALIDATION	15	11.17	39.85	133
DATA	16	3.72	20.51	117
	17	7.33	32.56	129
	18	4.40	25.56	133
	19	5.20	25.00	124
	20	3.32	17.14	140
	Mean	6.01	27.93	
	Std. Dev.	2.37	9.43	

Table A-10. 122nd and Burnside

NB Approach, 6 minute interval

	Interval	Mean Delay/veh	Mean % stops	Volume
	1	24.08	52.63	76
	2	24.32	60.81	74
	3	28.39	80.99	121
	4	38.13	72.29	83
CALIBRATION DATA	5	27.17	62.22	90
	6	39.45	86.30	73
	7	34.35	72.00	100
	8	26.67	75.00	108
	9	43.33	86.67	90
	10	38.28	74.63	67
	Mean	32.42	72.35	
	Std. Dev.	7.08	11.11	
	11	30.88	83.19	119
	12	24.69	70.77	65
	13	39.87	91.23	114
	14	27.69	64.10	117
VALIDATION DATA	15	23.31	58.68	121
	16	39.59	73.87	111
	17	43.65	93.00	100
	18	20.69	51.72	87
	19	28.81	64.36	101
	20	34.88	77.11	83
	Mean	31.41	72.80	
	Std. Dev.	7.80	13.62	

APPENDIX B:

FIELD AND MODELED TRAVEL TIME DATA AND COMPARISON TABLES

Table B-1. Calibration Travel Time Data

Network 1: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std. Dev.
Start Time	6:27	6:47	7:08	7:24	7:44	8:00		
West to East:								
1. Flower to Grand	42	33	53	66	32	22	41.33	15.97
2. Grand to Olive	6	7	88	11	6	10	21.33	32.73
3. Olive to Hill	7	13	24	7	88	6	24.17	32.00
4. Hill to Broadway	8	7	7	13	7	7	8.17	2.40
5. Broadway to Main	10	7	51	6	17	10	16.83	17.17
6. Main to Los Angeles	11	16	48	8	12	7	17.00	15.52
TOTAL	84	83	271	111	162	62	128.83	77.73
Start Time	6:43	7:02	7:21	7:38	7:56	8:12		
East to West:								
1. Los Angeles to Main	10	10	12	10	12	10	10.67	1.03
2. Main to Broadway	62	9	12	9	57	55	34.00	26.41
3. Broadway to Hill	56	8	86	33	9	10	33.67	31.83
4. Hill to Olive	9	11	6	9	7	6	8.00	2.00
5. Olive to Grand	5	7	8	10	5	5	6.67	2.07
6. Grand to Flower	69	79	69	71	38	70	66.00	14.23
TOTAL	211	124	193	142	128	156	159.00	35.62
Network 2: Los Angeles	Run 1	Run 2	Run 3	Run 4	Run5	Run 6	Mean	Std. Dev.
Start Time	6:33	6:50	7:11	7:29	7:45	8:02		
West to East:								
1. Los Angeles to Maple	35	33	48	13	52	18	33.17	15.59
2. Maple to Trinity	25	45	26	49	52	47	40.67	11.98
3. Trinity to San Pedro	56	22	17	14	16	14	23.17	16.35
4. San Pedro to Griffith	30	38	26	32	29	40	32.50	5.43
5. Griffith to Central	25	34	25	27	25	28	27.33	3.50
6. Central to Naomi	24	45	19	29	25	21	27.17	9.39
7. Naomi to Hooper	17	14	14	14	16	12	14.50	1.76
8. Hooper to Long Beach	62	77	84	61	67	71	70.33	8.94
9. Long Beach to Alameda	82	61	63	17	76	75	62.33	23.63
TOTAL	356	369	322	256	358	326	331.17	41.30
Start Time	6:40	7:00	7:18	7:36	7:54	8:09		
East to West:								
1. Alameda to Long Beach	26	102	21	40	26	26	40.17	30.96
2. Long Beach to Hooper	21	20	19	19	18	19	19.33	1.03
3. Hooper to Naomi	16	14	14	11	12	14	13.50	1.76
4. Naomi to Central	27	23	29	19	35	17	25.00	6.69
5. Central to Griffith	22	19	21	21	20	23	21.00	1.41
6. Griffith to San Pedro	36	31	32	34	33	41	34.50	3.62
7. San Pedro to Trinity	12	13	13	13	13	13	12.83	0.41
8. Trinity to Maple	19	17	18	16	18	22	18.33	2.07
9. Maple to Los Angeles	17	17	21	14	17	20	17.67	2.50
TOTAL	196	256	188	187	192	195	202.33	26.54
Network 3: Long Beach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std. Dev.
Start Time	4:28	4:36	4:45	5:07	5:25	5:41		
South to North:								
1. 1st to Broadway	12	28	39	15	9	11	19.00	11.92
2. Broadway to 3rd	16	16	35	14	14	9	17.33	9.03
3. 3rd to 4th	11	11	12	13	9	8	10.67	1.86
4. 4th to 5th	12	13	9	9	11	8	10.33	1.97
5. 5th to 6th	41	38	39	29	40	38	37.50	4.32
6. 6th to 7th	13	10	12	14	13	13	12.50	1.38
7. 7th to 8th	11	28	33	19	13	26	21.67	8.76
TOTAL	120	148	183	118	114	118	133.50	27.22
Start Time	4:31	4:39	4:48	5:12	5:28	5:44		
North to South:								
1. 8th to 7th	44	34	17	15	14	12	22.67	13.14
2. 7th to 6th	11	10	63	11	11	60	27.67	26.23
3. 6th to 5th	10	10	23	10	11	23	14.50	6.60
4. 5th to 4th	10	10	10	10	9	12	10.17	0.98
5. 4th to 3rd	55	54	54	52	45	56	52.67	3.98
6. 3rd to Broadway	45	12	14	12	11	11	17.50	13.52
7. Broadway to 1st	12	17	10	27	10	10	14.33	6.77
TOTAL	187	147	191	137	111	184	159.50	32.75

Table B-1. Calibration Travel Time Data (continued)

Network 4: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Mean	Std. Dev.
Start Time	7:16	7:22	7:28	7:34	7:41	7:49	7:55		
West to East:									
1. MLK to Grand	38	42	43	16	44	24	21	32.57	10.49
2. Grand to 6th	8	8	8	20	17	8	23	13.14	5.88
3. 6th to 7th	17	18	18	9	12	37	12	17.57	5.80
4. 7th to 9th	15	17	15	21	30	16	43	22.43	8.04
5. 9th to 11th	13	14	43	23	14	23	12	20.29	8.04
6. 11th to 13th	16	20	22	22	17	20	19	19.43	1.80
TOTAL	107	119	149	111	134	128	130	125.43	11.22

Network 5: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Mean	Std. Dev.
Start Time	4:37	4:45	4:55	5:15	5:24	5:34	5:45		
East to West:									
1. 122nd to 117th	42	28	28	29	31	32	55	35.00	7.71
2. 117th to 113th	27	33	20	19	24	19	21	23.29	4.04
3. 113th to 108th	28	28	26	27	33	26	26	27.71	1.67
4. 108th to 102nd	28	41	27	32	80	59	31	42.57	15.39
TOTAL	125	130	101	107	168	136	133	128.57	15.06
Start Time	4:40	4:49	4:58	5:19	5:29	5:39	5:49		
West to East:									
1. 102nd to 108th	30	44	30	42	28	28	28	32.86	5.80
2. 108th to 113th	37	30	51	24	24	48	34	35.43	8.49
3. 113th to 117th	23	27	28	34	15	24	20	24.43	4.49
4. 117th to 122nd	59	27	26	56	67	85	96	59.43	19.92
TOTAL	149	128	135	156	134	185	178	152.14	17.88

Table B-2. Uncalibrated Model Travel Times - With LRT

Network 1: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std. Dev.
West to East:								
1. Flower to Grand	50.8	49.5	50.3	52.2	52.5	50.4	50.95	1.17
2. Grand to Olive	20	22.9	21.2	22.9	22.4	21	21.73	1.18
3. Olive to Hill	9.1	8.3	8.2	10	12.6	12.5	10.12	1.99
4. Hill to Broadway	12.3	20.2	16.2	14.9	16.3	19.7	16.60	2.97
5. Broadway to Main	17.8	27.3	20.7	18.2	19.1	14.9	19.67	4.20
6. Main to Los Angeles	18.6	27.6	25.1	26.7	28.8	20.4	24.53	4.12
TOTAL	128.6	155.8	141.7	144.9	151.7	138.9	143.60	9.66
East to West:								
1. Los Angeles to Main	25	26	20.3	22.1	16.5	15.3	20.87	4.37
2. Main to Broadway	19.1	20.4	17.9	23.1	25.6	21.1	21.20	2.79
3. Broadway to Hill	32.3	19.8	20.3	32.8	27.6	25.2	26.33	5.65
4. Hill to Olive	13	15.8	9.8	9.7	11.6	14.6	12.42	2.51
5. Olive to Grand	8.4	12	19.7	14.7	12.2	12.3	13.22	3.76
6. Grand to Flower	62.8	58.2	39.6	45.6	50.7	47.9	50.80	8.48
TOTAL	160.6	152.2	127.6	148	144.2	136.4	144.83	11.67
Network 2: Los Angeles	Run 1	Run 2	Run 3	Run 4	Run5	Run 6	Mean	Std. Dev.
West to East:								
1. Los Angeles to Maple	17.7	17.8	19.9	19.6	23.3	19.5	19.63	2.03
2. Maple to Trinity	26.4	23.7	29.1	26	29.7	27.9	27.13	2.22
3. Trinity to San Pedro	32.3	34.2	33.6	36.6	27.7	38.8	33.87	3.81
4. San Pedro to Griffith	36.6	47.9	43.3	38.7	39	40.2	40.95	4.05
5. Griffith to Central	32.9	30.9	30.9	41	32.5	29.2	32.90	4.18
6. Central to Naomi	38.2	31.4	35.7	35	26.7	30.8	32.97	4.13
7. Naomi to Hooper	25.8	22.2	24	23.4	27.1	24.9	24.57	1.75
8. Hooper to Long Beach	73.2	64.9	72.5	73.4	73.1	76.7	72.30	3.92
9. Long Beach to Alameda	47.9	46.8	46.2	45.5	46.3	47.3	46.67	0.85
TOTAL	331	319.8	335.2	339.2	325.4	335.3	330.98	7.21
East to West:								
1. Alameda to Long Beach	44.5	47.4	44	45.4	46.2	42.4	44.98	1.75
2. Long Beach to Hooper	61.2	57.1	60.1	69.7	63.4	54.3	60.97	5.34
3. Hooper to Naomi	23.9	22.4	22.4	23.4	23.4	22.5	23.00	0.65
4. Naomi to Central	37.4	34.3	37.8	34.2	28.7	30.2	33.77	3.70
5. Central to Griffith	28.9	27.1	28.7	28.2	29.5	27.7	28.35	0.87
6. Griffith to San Pedro	39.3	40.8	39.5	40.1	42.8	37	39.92	1.91
7. San Pedro to Trinity	19.1	21.2	21.2	19.9	20.8	18.4	20.10	1.17
8. Trinity to Maple	20.1	23.2	24	21.3	25.1	23.4	22.85	1.83
9. Maple to Los Angeles	20.5	20.8	22.6	20.2	24	20.2	21.38	1.57
TOTAL	294.9	294.3	300.3	302.4	303.9	276.1	295.32	10.19
Network 3: Long Beach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std. Dev.
South to North:								
1. 1st to Broadway	25.5	18.6	17.8	20.6	21.4	19.9	20.63	2.72
2. Broadway to 3rd	14.8	11.3	10.7	13.3	13.8	11.9	12.63	1.58
3. 3rd to 4th	20.3	13.4	11.8	15.8	13.5	14.6	14.90	2.96
4. 4th to 5th	14.3	10.8	11.3	12.6	10.6	10.2	11.63	1.55
5. 5th to 6th	48.4	46.2	42.4	48.2	44	45.9	45.85	2.34
6. 6th to 7th	14.2	18.1	12.9	15.6	19.4	15.6	15.97	2.41
7. 7th to 8th	7.5	8.8	7.7	9.3	10	8.8	8.68	0.95
TOTAL	145	127.2	114.6	135.4	132.7	126.9	130.30	10.15
North to South:								
1. 8th to 7th	22.8	21.6	25	25.2	22.7	22.5	23.30	1.46
2. 7th to 6th	34.9	10.3	18.6	49.3	20.9	37.3	28.55	14.41
3. 6th to 5th	21.3	15.8	12.9	19.3	13.7	18.8	16.97	3.35
4. 5th to 4th	8.9	10.6	11.4	8.6	8.3	11	9.80	1.35
5. 4th to 3rd	17.1	29.9	16.3	26.3	20.2	20.5	21.72	5.34
6. 3rd to Broadway	34.2	37.1	34.3	22.1	26.3	30.8	30.80	5.65
7. Broadway to 1st	11.8	10.8	11.3	13.1	9.9	9.9	11.13	1.22
TOTAL	151	136.1	129.8	163.9	122	150.8	142.27	15.63

Table B-2. Uncalibrated Model Travel Times - With LRT (continued)

Network 4:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. MLK to Grand	29.6	40.9	32.5	26.7	29.8	28	25.9	40.9	40.5	33.5	32.83	5.64
2. Grand to 6th	18.7	22.2	20	13.9	15.5	17.8	17.3	25	18.4	19.6	18.84	3.01
3. 6th to 7th	28.1	26.4	28.1	29	32	26.9	30.4	29.9	28.5	24.7	28.40	1.99
4. 7th to 9th	21.7	24.8	21.9	19.1	22.5	26.6	26.1	17.7	20.2	22.1	22.27	2.75
5. 9th to 11th	25.4	25	26.3	25.3	26.4	27.7	24.9	16.6	24.7	24.6	24.69	2.85
6. 11th to 13th	36.4	36.2	41.2	38.2	45	39.6	40.5	29.7	34.1	36.3	37.72	4.00
TOTAL	159.9	175.5	170	152.2	171.2	166.6	165.1	159.8	166.4	160.8	164.75	6.42

Network 5:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
East to West:												
1. 122nd to 117th	41.4	38.2	38.5	41.1	42.8	37.7	40	43.1	44.2	40.6	40.76	2.09
2. 117th to 113th	32.5	28.2	30.4	32.2	33.2	30.4	30.6	29	36.7	32	31.52	2.28
3. 113th to 108th	42.3	38.3	43.2	41.9	41.4	41.9	39.2	42.8	41.9	43.3	41.62	1.56
4. 108th to 102nd	55.2	68.3	67.8	58.9	72.1	56.9	59	83.8	66.5	76.1	66.46	8.73
TOTAL	171.4	173	179.9	174.1	189.5	166.9	168.8	198.7	189.3	192	180.36	10.60
West to East:												
1. 102nd to 108th	44	46.4	47.8	45.5	48.9	41.6	46.8	46	54.6	48.5	47.01	3.26
2. 108th to 113th	46.2	44.5	46.3	46.4	47	46.1	44.8	44.4	43.8	45.6	45.51	1.01
3. 113th to 117th	34.4	33.7	32.7	32.1	32.7	32.2	33.2	33.4	32.8	31.7	32.89	0.77
4. 117th to 122nd	55.9	65.3	63.3	57.4	71.7	54.7	56.9	56.5	49	53.4	58.41	6.23
TOTAL	180.5	189.9	190.1	181.4	200.3	174.6	181.7	180.3	180.2	179.2	183.82	7.08

Table B-3. Uncalibrated Model Travel Times - Without LRT

Network 1: Los Angeles:	Run	Run	Run	Run	Run	Run	Mean	Std. Dev.
West to East:								
1. Flower to Grand	39	38	38.8	39.1	37.9	39.2	38.67	0.57
2. Grand to Olive	24	15.5	45.3	25.2	21.9	35.2	27.85	10.66
3. Olive to Hill	16.6	16.7	19.3	12.7	15	14.2	15.75	2.30
4. Hill to Broadway	18.9	20.3	20.2	14.1	18.6	18.9	18.50	2.27
5. Broadway to Main	19.6	17.9	16.8	15.5	24.4	16.6	18.47	3.22
6. Main to Los Angeles	21.7	20.7	21.4	22.3	22.2	22.8	21.85	0.75
TOTAL	139.8	129.1	161.8	128.9	140	146.9	141.08	12.31
East to West:								
1. Los Angeles to Main	20.2	21.1	22.6	20.6	16.6	21.7	20.47	2.07
2. Main to Broadway	25.6	26.8	21.2	23.9	27.4	26.1	25.17	2.28
3. Broadway to Hill	25.7	21.3	23.7	20.3	18.8	19.5	21.55	2.65
4. Hill to Olive	18.7	12.9	13.9	15.6	16.3	14.3	15.28	2.07
5. Olive to Grand	12.5	11.8	15.6	19.2	14.2	14.4	14.62	2.63
6. Grand to Flower	58.5	49.8	53.3	50.9	48.1	52.4	52.17	3.61
TOTAL	161.2	143.7	150.3	150.5	141.4	148.4	149.25	6.91
Network 2: Los Angeles	Run	Run	Run	Run	Run5	Run	Mean	Std. Dev.
West to East:								
1. Los Angeles to Maple	19.1	16.5	21.4	18.8	17.1	16.2	18.18	1.98
2. Maple to Trinity	27.8	27.1	25.9	24.3	30.7	28.5	27.38	2.20
3. Trinity to San Pedro	30.4	30.8	28.9	33.6	31.9	32.2	31.30	1.63
4. San Pedro to Griffith	34.5	39.3	35.3	38.8	35.6	39.8	37.22	2.33
5. Griffith to Central	34.7	36.8	29	33.8	54.9	42.6	38.63	9.11
6. Central to Naomi	32.9	30.3	32.7	34.1	34.8	32.2	32.83	1.57
7. Naomi to Hooper	24.5	22.5	21.2	23.6	23.1	24.8	23.28	1.33
8. Hooper to Long Beach	66.6	69.9	72.7	67.2	65.5	66.5	68.07	2.71
9. Long Beach to Alameda	50	51.6	57.6	59.8	54.7	57.6	55.22	3.82
TOTAL	320.5	324.8	324.7	334	348.3	340.4	332.12	10.75
East to West:								
1. Alameda to Long Beach	45.9	44.4	40	43.5	43.3	46.4	43.92	2.29
2. Long Beach to Hooper	67.4	62.7	61.8	61.3	57.8	61.6	62.10	3.10
3. Hooper to Naomi	25.8	22.7	22.2	20.9	21.5	22.7	22.63	1.70
4. Naomi to Central	36.9	26.7	30.7	31.2	31.5	33.5	31.75	3.36
5. Central to Griffith	31.2	30	28.5	27.6	30.1	28.7	29.35	1.31
6. Griffith to San Pedro	35.8	39.3	38.7	39.6	42.7	40.1	39.37	2.23
7. San Pedro to Trinity	18.7	19.4	18.8	18.6	20.4	19.5	19.23	0.68
8. Trinity to Maple	22.9	23.3	23.3	21.8	24.1	22.9	23.05	0.75
9. Maple to Los Angeles	23.1	20.7	21.3	21.4	20.5	21.1	21.35	0.92
TOTAL	307.7	289.2	285.3	285.9	291.9	296.5	292.75	8.41
Network 3: Long Beach	Run	Run	Run	Run	Run	Run	Mean	Std. Dev.
South to North:								
1. 1st to Broadway	18.5	18	10.3	16.5	20.6	15.6	16.58	3.53
2. Broadway to 3rd	16.5	14.3	13.5	15.6	12	16.4	14.72	1.78
3. 3rd to 4th	14.4	12.1	15.3	14.3	12	12.7	13.47	1.38
4. 4th to 5th	17.4	10.4	16	12	13.2	14.1	13.85	2.57
5. 5th to 6th	48.4	50.2	50.2	47.6	48.8	46.6	48.63	1.43
6. 6th to 7th	14.1	17.3	15.4	20.2	16.3	22.8	17.68	3.24
7. 7th to 8th	7.4	7.9	7.9	7.7	7.7	6.9	7.58	0.38
TOTAL	136.7	130.2	128.6	133.9	130.6	135.1	132.52	3.18
North to South:								
1. 8th to 7th	18.5	19.8	18.3	19.8	15.1	18.2	18.28	1.72
2. 7th to 6th	9.5	10.8	9.3	8.7	10	10.9	9.87	0.87
3. 6th to 5th	18.6	19.1	11.9	20	18.3	19.7	17.93	3.02
4. 5th to 4th	11.1	11.3	7.6	13.1	8.6	11.1	10.47	2.01
5. 4th to 3rd	19	24	26.2	14.9	21.4	30	22.58	5.35
6. 3rd to Broadway	26.7	33	32	36.9	30.8	26	30.90	4.08
7. Broadway to 1st	11.2	12.3	15.9	14.1	11.8	11.8	12.85	1.79
TOTAL	114.6	130.3	121.2	127.5	116	127.7	122.88	6.61

Table B-4. Uncalibrated Model Travel Time Comparison to Calibration Data

	Calibration Data			Model w/LRT			Model w/o LRT	
Network 1: Los Angeles:	Mean	Std. Dev.	Delta	Mean	Std. Dev.	Delta	Mean	Std.
West to East:								
1. Flower to Grand	41.33	15.97	9.62	50.95	1.17	-2.66	38.67	0.57
2. Grand to Olive	21.33	32.73	0.40	21.73	1.18	6.52	27.85	10.66
3. Olive to Hill	24.17	32.00	-14.05	10.12	1.99	-8.42	15.75	2.30
4. Hill to Broadway	8.17	2.40	8.43	16.60	2.97	10.33	18.50	2.27
5. Broadway to Main	16.83	17.17	2.84	19.67	4.20	1.64	18.47	3.22
6. Main to Los Angeles	17.00	15.52	7.53	24.53	4.12	4.85	21.85	0.75
TOTAL	128.83	77.73	14.77	143.60	9.66	12.25	141.08	12.31
East to West:								
1. Los Angeles to Main	10.67	1.03	10.20	20.87	4.37	9.80	20.47	2.07
2. Main to Broadway	34.00	26.41	-12.80	21.20	2.79	-8.83	25.17	2.28
3. Broadway to Hill	33.67	31.83	-7.34	26.33	5.65	-12.12	21.55	2.65
4. Hill to Olive	8.00	2.00	4.42	12.42	2.51	7.28	15.28	2.07
5. Olive to Grand	6.67	2.07	6.55	13.22	3.76	7.95	14.62	2.63
6. Grand to Flower	66.00	14.23	-15.20	50.80	8.48	-13.83	52.17	3.61
TOTAL	159.00	35.62	-14.17	144.83	11.67	-9.75	149.25	6.91
Network 2: Los Angeles	Mean	Std. Dev.	Delta	Mean	Std. Dev.	Delta	Mean	Std.
West to East:								
1. Los Angeles to Maple	33.17	15.59	-13.54	19.63	2.03	-14.99	18.18	1.98
2. Maple to Trinity	40.67	11.98	-13.54	27.13	2.22	-13.29	27.38	2.20
3. Trinity to San Pedro	23.17	16.35	10.70	33.87	3.81	8.13	31.30	1.63
4. San Pedro to Griffith	32.50	5.43	8.45	40.95	4.05	4.72	37.22	2.33
5. Griffith to Central	27.33	3.50	5.57	32.90	4.18	11.30	38.63	9.11
6. Central to Naomi	27.17	9.39	5.80	32.97	4.13	5.66	32.83	1.57
7. Naomi to Hooper	14.50	1.76	10.07	24.57	1.75	8.78	23.28	1.33
8. Hooper to Long Beach	70.33	8.94	1.97	72.30	3.92	-2.26	68.07	2.71
9. Long Beach to Alameda	62.33	23.63	-15.66	46.67	0.85	-7.11	55.22	3.82
TOTAL	331.17	41.30	-0.19	330.98	7.21	0.95	332.12	10.75
East to West:								
1. Alameda to Long Beach	40.17	30.96	4.81	44.98	1.75	3.75	43.92	2.29
2. Long Beach to Hooper	19.33	1.03	41.64	60.97	5.34	42.77	62.10	3.10
3. Hooper to Naomi	13.50	1.76	9.50	23.00	0.65	9.13	22.63	1.70
4. Naomi to Central	25.00	6.69	8.77	33.77	3.70	6.75	31.75	3.36
5. Central to Griffith	21.00	1.41	7.35	28.35	0.87	8.35	29.35	1.31
6. Griffith to San Pedro	34.50	3.62	5.42	39.92	1.91	4.87	39.37	2.23
7. San Pedro to Trinity	12.83	0.41	7.27	20.10	1.17	6.40	19.23	0.68
8. Trinity to Maple	18.33	2.07	4.52	22.85	1.83	4.72	23.05	0.75
9. Maple to Los Angeles	17.67	2.50	3.71	21.38	1.57	3.68	21.35	0.92
TOTAL	202.33	26.54	92.99	295.32	10.19	90.42	292.75	8.41
Network 3: Long Beach	Mean	Std. Dev.	Delta	Mean	Std. Dev.	Delta	Mean	Std.
South to North:								
1. 1st to Broadway	19.00	11.92	1.63	20.63	2.72	-2.42	16.58	3.53
2. Broadway to 3rd	17.33	9.03	-4.70	12.63	1.58	-2.61	14.72	1.78
3. 3rd to 4th	10.67	1.86	4.23	14.90	2.96	2.80	13.47	1.38
4. 4th to 5th	10.33	1.97	1.30	11.63	1.55	3.52	13.85	2.57
5. 5th to 6th	37.50	4.32	8.35	45.85	2.34	11.13	48.63	1.43
6. 6th to 7th	12.50	1.38	3.47	15.97	2.41	5.18	17.68	3.24
7. 7th to 8th	21.67	8.76	-12.99	8.68	0.95	-14.09	7.58	0.38
TOTAL	133.50	27.22	-3.20	130.30	10.15	-0.98	132.52	3.18
North to South:								
1. 8th to 7th	22.67	13.14	0.63	23.30	1.46	-4.39	18.28	1.72
2. 7th to 6th	27.67	26.23	0.88	28.55	14.41	-17.80	9.87	0.87
3. 6th to 5th	14.50	6.60	2.47	16.97	3.35	3.43	17.93	3.02
4. 5th to 4th	10.17	0.98	-0.37	9.80	1.35	0.30	10.47	2.01
5. 4th to 3rd	52.67	3.98	-30.95	21.72	5.34	-30.09	22.58	5.35
6. 3rd to Broadway	17.50	13.52	13.30	30.80	5.65	13.40	30.90	4.08
7. Broadway to 1st	14.33	6.77	-3.20	11.13	1.22	-1.48	12.85	1.79
TOTAL	159.50	32.75	-17.23	142.27	15.63	-36.62	122.88	6.61

Table B-4. Uncalibrated Model Travel Time Comparison to Calibration Data (continued)

	Calibration Data		Model w/LRT			Model w/o LRT		
Network 4: Portland:	Mean	Std.	Delta	Mean	Std.	Delta	Mean	Std.
West to East:								
1. MLK to Grand	32.57	10.49	0.26	32.83	5.64			
2. Grand to 6th	13.14	5.88	5.70	18.84	3.01			
3. 6th to 7th	17.57	5.80	10.83	28.40	1.99		N/A	
4. 7th to 9th	22.43	8.04	699.77	722.20	2.75			
5. 9th to 11th	20.29	8.04	4.40	24.69	2.85			
6. 11th to 13th	19.43	1.80	18.29	37.72	4.00			
TOTAL	125.43	11.22	39.32	164.75	6.42			
Network 2: Los Angeles	Mean	Std.	Delta	Mean	Std.	Delta	Mean	Std.
East to West:								
1. 122nd to 117th	35.00	7.71	5.76	40.76	2.09			
2. 117th to 113th	23.29	4.04	8.23	31.52	2.28		N/A	
3. 113th to 108th	27.71	1.67	13.91	41.62	1.56			
4. 108th to 102nd	42.57	15.39	23.89	66.46	8.73			
TOTAL	128.57	15.06	51.79	180.36	10.60			
West to East:								
1. 102nd to 108th	32.86	5.80	14.15	47.01	3.26			
2. 108th to 113th	35.43	8.49	10.08	45.51	1.01		N/A	
3. 113th to 117th	24.43	4.49	8.46	32.89	0.77			
4. 117th to 122nd	59.43	19.92	-1.02	58.41	6.23			
TOTAL	152.14	17.88	31.68	183.82	7.08			

Table B-5. Validation Travel Time Data

Network 1: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std. Dev.
Start Time	7:08	7:26	7:38	7:54	8:12	8:30		
West to East:								
1. Flower to Grand	16	29	18	23	15	64	27.50	18.62
2. Grand to Olive	8	26	56	8	44	7	24.83	21.09
3. Olive to Hill	6	5	7	56	6	7	14.50	20.34
4. Hill to Broadway	53	9	9	18	8	9	17.67	17.71
5. Broadway to Main	56	51	7	9	56	7	31.00	25.64
6. Main to Los Angeles	9	18	8	10	7	54	17.67	18.23
TOTAL	148	138	105	124	136	148	133.17	16.42
Start Time	7:21	7:42	7:48	8:07	8:23	8:41		
East to West:								
1. Los Angeles to Main	14	9	57	12	11	9	18.67	18.88
2. Main to Broadway	9	27	10	10	55	51	27.00	21.27
3. Broadway to Hill	12	58	8	59	10	9	26.00	25.21
4. Hill to Olive	8	16	50	10	7	7	16.33	16.84
5. Olive to Grand	8	7	7	7	5	6	6.67	1.03
6. Grand to Flower	70	15	69	59	52	47	52.00	20.28
TOTAL	121	132	201	157	140	129	146.67	29.29
Network 2: Los Angeles	Run 1	Run 2	Run 3	Run 4	Run5	Run 6	Mean	Std. Dev.
Start Time	7:11	7:30	7:39	7:57	8:14	8:35		
West to East:								
1. Los Angeles to Maple	14	64	16	43	54	34	37.50	20.16
2. Maple to Trinity	19	40	29	14	44	27	28.83	11.62
3. Trinity to San Pedro	16	19	13	15	14	17	15.67	2.16
4. San Pedro to Griffith	53	41	39	45	38	32	41.33	7.12
5. Griffith to Central	23	75	36	22	22	21	33.17	21.25
6. Central to Naomi	22	105	17	36	18	16	35.67	34.76
7. Naomi to Hooper	23	19	13	15	17	15	17.00	3.58
8. Hooper to Long Beach	62	56	69	60	67	59	62.17	4.96
9. Long Beach to Alameda	66	69	71	81	78	76	73.50	5.75
TOTAL	298	488	303	331	352	297	344.83	73.45
Start Time	7:18	7:39	7:46	8:04	8:20	8:45		
East to West:								
1. Alameda to Long Beach	22	25	22	22	21	22	22.33	1.37
2. Long Beach to Hooper	24	23	20	17	21	19	20.67	2.58
3. Hooper to Naomi	14	15	14	12	12	16	13.83	1.60
4. Naomi to Central	21	19	17	20	15	20	18.67	2.25
5. Central to Griffith	22	20	29	23	23	25	23.67	3.08
6. Griffith to San Pedro	30	29	25	30	34	27	29.17	3.06
7. San Pedro to Trinity	14	13	15	15	13	14	14.00	0.89
8. Trinity to Maple	14	22	16	17	16	18	17.17	2.71
9. Maple to Los Angeles	20	16	17	19	18	17	17.83	1.47
TOTAL	181	182	175	175	173	178	177.33	3.61
Network 3: Long Beach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std. Dev.
Start Time	4:38	4:47	4:56	5:06	5:14	5:21		
South to North:								
1. 1st to Broadway	58	60	35	44	41	13	41.83	17.17
2. Broadway to 3rd	10	13	22	12	10	9	12.67	4.80
3. 3rd to 4th	13	15	11	10	11	9	11.50	2.17
4. 4th to 5th	9	10	9	10	9	8	9.17	0.75
5. 5th to 6th	30	40	41	39	35	31	36.00	4.73
6. 6th to 7th	11	13	12	13	12	11	12.00	0.89
7. 7th to 8th	10	15	16	30	10	10	15.17	7.76
TOTAL	141	166	146	158	128	91	138.33	26.70
Start Time	4:42	4:51	5:00	5:09	5:16	5:24		
North to South:								
1. 8th to 7th	12	56	57	48	37	45	42.50	16.67
2. 7th to 6th	47	12	15	12	12	12	18.33	14.09
3. 6th to 5th	14	11	11	9	11	10	11.00	1.67
4. 5th to 4th	9	9	13	10	10	15	11.00	2.45
5. 4th to 3rd	10	51	52	53	51	51	44.67	17.00
6. 3rd to Broadway	11	59	12	11	11	13	19.50	19.37
7. Broadway to 1st	13	11	9	39	9	11	15.33	11.69
TOTAL	116	209	169	182	141	157	162.33	32.37

Table B-5. Validation Travel Time Data (continued)

Network 4: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Mean	Std. Dev.
Start Time	7:25	7:39	7:50	7:56	8:02	8:06	8:13		
West to East:									
1. MLK to Grand	22	40	41	32	42	50	30	36.71	7.47
2. Grand to 6th	18	30	13	8	8	10	16	14.71	5.67
3. 6th to 7th	10	8	7	27	7	15	12	12.29	4.98
4. 7th to 9th	16	14	13	42	14	30	15	20.57	8.82
5. 9th to 11th	30	33	41	21	12	14	33	26.29	9.10
6. 11th to 13th	18	15	19	21	18	18	19	18.29	1.18
TOTAL	114	140	134	151	101	137	125	128.86	13.31

Network 5: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Mean	Std. Dev.
Start Time	6:02	6:12	4:20	4:30	4:39	4:47	4:56		
East to West:									
1. 122nd to 117th	41	44	23	24	22	22	34	30.00	8.29
2. 117th to 113th	39	31	18	36	38	18	32	30.29	7.02
3. 113th to 108th	33	41	32	29	28	40	29	33.14	4.20
4. 108th to 102nd	31	26	32	27	66	54	33	38.43	12.33
TOTAL	144	142	105	116	154	134	128	131.86	13.31
Start Time	6:06	6:17	4:24	4:34	4:43	4:53	5:01		
West to East:									
1. 102nd to 108th	37	34	29	40	35	31	45	35.86	4.12
2. 108th to 113th	32	27	25	37	28	32	58	34.14	7.63
3. 113th to 117th	20	16	16	21	17	31	22	20.43	3.63
4. 117th to 122nd	82	69	81	72	25	35	84	64.00	19.43
TOTAL	171	146	151	170	105	129	209	154.43	24.78

Table B-6. Calibrated Model Travel Times - With LRT

Network 1: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. Flower to Grand	40.3	39.7	40.8	45.9	43	39.9	37.1	39	36.3	41.7	40.37	2.774106
2. Grand to Olive	29.1	25.4	22.9	27.6	25.5	26.6	29.3	28.1	30.4	29.2	27.41	2.303837
3. Olive to Hill	12.6	10.7	11.4	12.5	11.2	11.4	11.1	15.3	12.6	11	11.98	1.36284
4. Hill to Broadway	20	18	12.8	16	15	15.2	15.1	12.9	18.8	19.7	16.35	2.637444
5. Broadway to Main	13.1	16.2	12.6	14	15.7	12.8	13.6	15.2	12.5	20.7	14.64	2.507411
6. Main to Los Angeles	29.9	26.7	24.6	21.7	25.6	28.6	26	22.9	26.9	23.9	25.68	2.513873
TOTAL	145	136.7	125.1	137.7	136	134.5	132.2	133.4	137.5	146.2	136.43	6.06521
East to West:												
1. Los Angeles to Main	15.4	19.9	17.5	16.9	20.3	18.8	14.8	17	17.1	16.1	17.38	1.812794
2. Main to Broadway	18.8	19.6	17	19.9	17.2	18.7	17.4	17.7	18.7	20.2	18.52	1.15547
3. Broadway to Hill	28.6	26.7	25.4	29.6	26.8	30.7	26.7	25.4	27.3	25	27.22	1.884321
4. Hill to Olive	13.4	13	12.6	10.9	12.3	11.6	11.8	12.2	13.9	13.9	12.56	0.996884
5. Olive to Grand	14.5	14.7	11.6	16.1	12.4	13.5	14.4	14.8	11.7	17	14.07	1.787643
6. Grand to Flower	57.1	56.3	61.4	55	58.6	57	58.7	61.2	59.2	56.6	58.11	2.098386
TOTAL	147.8	150.2	145.5	148.4	147.6	150.3	143.8	148.3	147.9	148.8	147.86	1.969884
Network 2: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. Los Angeles to Maple	23.8	23.8	23.5	23.4	22.8	23	23	23.1	23.7	22.8	23.29	0.398469
2. Maple to Trinity	26.8	25.6	27.6	26.5	27.7	26.9	26.7	27.8	26.9	27.2	26.97	0.656675
3. Trinity to San Pedro	25	29.6	25.9	26.3	25.5	27.7	26.3	28.4	28.3	27.4	27.04	1.471356
4. San Pedro to Griffith	34	36.8	33.8	35.2	34.6	36.3	33.7	31.4	35.3	34.8	34.59	1.515439
5. Griffith to Central	31.1	28.1	31.9	28.1	29.1	28.4	27.2	28.4	27.4	29.2	28.89	1.523483
6. Central to Naomi	28.3	29.9	29.5	29	29.3	31.7	31.4	30.3	29.7	29.2	29.83	1.055199
7. Naomi to Hooper	21.6	20.9	19	21.7	18.8	20.1	20.4	20.8	20.1	20.3	20.37	0.956905
8. Hooper to Long Beach	80.4	78.8	81	83.2	86.9	83.3	91.5	89.9	74.6	92.2	84.18	5.820233
9. Long Beach to Alameda	42.7	41.7	33.7	43.6	42.7	42.6	44.6	43.7	43.8	40	41.91	3.156809
TOTAL	313.7	315.2	305.9	317	317.4	320	324.8	323.8	309.8	323.1	317.07	6.169648
East to West:												
1. Alameda to Long Beach	37.6	38.6	35.5	49.1	42.5	43.6	38.8	32.9	38.1	39.7	39.64	4.52455
2. Long Beach to Hooper	48.6	46.3	43.5	49.3	39.3	41.3	50.3	49.1	49.3	44.5	46.15	3.829491
3. Hooper to Naomi	20	19.4	19.8	20.8	20.3	19.4	21.1	24.8	20.5	18.9	20.5	1.656636
4. Naomi to Central	27.6	25.2	26.3	27.9	25.8	29.5	27.6	26.9	25.4	28.1	27.03	1.363044
5. Central to Griffith	24.9	25.7	25.6	26	26.4	24.1	26.5	27.8	24.9	24.6	25.65	1.088577
6. Griffith to San Pedro	42.3	37.2	37.2	34.4	36.4	38.4	35.2	35.1	35.7	35.3	36.72	2.306898
7. San Pedro to Trinity	17.8	18.5	18.5	19.5	18.8	18.9	19.6	19.5	18.8	19	18.89	0.554677
8. Trinity to Maple	20.1	22.1	20.9	19.4	21.3	21.2	19.8	22.5	21.2	20.5	20.9	0.977525
9. Maple to Los Angeles	19.3	19	21.4	21	21.6	20.4	21.2	22	31	20.4	21.73	3.396747
TOTAL	258.2	252	248.7	267.4	252.4	256.8	260.1	260.6	264.9	251	257.21	6.193446
Network 3: Long Beach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
South to North:												
1. 1st to Broadway	17.3	22.2	15.9	18	16.3	17.1	20	18.4	18.2	16.2	17.96	1.934023
2. Broadway to 3rd	10.6	12.8	12.3	16.7	13.4	13.1	13.3	13.4	13.5	14.6	13.37	1.557812
3. 3rd to 4th	14.7	12.3	11.3	13.6	14	10.4	15.6	13.3	14.1	13.3	13.26	1.558632
4. 4th to 5th	11.4	11.9	11.9	12.1	10.2	13.6	12	10.8	10.7	12.4	11.7	0.976388
5. 5th to 6th	46.9	49.5	44.6	41.7	43.3	44.5	47	45.8	47.7	46	45.7	2.262742
6. 6th to 7th	13.6	13	13.1	14	15.7	13.9	11.8	11.8	15.2	14.6	13.67	1.302178
7. 7th to 8th	10.5	11.4	10.1	12.7	10.8	11.9	12.1	10.1	12.3	12.3	11.42	0.977298
TOTAL	125	133.1	119.2	128.8	123.7	124.5	131.8	123.6	131.7	129.4	127.08	4.531568
North to South:												
1. 8th to 7th	19.5	18.2	20.6	17.5	17	21.2	19.1	20.9	16.8	17.8	18.86	1.641273
2. 7th to 6th	59.9	21.6	21.5	40.1	19.5	54.4	14.4	13.5	30.5	71.4	34.68	20.69685
3. 6th to 5th	14.1	12	14.2	12.6	16	15.1	14.5	14.5	14.1	12.3	13.94	1.272967
4. 5th to 4th	10.4	6.8	10.8	9.5	8.4	8.1	7.1	9.5	6.4	10.8	8.78	1.661191
5. 4th to 3rd	27	45.8	31.2	23.1	36.4	16.9	44.6	45.1	34.1	23.5	32.77	10.24023
6. 3rd to Broadway	31.6	21	29.6	30.7	27.4	29.1	24.4	29.4	35.6	28.2	28.7	3.96092
7. Broadway to 1st	10.2	15.8	14.3	16.5	16.2	14.8	15	14.1	15.6	14.5	14.7	1.777014
TOTAL	172.7	141.2	142.2	150	140.9	159.6	139.1	147	153.1	178.5	152.43	13.82092

Table B-6. Calibrated Model Travel Times - With LRT (continued)

Network 4: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. MLK to Grand	26.7	29.6	16.7	30.4	20.9	27.6	28.5	33.3	29.1	34.8	27.76	5.41073
2. Grand to 6th	24.3	23	21.8	18.3	18.4	21.8	15.4	16.8	17.3	18.6	19.57	2.948088
3. 6th to 7th	20.5	18.8	18.3	20.3	24.5	16.6	16.3	16.5	20.1	14	18.59	2.954262
4. 7th to 9th	15.8	17.1	15.1	15.4	19.3	16.6	17.8	20.4	18.6	22.1	17.82	2.288037
5. 9th to 11th	21.1	22.8	24.1	25.2	19.9	20.4	21.9	26	20.4	17.5	21.93	2.621302
6. 11th to 13th	26	20.9	20.8	25.7	26.7	18.8	25	18.8	18.8	21	22.25	3.240799
TOTAL	134.4	132.2	116.8	135.3	129.7	121.8	124.9	131.8	124.3	128	127.92	5.928612

Network 5: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
East to West:												
1. 122nd to 117th	34.5	33.9	35	34.7	38	34.1	40.8	35.1	31.4	38.8	35.63	2.757636
2. 117th to 113th	26	25.9	25.5	24.2	25.9	25.6	23.1	31.1	27.4	27.4	26.21	2.149134
3. 113th to 108th	34.1	29.1	29.9	31.7	29.8	29.5	34.9	35.9	29.7	32.2	31.68	2.50191
4. 108th to 102nd	43.4	43.1	47.8	51.5	44.2	46.8	51.2	42.1	45.2	48.2	46.35	3.317378
TOTAL	138	132	138.2	142.1	137.9	136	150	144.2	133.7	146.6	139.87	5.742444
West to East:												
1. 102nd to 108th	38.3	41.6	33	36.9	43.7	35.6	37.3	34.7	42.7	39.3	38.31	3.523083
2. 108th to 113th	32.2	29.9	32.4	36.3	33	32.3	33.4	31	30.7	28.8	32	2.0838
3. 113th to 117th	24.2	26.7	29.5	31.1	29.2	28.6	29.4	25.1	30.1	27.2	28.11	2.238278
4. 117th to 122nd	43.9	45.6	56	53.5	42	58.9	64.6	47.8	45.4	50.1	50.78	7.311452
TOTAL	138.6	143.8	150.9	157.8	147.9	155.4	164.7	138.6	148.9	145.4	149.2	8.337599

Table B-7. Calibrated Model Travel Times - Without LRT

Network 1: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. Flower to Grand	54.7	54.4	50.6	55.6	53.9	52.1	51.4	53.7	53.4	50.3	53.01	1.81013
2. Grand to Olive	22.4	22.5	25.8	27.2	21.7	26.8	22.4	24.6	26.4	25.7	24.55	2.10726
3. Olive to Hill	10.7	11.4	12.2	12.1	11.6	10.7	14	12.1	11.9	11.8	11.85	0.93005
4. Hill to Broadway	17.4	18.9	19.5	19.3	18.2	17.4	20.2	19.1	22.7	18	19.07	1.5706
5. Broadway to Main	24.2	23.6	21	22.8	25.4	21.5	17.3	21.2	20.7	22	21.97	2.24254
6. Main to Los Angeles	25.7	21.3	27	25.8	22.9	23.6	23	24.6	24.3	24.5	24.27	1.65868
TOTAL	155.1	152.1	156.1	162.8	153.7	152.1	148.3	155.3	159.4	152.3	154.72	4.10171
East to West:												
1. Los Angeles to Main	18.6	19.4	19.6	21.1	18.3	19.7	20.4	19.9	19	19.4	19.54	0.82219
2. Main to Broadway	23.5	24.8	23.8	24.2	25.5	24.4	24.5	23.9	25.9	22.7	24.32	0.93785
3. Broadway to Hill	20.9	21.9	21.2	19	21.5	21.3	18.8	22.4	19.2	22.4	20.86	1.37453
4. Hill to Olive	16.4	15.6	17.2	14.8	14.9	15.4	14.7	14	14.2	15.8	15.3	0.99107
5. Olive to Grand	15.7	14.3	16.6	14	14.2	15.7	16.1	15.2	15.4	15.4	15.26	0.85401
6. Grand to Flower	54.4	54.1	54.9	53.5	56.3	56.1	54.1	56.6	54.2	53.4	54.76	1.17019
TOTAL	149.5	150.1	153.3	146.6	150.7	152.6	148.6	152	147.9	149.1	150.04	2.1376
Network 2: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. Los Angeles to Maple	23.4	22.2	22.7	21.8	22.8	23.1	22.6	23.6	22.4	22.5	22.71	0.54457
2. Maple to Trinity	27.2	24.5	24.9	25.8	24.6	26.1	25.7	27.5	25.6	25.4	25.73	1.00228
3. Trinity to San Pedro	21.2	21.6	21.9	23.2	26.1	22.9	22.9	22.3	21.5	21.6	22.52	1.43279
4. San Pedro to Griffith	32.2	32.1	34.2	31.1	33.4	30.9	34.3	29.6	32.9	33.9	32.46	1.57141
5. Griffith to Central	28.7	28.8	27.8	32.8	28.5	28.7	30.5	27.3	27.9	31.3	29.23	1.74677
6. Central to Naomi	29.4	30.3	28	29.5	29.6	29	29.8	30.7	29.1	29	29.44	0.75011
7. Naomi to Hooper	19.6	19.3	19.3	21.1	20.2	19.7	19.9	21.8	20.7	20.3	20.19	0.81302
8. Hooper to Long Beach	81.2	77.9	74.6	74.7	76.3	77.5	76.3	78.7	78	75.5	77.07	2.02268
9. Long Beach to Alameda	47	48.5	48.3	48.3	48.6	47.7	46.8	47.9	47	47	47.71	0.70624
TOTAL	309.9	305.2	301.7	308.3	310.1	305.6	308.8	309.4	305.1	306.5	307.06	2.7044
East to West:												
1. Alameda to Long Beach	44	40.6	39.8	44.3	39.8	55.4	49.3	43.8	63	42.1	46.21	7.60693
2. Long Beach to Hooper	48.4	49.5	47.6	45.6	44.8	47.8	47.2	46.6	45.8	48.1	47.14	1.44006
3. Hooper to Naomi	20.6	19.7	20.4	19.7	19.6	20.2	19.8	18.7	20.6	19.2	19.85	0.61509
4. Naomi to Central	26.8	27	25.5	29.9	25.5	25.8	26.4	26.4	27.8	27.7	26.88	1.33733
5. Central to Griffith	23.7	24.1	23.7	24	24.1	25.5	24.3	23.8	24.1	23.2	24.05	0.59675
6. Griffith to San Pedro	32.8	33.4	36.9	31.6	35.8	35.1	33.5	33.9	34.4	34.2	34.16	1.51379
7. San Pedro to Trinity	17.8	18.7	18.9	18.9	16.2	18.6	18.5	18.1	17.1	17.3	18.01	0.90117
8. Trinity to Maple	19.3	20.1	18.2	18.9	17.7	20	20	16.9	19.8	18.6	18.95	1.09671
9. Maple to Los Angeles	20.7	21	19.3	20	21	19.4	20.5	22.2	19.9	19.6	20.36	0.90086
TOTAL	254.1	254.1	250.3	252.9	244.5	267.8	259.5	250.4	272.5	250	255.61	8.63551
Network 3: Long Beach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
South to North:												
1. 1st to Broadway	15.9	16.3	16.5	12.5	13.4	15.5	13.5	17.5	15.1	14.5	15.07	1.58188
2. Broadway to 3rd	13.6	12.5	16.4	12.7	12.8	12.1	13	13.5	13.2	15.1	13.49	1.30848
3. 3rd to 4th	13.2	13.5	10.5	15.4	12.6	16.4	16	12.7	13.3	11.8	13.54	1.87747
4. 4th to 5th	13.7	12.5	12.5	15.6	11.9	11.7	11.1	12.6	10.3	11.2	12.31	1.49774
5. 5th to 6th	48.1	45.7	46.6	47	48.4	48.5	44.2	46.7	46.3	46.2	46.77	1.32502
6. 6th to 7th	14.2	15.3	15.4	13.8	14.6	13.7	19.1	13.5	14.4	15	14.9	1.61589
7. 7th to 8th	6.6	7	6.6	7.2	7.8	6.4	7.2	6.7	7.2	7.6	7.03	0.45717
TOTAL	125.3	122.8	124.5	124.2	121.5	124.3	124.1	123.2	119.8	121.4	123.11	1.72849
North to South:												
1. 8th to 7th	42.8	45.7	44.6	41.4	46.6	47.3	45.3	45.2	44	45.4	44.83	1.74168
2. 7th to 6th	11.3	12.5	17.3	14.2	12.5	13	15	14.8	13.3	12.6	13.65	1.71869
3. 6th to 5th	12.4	12.6	11.3	17.7	12.9	15	12.3	10.9	16.4	13.8	13.53	2.20608
4. 5th to 4th	11.7	11.4	10.9	10	8	9.8	11.3	11.7	10.3	8.8	10.39	1.26003
5. 4th to 3rd	9.6	8.7	11	8.5	11	10.3	8.6	8.3	9.6	8.4	9.4	1.06249
6. 3rd to Broadway	47.8	44.3	39.9	38.4	33.7	37.6	34.3	45.3	36.1	40.7	39.81	4.75241
7. Broadway to 1st	12.8	12.1	15.3	13.2	11	13	14	15.7	14.3	11.8	13.32	1.51203
TOTAL	148.4	147.3	150.3	143.4	135.7	146	140.8	151.9	144	141.5	144.93	4.86987

Table B-8. Calibrated Model Travel Time Comparison to Validation Data

	Validation Data			Model w/LRT				Model w/o LRT		
Network 1: Los Angeles:	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
West to East:										
1. Flower to Grand	27.50	18.62	46.80	12.87	40.37	2.77	92.76	26..51	53.01	1.81
2. Grand to Olive	24.83	21.09	10.39	2.58	27.41	2.30	-1.13	-0.28	24.55	2.10
3. Olive to Hill	14.50	20.34	-17.38	-2.52	11.98	1.36	-18.28	-3.65	11.85	0.93
4. Hill to Broadway	17.67	17.70	-7.47	-1.32	16.35	2.64	7.92	1.40	19.07	1.57
5. Broadway to Main	31.00	25.64	-52.77	-16.3	14.64	2.51	-29.13	-9.03	21.97	2.24
6. Main to Los Angeles	17.67	18.23	45.33	8.01	25.68	2.51	37.35	7.60	24.27	1.66
TOTAL	133.17	16.42		3.26	136.43	6.07		22..55	154.7	4.10
East to West:										
1. Los Angeles to Main	18.67	18.88	-6.89	-1.29	17.38	1.81	4.68	1.87	19.54	0.82
2. Main to Broadway	27.00	21.27	-31.41	-8.48	18.52	1.56	-9.93	-3.68	24.32	0.94
3. Broadway to Hill	26.00	25.21	4.69	1.22	27.22	1.88	-19.77	-5.14	20.86	1.37
4. Hill to Olive	16.33	16.84	-23.09	-3.77	12.56	1.00	-6.31	-1.03	15.30	0.99
5. Olive to Grand	6.67	1.03	111.05	7.40	14.07	1.79	128.90	9.59	15.26	0.85
6. Grand to Flower	52.00	20.28	11.75	6.11	58.11	2.10	5.31	3.76	54.76	1.17
TOTAL	146.67	29.29		1.19	147.86	1.97		3.37	150.0	2.14
Network 2: Los Angeles	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
West to East:										
1. Los Angeles to Maple	37.50	20.16	-37.89	-14.2	23.29	0.40	-39.44	-15.4.7	22.71	0.54
2. Maple to Trinity	28.83	11.62	-6.45	-1.86	26.97	0.66	-10.75	-3.10	25.73	1.00
3. Trinity to San Pedro	15.67	2.16	72.60	11.37	27.04	1.47	43.74	7.85	22.52	1.43
4. San Pedro to Griffith	41.33	7.12	-16.31	-6.74	34.59	1.52	-21.46	-9.87	32.46	1.57
5. Griffith to Central	33.17	21.25	-12.90	-4.28	28.89	1.52	-11.88	-4.94	29.23	1.75
6. Central to Naomi	35.67	34.76	-16.37	-5.84	29.83	1.06	-17.47	-6.23	29.44	0.75
7. Naomi to Hooper	17.00	3.58	19.82	3.37	20.37	0.96	18.76	3.19	20.19	0.81
8. Hooper to Long Beach	62.17	4.96	35.40	22.01	84.18	5.82	23.97	15..90	77.07	2.02
9. Long Beach to Alameda	73.50	5.75	-42.98	-31.5	41.91	3.16	-35.09	-26.5.7	47.71	0.71
TOTAL	344.83	73.44		-27.7	317.07	6.17		-38.7.7	307.0	2.70
East to West:										
1. Alameda to Long Beach	22.33	1.37	77.49	17.31	39.64	4.52	106.91	24..88	46.21	7.61
2. Long Beach to Hooper	20.67	2.58	123.27	25.48	46.15	3.83	128.06	26..47	47.14	1.44
3. Hooper to Naomi	13.83	1.60	48.19	6.67	20.50	1.66	43.49	6.02	19.85	0.62
4. Naomi to Central	18.67	2.25	44.78	8.36	27.03	1.36	43.97	8.21	26.88	1.34
5. Central to Griffith	23.67	3.08	8.38	1.98	25.65	1.09	1.62	0.38	24.05	0.60
6. Griffith to San Pedro	29.17	3.06	25.88	7.55	36.72	2.31	17.11	5.99	34.16	1.51
7. San Pedro to Trinity	14.00	0.89	34.93	4.89	18.89	0.55	28.64	4.01	18.01	0.90
8. Trinity to Maple	17.17	2.71	21.72	3.73	20.90	0.98	10.37	2.78	18.95	1.10
9. Maple to Los Angeles	17.83	1.47	21.85	3.90	21.73	3.40	14.17	3.53	20.36	0.90
TOTAL	177.33	3.61		79.88	257.21	6.19		78..28	255.6	8.64
Network 3: Long Beach	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
South to North:										
1. 1st to Broadway	41.83	17.17	-57.06	-23.8	17.96	1.93	-63.97	-27.6.7	15.07	1.58
2. Broadway to 3rd	12.67	4.80	5.55	0.70	13.37	1.56	6.50	1.82	13.49	1.31
3. 3rd to 4th	11.50	2.17	15.30	1.76	13.26	1.56	17.74	2.04	13.54	1.88
4. 4th to 5th	9.17	0.75	27.64	2.53	11.70	0.98	34.29	3.14	12.31	1.50
5. 5th to 6th	36.00	4.73	26.94	9.70	45.70	2.26	29.92	11..77	46.77	1.33
6. 6th to 7th	12.00	0.89	13.92	1.67	13.67	1.30	24.17	3.90	14.90	1.62
7. 7th to 8th	15.17	7.76	-24.70	-3.75	11.42	0.98	-53.65	-8.14	7.03	0.46
TOTAL	138.33	26.70		-11.2	127.08	4.53		-15.5.2	123.1	1.73
North to South:										
1. 8th to 7th	42.50	16.67	-55.62	-23.6	18.86	1.64	5.48	2.33	44.83	1.74
2. 7th to 6th	18.33	14.09	89.16	16.35	34.68	20.70	-25.55	-5.68	13.65	1.72
3. 6th to 5th	11.00	1.67	26.73	2.94	13.94	1.27	23.00	3.53	13.53	2.21
4. 5th to 4th	11.00	2.45	-20.18	-2.22	8.78	1.66	-5.55	-1.61	10.39	1.26
5. 4th to 3rd	44.67	17.00	-26.63	-11.9	32.77	10.24	-78.96	-35.5.2	9.40	1.06
6. 3rd to Broadway	19.50	19.37	47.18	9.20	28.70	3.96	104.15	20..31	39.81	4.75
7. Broadway to 1st	15.33	11.69	-4.13	-0.63	14.70	1.78	-13.13	-2.01	13.32	1.51
TOTAL	162.33	32.37		-9.90	152.43	13.82		-17.7.4	144.9	4.87

Table B-8. Calibrated Model Travel Time Comparison to Calibration Data (continued)

	Validation Data			Model w/LRT				Model w/o LRT		
Network 4: Portland:	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.	Percent Differenc	Delta	Mean	Std. Dev.
West to East:										
1. MLK to Grand	36.71	7.47	-24.38	-8.95	27.76	5.41				
2. Grand to 6th	14.71	5.67	33.04	4.86	19.57	2.95				
3. 6th to 7th	12.29	4.98	51.26	6.30	18.59	2.95			N/A	
4. 7th to 9th	20.57	8.82	-13.37	-2.75	17.82	2.29				
5. 9th to 11th	26.29	9.10	-16.58	-4.36	21.93	2.62				
6. 11th to 13th	18.29	1.18	21.65	3.96	22.25	3.24				
TOTAL	128.86	13.31		-0.94	127.92	5.93				
Network 2: Los Angeles	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.	Percent Differenc	Delta	Mean	Std. Dev.
East to West:										
1. 122nd to 117th	30.00	8.29	18.67	5.60	35.60	2.76				
2. 117th to 113th	30.29	7.02	-13.47	-4.08	26.21	2.15			N/A	
3. 113th to 108th	33.14	4.20	-4.41	-1.46	31.68	2.50				
4. 108th to 102nd	38.43	12.33	20.61	7.92	46.35	3.31				
TOTAL	131.86	13.31		8.017	139.87	5.74				
West to East:										
1. 102nd to 108th	35.86	4.12	6.83	2.45	38.31	3.52				
2. 108th to 113th	34.14	7.63	-6.27	-2.14	32.00	2.08			N/A	
3. 113th to 117th	20.43	3.63	37.59	7.68	28.11	2.24				
4. 117th to 122nd	64.00	19.43	-20.66	-13.2	50.78	7.31				
TOTAL	154.43	24.78		-5.23	149.20	8.34				

APPENDIX C:

TRANSSIM II™ MODEL DATA AND FIELD DATA COMPARISON TABLES

Table C-1. Calibrated Model Travel Times (TransSim II™)

Network 1: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. Flower to Grand	35.97	37.66	37.05	37.21	38.26	36.79	36.62	37.41	34.63	36.82	36.841649	0.993118
2. Grand to Olive	13.66	13.59	13.27	13.85	13.48	13.95	13.03	13.63	13.58	13.66	13.565692	0.265162
3. Olive to Hill	17.22	16.70	16.00	17.47	16.68	18.57	16.56	17.02	16.29	16.09	16.859406	0.766238
4. Hill to Broadway	18.78	18.96	18.59	19.54	18.67	19.35	19.36	18.74	18.07	18.82	18.887887	0.43591
5. Broadway to Main	16.73	17.22	17.30	17.12	17.70	17.09	16.83	17.28	16.20	17.13	17.061968	0.401672
6. Main to Los Angeles	19.87	20.57	19.91	20.17	20.62	19.91	19.55	20.08	19.26	19.98	19.991662	0.41126
TOTAL	122.23	124.70	122.11	125.36	125.41	125.65	121.94	124.16	118.03	122.49	123.20826	2.349371
East to West:												
1. Los Angeles to Main	17.26	17.15	16.49	17.23	17.67	17.18	16.24	17.26	18.17	17.28	17.194162	0.536999
2. Main to Broadway	19.85	20.31	19.81	19.57	19.59	19.95	19.49	19.77	20.05	19.87	19.829968	0.244913
3. Broadway to Hill	16.16	16.52	17.54	16.45	16.25	18.02	16.79	16.66	16.07	17.26	16.775387	0.641602
4. Hill to Olive	8.59	9.09	9.09	8.73	8.69	9.33	8.85	8.77	8.47	8.99	8.8592063	0.263017
5. Olive to Grand	17.81	20.51	19.38	18.35	17.76	19.29	18.48	18.47	18.42	19.40	18.785192	0.848058
6. Grand to Flower	47.72	50.05	48.92	47.84	47.93	48.26	47.46	48.21	48.67	48.11	48.317249	0.747613
TOTAL	127.39	133.64	131.24	128.17	127.90	132.04	127.33	129.13	129.86	130.91	129.76116	2.152982
Network 2: Los Angeles:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. Los Angeles to Maple	21.93	21.83	22.08	22.13	22.47	21.28	21.79	21.72	22.84	22.93	22.101914	0.515256
2. Maple to Trinity	26.49	27.10	26.43	27.38	27.34	26.08	26.99	26.14	27.51	27.77	26.918986	0.599519
3. Trinity to San Pedro	18.55	19.04	19.05	18.83	18.91	18.58	19.34	18.66	19.03	18.59	18.855007	0.262162
4. San Pedro to Griffith	33.09	33.66	33.45	33.67	33.56	33.11	33.89	33.06	33.67	33.35	33.453595	0.289423
5. Griffith to Central	25.79	25.40	25.69	25.53	25.58	25.55	25.90	25.70	25.63	25.68	25.645982	0.141048
6. Central to Naomi	24.38	24.33	24.37	24.27	24.38	24.14	24.47	24.40	24.27	24.35	24.338566	0.090946
7. Naomi to Hooper	16.18	16.24	16.12	16.14	16.14	16.16	16.24	16.12	16.27	16.12	16.173224	0.05697
8. Hooper to Long Beach	47.28	47.55	47.16	47.56	47.67	46.75	47.72	46.90	47.80	47.49	47.386688	0.355052
9. Long Beach to Alameda	44.06	44.09	43.87	44.36	44.25	43.59	44.42	43.75	44.46	44.36	44.123362	0.302304
TOTAL	257.75	259.24	258.22	259.87	260.30	255.24	260.76	256.45	261.48	260.64	258.99732	2.034504
East to West:												
1. Alameda to Long Beach	30.12	29.93	30.63	30.08	30.76	29.85	30.27	30.14	30.28	30.63	30.271362	0.310356
2. Long Beach to Hooper	32.01	31.33	32.07	31.65	30.98	32.54	32.13	32.13	31.47	31.36	31.765688	0.481873
3. Hooper to Naomi	17.59	17.49	17.57	17.40	17.40	17.48	17.47	17.49	17.48	17.38	17.475224	0.069162
4. Naomi to Central	32.27	31.92	32.07	32.00	32.25	32.10	31.76	31.74	32.22	31.74	32.009566	0.210135
5. Central to Griffith	23.13	23.08	23.20	23.14	23.02	23.09	23.11	23.02	23.11	23.02	23.092982	0.059404
6. Griffith to San Pedro	33.69	33.21	33.86	33.36	33.50	33.36	33.63	33.62	33.60	33.59	33.544595	0.188786
7. San Pedro to Trinity	13.24	13.22	13.25	13.22	13.23	13.22	13.23	13.23	13.24	13.24	13.229007	0.010328
8. Trinity to Maple	20.49	20.56	20.59	20.54	20.44	20.32	20.40	20.32	20.54	20.37	20.452986	0.101001
9. Maple to Los Angeles	18.39	18.52	18.57	18.36	18.60	18.42	18.26	18.57	18.32	18.24	18.426914	0.133187
TOTAL	220.93	219.26	221.81	219.75	220.18	220.38	220.26	220.26	220.26	219.57	220.26832	0.715545
Network 3: Long Beach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
South to North:												
1. 1st to Broadway	23.26	15.66	12.63	13.01	19.03	22.79	13.86	25.34	32.65	8.57	18.678296	7.309581
2. Broadway to 3rd	7.70	7.44	7.03	7.30	7.47	7.49	7.25	7.84	7.62	6.89	7.4021961	0.293187
3. 3rd to 4th	10.36	10.55	8.24	8.90	10.66	9.06	8.91	10.18	10.71	8.74	9.6296961	0.943667
4. 4th to 5th	16.27	12.04	14.77	11.50	15.21	13.11	13.76	13.73	14.12	10.96	13.546796	1.678843
5. 5th to 6th	57.57	49.26	43.38	45.61	52.07	47.42	46.10	52.16	51.08	37.34	48.198996	5.584934
6. 6th to 7th	17.42	12.98	14.03	14.77	10.96	15.68	14.73	24.60	21.39	19.28	16.584996	4.137407
7. 7th to 8th	13.02	10.49	11.15	11.62	9.16	12.19	11.65	12.21	11.70	11.17	11.435896	1.056248
TOTAL	145.60	118.42	111.22	112.72	124.55	127.73	116.24	146.06	149.27	102.96	125.47687	16.35955
North to South:												
1. 8th to 7th	51.54	47.85	49.06	62.68	33.54	51.05	46.08	49.70	68.76	97.81	55.802996	17.50134
2. 7th to 6th	44.52	28.06	24.09	44.73	19.46	25.64	28.23	44.05	27.98	16.14	30.285996	10.50117
3. 6th to 5th	7.34	7.84	6.90	7.83	7.73	7.01	7.55	7.09	7.90	7.72	7.4869961	0.377314
4. 5th to 4th	20.04	15.99	14.66	17.01	16.23	15.57	16.87	19.65	16.23	12.16	16.436996	2.26834
5. 4th to 3rd	14.97	10.72	10.82	11.56	11.17	10.75	11.68	13.66	11.48	9.90	11.666996	1.518504
6. 3rd to Broadway	30.64	23.29	19.98	26.37	22.92	21.95	23.55	28.28	22.80	15.11	23.484996	4.322058
7. Broadway to 1st	25.07	18.76	21.94	19.98	21.50	19.70	21.25	21.54	21.08	19.24	21.001996	1.792089
TOTAL	194.09	152.48	147.42	190.13	132.52	151.64	155.18	183.94	176.20	178.05	166.16697	20.85484

Table C-1. Calibrated Model Travel Times (TransSim II™ - continued)

Network 4: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
West to East:												
1. MLK to Grand	25.52	19.82	24.28	36.17	28.42	26.23	24.21	21.45	32.93	21.95	26.098	5.152749
2. Grand to 6th	14.76	16.06	14.00	26.63	23.11	19.14	19.38	14.09	26.77	13.88	18.782	5.132839
3. 6th to 7th	19.13	11.78	10.57	14.26	18.24	11.40	13.68	9.42	13.11	7.78	12.9368	3.606974
4. 7th to 9th	22.21	23.33	19.85	21.34	23.95	22.60	23.53	19.93	21.77	23.17	22.168	1.445259
5. 9th to 11th	29.16	29.75	27.56	30.60	30.86	29.07	29.39	27.96	29.66	29.99	29.4	1.040064
6. 11th to 13th	28.29	25.42	26.20	27.14	26.78	25.94	25.47	24.57	26.83	25.69	26.233	1.05935
TOTAL	139.07	126.16	122.46	156.14	151.36	134.38	135.66	117.42	151.07	122.46	135.6178	13.69561

Network 5: Portland:	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Mean	Std. Dev.
East to West:												
1. 122nd to 117th	34.80	34.49	33.75	34.49	35.32	34.15	35.39	34.40	33.05	35.39	34.522341	0.757117
2. 117th to 113th	27.28	27.10	28.33	28.63	27.72	27.67	26.13	28.25	26.36	26.87	27.433347	0.838001
3. 113th to 108th	35.76	36.02	36.01	36.57	37.14	36.02	37.91	37.54	36.07	37.57	36.663181	0.804182
4. 108th to 102nd	41.35	40.57	41.08	43.49	42.28	41.44	40.09	41.56	39.70	40.43	41.198187	1.109045
TOTAL	139.19	138.17	139.16	143.17	142.46	139.27	139.53	141.76	135.18	140.26	139.81706	2.30065
West to East:												
1. 102nd to 108th	48.92	42.89	44.39	51.52	51.54	43.60	57.61	42.88	45.05	52.77	48.11858	5.101385
2. 108th to 113th	39.83	41.84	41.09	40.22	39.97	40.89	39.49	40.70	40.93	40.02	40.497134	0.712027
3. 113th to 117th	32.87	33.37	33.91	34.37	33.70	33.17	32.37	34.52	35.53	34.00	33.78104	0.906076
4. 117th to 122nd	41.99	42.35	43.44	41.36	42.55	42.18	42.23	42.44	41.39	42.00	42.193879	0.594114
TOTAL	163.60	160.45	162.83	167.47	167.77	159.85	171.71	160.54	162.91	168.79	164.59063	4.078486

Table C-2. Calibrated Model Travel Time Comparison to Validation Data (TransSim II^{TM})

	Validation Data				Model w/LRT	
Network 1: Los Angeles:	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
West to East:						
1. Flower to Grand	27.50	18.62	33.97	9.34	36.84	0.99
2. Grand to Olive	24.83	21.09	-45.37	-11.26	13.57	0.27
3. Olive to Hill	14.50	20.34	16.27	2.36	16.86	0.77
4. Hill to Broadway	17.67	17.70	6.89	1.22	18.89	0.44
5. Broadway to Main	31.00	25.64	-44.96	-13.94	17.06	0.40
6. Main to Los Angeles	17.67	18.23	13.14	2.32	19.99	0.41
TOTAL	133.17	16.42		-9.96	123.21	2.35
East to West:						
1. Los Angeles to Main	18.67	18.88	-7.89	-1.47	17.19	0.54
2. Main to Broadway	27.00	21.27	-26.56	-7.17	19.83	0.24
3. Broadway to Hill	26.00	25.21	-35.48	-9.22	16.78	0.64
4. Hill to Olive	16.33	16.84	-45.75	-7.47	8.86	0.26
5. Olive to Grand	6.67	1.03	181.78	12.12	18.79	0.85
6. Grand to Flower	52.00	20.28	-7.08	-3.68	48.32	0.75
TOTAL	146.67	29.29		-16.91	129.76	2.15
Network 2: Los Angeles	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
West to East:						
1. Los Angeles to Maple	37.50	20.16	-41.06	-15.40	22.10	0.52
2. Maple to Trinity	28.83	11.62	-6.63	-1.91	26.92	0.60
3. Trinity to San Pedro	15.67	2.16	20.35	3.19	18.86	0.26
4. San Pedro to Griffith	41.33	7.12	-19.06	-7.88	33.45	0.29
5. Griffith to Central	33.17	21.25	-22.68	-7.52	25.65	0.14
6. Central to Naomi	35.67	34.76	-31.77	-11.33	24.34	0.09
7. Naomi to Hooper	17.00	3.58	-4.86	-0.83	16.17	0.06
8. Hooper to Long Beach	62.17	4.96	-23.78	-14.78	47.39	0.36
9. Long Beach to Alameda	73.50	5.75	-39.97	-29.38	44.12	0.30
TOTAL	344.83	73.44		-85.83	259.00	2.03
East to West:						
1. Alameda to Long Beach	22.33	1.37	35.54	7.94	30.27	0.31
2. Long Beach to Hooper	20.67	2.58	53.68	11.10	31.77	0.48
3. Hooper to Naomi	13.83	1.60	26.33	3.64	17.48	0.07
4. Naomi to Central	18.67	2.25	71.45	13.34	32.01	0.21
5. Central to Griffith	23.67	3.08	-2.42	-0.57	23.09	0.06
6. Griffith to San Pedro	29.17	3.06	15.00	4.37	33.54	0.19
7. San Pedro to Trinity	14.00	0.89	-5.51	-0.77	13.23	0.01
8. Trinity to Maple	17.17	2.71	19.12	3.28	20.45	0.10
9. Maple to Los Angeles	17.83	1.47	3.33	0.59	18.43	0.13
TOTAL	177.33	3.61		42.94	220.27	0.72
Network 3: Long Beach	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
South to North:						
1. 1st to Broadway	41.83	17.17	-55.35	-23.15	18.68	7.31
2. Broadway to 3rd	12.67	4.80	-41.56	-5.26	7.40	0.29
3. 3rd to 4th	11.50	2.17	-16.26	-1.87	9.63	0.94
4. 4th to 5th	9.17	0.75	47.78	4.38	13.55	1.68
5. 5th to 6th	36.00	4.73	33.89	12.20	48.20	5.58
6. 6th to 7th	12.00	0.89	38.21	4.59	16.59	4.14
7. 7th to 8th	15.17	7.76	-24.60	-3.73	11.44	1.06
TOTAL	138.33	26.70		-12.85	125.48	16.36
North to South:						
1. 8th to 7th	42.50	16.67	31.30	13.30	55.80	17.50
2. 7th to 6th	18.33	14.09	65.20	11.95	30.29	10.50
3. 6th to 5th	11.00	1.67	-31.94	-3.51	7.49	0.38
4. 5th to 4th	11.00	2.45	49.43	5.44	16.44	2.27
5. 4th to 3rd	44.67	17.00	-73.88	-33.00	11.67	1.52
6. 3rd to Broadway	19.50	19.37	20.44	3.99	23.49	4.32
7. Broadway to 1st	15.33	11.69	36.97	5.67	21.00	1.79
TOTAL	162.33	32.37		3.84	166.17	20.85

Table C-2. Calibrated Model Travel Time Comparison to Validation Data (TransSim II™ - continued)

Network 4: Portland:	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
West to East:						
1. MLK to Grand	36.71	7.47	-28.91	-10.61	26.10	5.15
2. Grand to 6th	14.71	5.67	27.63	4.07	18.78	5.13
3. 6th to 7th	12.29	4.98	5.33	0.65	12.94	3.61
4. 7th to 9th	20.57	8.82	7.77	1.60	22.17	1.45
5. 9th to 11th	26.29	9.10	11.85	3.11	29.40	1.04
6. 11th to 13th	18.29	1.18	43.45	7.94	26.23	1.06
TOTAL	128.86	13.31		6.75	135.61	13.70

Network 5: Portland:	Mean	Std. Dev.	Percent Difference	Delta	Mean	Std. Dev.
East to West:						
1. 122nd to 117th	30.00	8.29	15.07	4.52	34.52	0.76
2. 117th to 113th	30.29	7.02	-9.42	-2.85	27.43	0.84
3. 113th to 108th	33.14	4.20	10.62	3.52	36.66	0.80
4. 108th to 102nd	38.43	12.33	7.21	2.77	41.20	1.11
TOTAL	131.86	13.31		7.96	139.82	2.30
West to East:						
1. 102nd to 108th	35.86	4.12	34.20	12.26	48.12	5.10
2. 108th to 113th	34.14	7.63	18.61	6.35	40.50	0.71
3. 113th to 117th	20.43	3.63	65.36	13.35	33.78	0.91
4. 117th to 122nd	64.00	19.43	-34.07	-21.81	42.19	0.59
TOTAL	154.43	24.78		10.16	164.59	4.08