TRANSPORTATION ANALYSIS SIMULATION SYSTEM (TRANSIMS)

RELEASE 1.0

The Dallas-Ft. Worth Case Study

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Forward

There are three fundamental aspects of the transportation planning process that establish the context for future improvements in both process and product. The product in this case is transportation systems. The process, for the purpose of this paper, relates to the technical tools used to assist policy leaders in decision-making.

1) The first item establishing the context for an enhanced urban transportation decision-making process comes from all three branches of the U.S. government. Recent trends have placed emphasis on more technical and systematic decision-making. Congress has clearly established this desire in both the 1990 passage of the Clean Air Act and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). Courts in San Francisco and Chicago, to name a few, are placing greater weight on the technical elements of the transportation planning process, and the Executive Branch has passed Executive Orders and regulations from equity analysis to air quality conformity.

2) The second context for transportation planning is the *reality* of decision-making. Issues related to constraints on land availability, needed financial resources, and environmental constraints (e.g., hydrology, earthquakes, and safety) have placed greater demands on consensus building. Adding the increasing attention on quality of life and sustainable communities, public access and involvement have grown to new heights. The information demands, expectations, quality control, and validation standards of a fully operational public involvement process are, at times, overwhelming. It is not uncommon for major transportation corridor improvements under such constraints to exceed $500 million.

3) The third item (and the one that typically gets most of the ink on this topic) is the adequacy of the current modeling and technical tools in being able to respond to questions and requirements never imagined when such tools were developed. For example, authors of the Highway Performance Monitoring System never imagined its use in constraining vehicle miles of travel estimates for air quality purposes. The behavioral context of current tools was responding to a time when the questions being asked were largely roadway oriented and freeway in nature. The contextual factors have changed dramatically, and so should the technical tools. Today's technology permits a response to these fundamental needs.

Partnership Direction of Transportation Implementation

Today it is rare that one public entity can design, fund, and obtain public support without the assistance of others. It takes the support of the impacted neighborhoods, the private sector, goods movement interests, transportation authorities, state interests, and the Federal government. This partnership *reality* is at the hub of both the Clean Air Act and ISTEA. Not since the 1970s have we had a Federal government willing to take a leadership position on responding to the need for improved transportation planning technical tools. The U.S. Department of Transportation (DOT) has established a Travel Model Improvement Program (TMIP) to address five specific areas for improvement:

1) Near-term model needs

2) Data collection

3) Land use models

4) Long-term model needs

5) Technology transfer

No one area is more important than the next. This multi-prong approach is designed to respond to the contextual demands summarized above and the partnership *reality* in constructing tomorrow's transportation systems today. Through ISTEA, partnerships are being enhanced and developed and new technical tools are being asked to respond to the scrutiny of all its partners.

TRANSIMS

The TRansportation ANalysis and SIMulation System (TRANSIMS) is the tool being developed by Los Alamos National Laboratory (with assistance from metropolitan planning organizations, states, and research interests) to address the long-term model needs in urban transportation planning. The DOT has sponsorship from the Federal Highway Administration, Federal Transit Administration, and the Office of the Secretary. The Environmental Protection Agency and Department of Energy are also funding work in this partnership effort.

TRANSIMS is an approach with tremendous upside gain. It is not intended to be used to respond to every transportation inquiry, but is intended to better identify the behavioral elements of our transportation choices. Its application will be more slanted to both regional system planning uses and major investment studies. This Dallas-Ft. Worth case study is corridor-specific and tests the microsimulation module and the fundamental behavior of a vehicle driver that has all of the socio-economic characteristics of real world drivers.

Although you would think that, at this point in our understanding of transportation, we would already know driving behavior and microsimulation pretty well, nothing could be further from the truth. Driving behavior has very significant implications on air quality planning (e.g., hard acceleration and stop-and-go traffic), as well as in activity planning and selection of route choice from origin to destination. TRANSIMS is a national initiative that has drawn together interested partners in a collaborative process. The research is far from over, but the first case study on the first module is preparing us for the 21st Century – not alone, but in conjunction with improvements to data collection, land use integrations, near-term model needs, and technology transfer.

Dallas-Ft. Worth Case Study Results

The following points highlight the Dallas-Ft. Worth case study findings:

- Travel time feedback to the trip planner is necessary and impacts activity plans and route choice.
- The uncertainty analysis confirms that the order of model sensitivity is 1) assignment of trip activities, 2) feedback to route choice, and 3) microsimulation randomness.
- New performance measures, such as transportation reliability or percent time under engine load, can be established.
- Arterial street improvements, including traffic engineering operations, can be simulated in the same model system as traditional transportation systems.
- The study findings show that freeway improvements were better for certain hours of the day, whereas arterial improvements were better for other hours.

- Equity analysis was demonstrated by land-use type as well as by travel orientation (i.e., through and local).

- Coding is very detailed, with sensitivity analysis yet to be conducted to determine network requirements.

- Computer simulations were conducted in real time, with second-by-second movements of 200,000 planned activities over a five-hour period.

- Application use remains both regional (to support air quality needs and system planning) and corridor-specific (to support financial decisions and consensus building in major investment studies).

Unfortunately, we often witness these breakthroughs in technology as ordinary.

Implications

This case study on microsimulation began with a roadway network where

- geometric conflicts are resolved with literal representation of roadway pavement,

- local or neighborhood streets are included,

- intersection detail is present,

- traffic signals are included, and

- traffic loading nodes are coded.

The result is a second-by-second microsimulation on a robust network. It is premature at this point to conclude if all of this detail will end up being necessary. Subsequent sensitivity tests will determine the feasibility, accuracy, and overall value of less detailed networks.

Improvements in the interim software have already been developed in response to the case study. One set of improvements updates the driver's behavior logic, and a second establishes feedback to the trip planner for improving route choice. Additional improvements in microsimulation will be developed after the other TRANSIMS modules have progressed to the completion level of the microsimulation module. In addition to the sensitivity testing of network detail, parametric testing of driver behavior rules and microsimulation fidelity will be conducted. And finally, new performance measures and techniques are under review to enhance decision-making, with work already begun in Portland to develop the trip planner module.

As you can see from the Dallas-Ft. Worth case study, technology is responding to the context of transportation planning today and the *reality* of constraints in urban transportation corridors. The journey has begun!

M. Morris
North Central Texas Council of Governors

Executive Summary

Goal

The goal of the TRANSIMS case study in Dallas-Ft. Worth (DFW) was to demonstrate a working traffic microsimulation using data provided by DFW to address realistic planning issues in this region. Integral to the case study was the development of new measures of effectiveness that significantly complement and extend traditional analysis techniques.

Background

This document summarizes the results and conclusions from the TRANSIMS case study conducted in Dallas-Ft. Worth. The goal of the TRANSIMS project is to conduct major research and development of fundamentally new approaches to travel demand forecasting. The long-term project emphasizes and quantifies aspects of: (1) activity-based travel demand; (2) intermodal trip planning; (3) traffic microsimulation; and (4) air quality and other macro analyses using four computational modules within a single, unified architecture that is presented in Figure 1 (see Appendix A). These modules are still in development; interim versions of the first three modules were used for the DFW case study with emphasis on the microsimulation module.

TRANSIMS represents a marked change from traditional demand forecasting and impact analysis methods commonly in use. New technical approaches in TRANSIMS respond to equity issues, technology issues (e.g., the Intelligent Transportation Infrastructure (ITI)), and Federal legislative concerns manifested in issues derived from the Intermodal Surface Transportation Efficiency Act (ISTEA) and the Clean Air Act Amendments (CAAA).

TRANSIMS maintains individual traveler identities throughout the four modules of the architecture indicated in Figure 1 (see Appendix A). Traveler identities are generated through the development of a synthetic population for a specific metropolitan region using a variety of data sources, including census data and surveys. The intermodal route plans generated by the planner module maintain traveler identities, as does the microsimulation. Traffic dynamics emerge from the resulting simulation output, which provides a detailed time history of every traveler in the system. Impact studies are conducted based on the output of the synthetic population, intermodal planner, and microsimulation modules. This approach produces an elegantly simple, consistent architecture – one that provides planners with a deeper insight into the underlying second-to-second dynamics of the traffic system under different local and global conditions. TRANSIMS is computationally intense, but affordable hardware and software that will be available within the next two years is adequate to address TRANSIMS computational requirements.

All traditional analyses can be done with TRANSIMS using the aggregate, summary data that results from the microsimulation. However, one of the real advances represented by TRANSIMS is the ability to provide new and different insights about the transportation system under study.

Methodological Advances Demonstrated in the DFW Case Study

The TRANSIMS project has developed and successfully demonstrated feasible technical approaches for conducting the following four analyses:

1) **Variability Analyses.** Aggregate methods normally depend on averages and expected values of such key variables as link travel times and link speeds. These averages pertain to all vehicles using the links during a given time period. Estimates for the averages are based

on simple models that notionally relate traffic volume to the average speed of all vehicles using a particular link. *In contrast*, TRANSIMS uses local interactions of simulated vehicles (updated every second) to *generate* instantaneous vehicle speeds that can be averaged over user-defined time periods. These averages are sensitive to signal timing, local traffic conditions, ITI options, etc. Because travelers are tracked throughout, TRANSIMS can produce variability measures by comparing the impact on individual travelers or subpopulations of travelers with overall population trends. Statistical measures generated by these methods can address questions such as:

- “What is the variance, or spread, in total travel times for the subpopulation of mall travelers between the infrastructure changes being considered?”

- “Given that the average travel time for the subpopulation of mall travelers improves, does the variance or spread of their travel times improve also, and if so, by how much?”

Variability measures are extremely important. They may be used (1) to assess infrastructure reliability, (2) in equity analysis, and (3) to assess uncertainty induced by the model components. These variability measures are discussed in the following sections.

2) **Infrastructure Reliability Analyses**. Much of the inspiration for this new type of analysis and thinking is motivated by the insights of the DFW North Central Texas Council of Governments (NCTCOG). The basic notion is to define the network *reliability* in terms of its dependability to meet traveler expectations day to day. For example, if a certain percentage of the population, say 5%, experiences a dramatic variation in the time it takes to make the same trip, using the same route, under the same conditions from one day to the next, one could subjectively conclude that their individual view of the dependability of the network is "iffy". That is, these travelers are not very confident that they can accurately predict, day to day, how long their trips will take. It is a matter for transportation planners to decide acceptable measures on how big the percentage of the population who view their travel time predictions as "iffy" can be, and how large the variance in their travel time can grow to make some conclusion about the *UN-reliability* of the network from day to day. However, this measure, which is easily computed by TRANSIMS, is relevant and manifests itself frequently in real traffic systems – especially those at or near maximum capacity. Having the capability to compare proposed infrastructure alternatives using measures such as reliability is unique to TRANSIMS and codes that track individual travelers. These measures will allow planners to focus better on that subset of the population likely to be dissatisfied because, as individual travelers, they get "jerked around" day to day by differences experienced in actual travel times on repeated trips such as home to work. If the percentage of travelers in this category is large enough and the variability in travel time is big enough, these factors are likely to be of greater importance to planners than improving the average travel time for the overall population by some marginal amount.

3) **Equity Analyses.** Equity analysis is an important aspect of any travel network study. The subpopulations used for equity comparisons may be based on travel characteristics such as origins or destinations, length of trips, or traveler demographics. The availability of tracking information on individual travelers in TRANSIMS makes partitions of the populations based on any of these factors very simple. In the future, as TRANSIMS is to include environmental and other kinds of impact analyses, one also can begin to measure effects such as the total pollution, energy utilization, etc., attributable to a given subpopulation such as the mall travelers. While traditional equity analyses usually discriminate subpopulations based on

information intrinsic to the supporting databases (e.g., zone of origin, type of trip, etc.), TRANSIMS provides an interesting capability to discriminate subpopulations based on dynamic information resulting from the microsimulation. For example, one could ask if there is any correlation between the subpopulation of travelers experiencing a large variability in travel times day to day, where they live, what routes they have in common, etc.

4) **Uncertainty Analyses.** Like all simulations or models, TRANSIMS only approximates reality. Accordingly, it is imperative for analysts and decision makers to understand how much of the change in simulation results is attributable to the structural properties of the computational components of the simulation. These types of effects are defined as *uncertainty* in simulation results induced by the computational system itself. For example, if a particular algorithm represents a random process, one would like to know how changing a random number seed will affect the simulation results. If these effects are large compared to effects attributable to an infrastructure change, then, on the basis of the simulation results, one should be much less confident that the infrastructure change will make any difference. There has been a significant effort in the first case study to define and quantify the effects of uncertainty.

Description of the Case Study and Results

The DFW case study emphasized the use of the microsimulation module of TRANSIMS. Because the TRANSIMS microsimulation uses individual traveler plans as input (see Figure 1), methods were developed as part of the case study to use existing DFW zonal production/attraction (PA) matrices as the source of traveler demand on the system. Only vehicle trips were considered. Figure 2 (see Appendix A) shows the relationship between the interim DFW TRANSIMS capability and the traditional four-step planning process. Aggregate zone-to-zone traveler demand derived from the four-step distribution process was disaggregated on a traveler-by-traveler basis. The disaggregation was performed in space and time:

- Space. Zones were disaggregated to individual point locations within each zone, which represented the locations of households and businesses.

- Time. Time blocks associated with the PAs were disaggregated statistically to produce actual start times represented to the second (e.g., 7:24:32 a.m.).

To produce traveler plans, the TRANSIMS interim Route Planning module used disaggregated travelers derived from 800 zones in the DFW PA data, which is in essence all of the planning zones in the DFW region. The disaggregated data represented 3.5 million trips over the five-hour period of 5:00 to 10:00 a.m. The routing was throughout a region of 3,900 square miles where 9,300 miles of roadway within the DFW region were represented. This region considered by the Route Planning module is called the ***traveler planning region*** (see Figure 3, Appendix A).

Within the traveler planning region is a more focused mile region that was the subject of the study. This region is called the microsimulation ***study region.*** The roadway network within the study region was represented in more detail than in the planning region; the representation included freeways, arterials, and local streets. Two major roadways bisect this region: the Lyndon B. Johnson Freeway (I-635), which runs east-west; and the Dallas North Tollway, which runs north-south. Near the intersection of these major roads are two major malls, the Galleria and Valley View Mall. The microsimulation output was used to compare two alternative improvements to the highway infrastructure in the vicinity of these two major, heavily used malls. Ostensibly, these improvements were intended to alleviate the congested conditions along the LBJ corridor adjacent to the malls during rush hour. Infrastructure Change 1 (IC1) added another lane to I-635 in both directions. Infrastructure Change 2 (IC2) included additional lanes on four major arterials, additional frontage roads to improve continuity and Galleria access, a grade-separated intersection, and additional turn bays at several major intersections.

Computations supporting the case study were conducted in the following way for the base case and each of the two alternatives. First, travelers and their associated activities were produced by the traveler disaggregation module shown in Figure 2. They were held constant for each of the alternatives, except for some random variations in travel time departures used for uncertainty analyses. All trips were automobile trips. The planner module produced a minimum time route plan for each of the travelers. Travel times for each link were estimated initially based on free flow traffic conditions.

Next the simulation was run as each traveler tried to follow the given route plan. Based on realized travel times from the microsimulation, a certain percentage of the plans were replanned using the updated travel time estimates. This procedure was repeated until the overall iterated solution between the planner and microsimulation produced reasonable traffic patterns. This feedback and replanning between the microsimulation and planner was a feature that the project team had not anticipated completing and using during the first case study.

The Study Issue

The study focused on understanding to what degree, if any, each of the two considered infrastructure alternatives helped alleviate the congested conditions along I-635 during the morning rush hour.

Results Using Traditional MOEs

Figure 4 (see Appendix A) shows the comparison, in median travel times, for each alternative and the baseline by time of day. Note the peak for each infrastructure during the *rush hour* period between 7 and 9 a.m. The results showed that both IC1 and IC2 improve this metric for the entire population by an approximately equal measure. Importantly, IC2 (improvements to the arterial network) showed a greater improvement for the entire population during the critical period of 8 to 9 a.m. This result was somewhat surprising because it was not expected that arterial changes would improve the overall result this much and in this way.

Reliability Measures of Effectiveness

Network reliability, a new Measure of Effectiveness (MOE) introduced into the DFW case study, is show in Figure 5 (see Appendix A). Network reliability is a measure of day-to-day variability in travel times experienced by a selected proportion of travelers. Figure 5 shows the travel time variability for the 5% of the population with the largest variability. One could interpret travelers in this category as those least confident that their expected time of travel for a given trip will be realized. From Figure 5, one can say that IC2, the arterial infrastructure change, is the most effective in reducing the day-to-day variability of travel times; hence, it is the *most reliable* network of the alternatives. The increased reliability is evident as early as 7 a.m.

Equity Issues

Both of the subpopulations, the mall and non-mall travelers, benefited from both of the infrastructure changes. The mall travelers benefited more from the arterial infrastructure change (IC2) than they did from adding lanes to the I-635 (IC1). Moreover, there was a slight but noticeable improvement to non-mall travelers stemming from the arterial infrastructure change when compared to the freeway change in IC1.

Uncertainty Analyses

Figure 6 (see Appendix A) shows the results of the uncertainty analyses that were conducted as part of the case study. Contrasting Figure 6 with Figure 4, notice that there are three solid lines for the base case infrastructure rather than just one. These results are not usually given by other simulation systems, but for any system, they are necessary to completely assess the study results. They show the size of the possible uncertainty in the base case results. These uncertainty results were computed by first varying the random number seed that governs the vehicle-to-vehicle dynamics in the microsimulation, and second by varying the individual trips to be replanned during the iteration between the microsimulation and interim route planner (see Figure 2). The results show the size of the possible uncertainty in the base case results caused by the intrinsic computational properties of the TRANSIMS system. Because median travel times of both infrastructure results are outside of this uncertainty band, both infrastructures can be said to improve travel times to a degree greater than the uncertainty of the underlying simulations system. Were this not the case, the team would be much less confident that the impact of the simulated infrastructure changes was really significant.

Calibration and Validation

In TRANSIMS, calibration and validation are different concepts and are assessed by using two different analysis techniques.

- Calibration has to do with comparing microsimulation output to the observed dynamics of the real traffic systems or references, such as the Highway Capacity Manual (HCM). The microsimulation is calibrated with simplified networks that are representative of selected portions of the real system (e.g., a four-lane signalized intersection). The characteristics of traffic simulated on these networks, such as flow-density relationships and the number of left turns across oncoming traffic, are compared to standards derived from established references such as the HCM. The microsimulation in the case study matches these standards.

- Validation is concerned with the comparison of traffic counts on a study network with *ground truth* volumes collected by NCTCOG. Validation is carried out with comparisons of peak hour simulated counts and NCTCOG estimated volumes. There is good agreement between these two techniques for all classes of roadway except collectors, which are not estimated well by NCTCOG.

Conclusions

The DFW case study successfully demonstrated the TRANSIMS interim operational capability. Using existing DFW production/attraction zonal data, activities and plans for approximately 3.5 million travelers were generated for the hours of 5:00 to 10:00 a.m. Of these plans, those falling within a 25-square mile study region were used as input to the microsimulation module to compare two infrastructure changes with respect to how each helped alleviate congestion. Traditional Measures of Effectiveness (MOEs) such as median travel time and median speed were used as a basis of comparison, as well as new measures such as ***network reliability*** and ***traveler variability.*** While both alternatives improved congested conditions and flow along the freeway from the viewpoint of traditional MOEs, the project team was surprised that the alternative of improving local arterials was superior to the alternative of adding lanes to the freeway from the perspective of ***network reliability.*** The case study also demonstrated the capability to feed back microsimulation results into the route planner, which had the effect of producing very reasonable traffic patterns for the whole population of travelers. Another phenomena noted during the iterated planner and microsimulation runs, was that as capacity improved with both options, they both had the effect of ***inducing additional demand*** by about 10%, thus offsetting the improvements somewhat.

Of the many test runs made during the study, the full report describes only a few of the results available in the output data. The DFW NCTCOG will, over a period of months, begin to perform sensitivity analyses both using data already computed, and producing new simulation results to test other features of the Interim Operational Capability. In addition, the project team anticipates working with a number of Universities that will use the IOC as a basis for teaching curriculums and research.

In the next phase of the project focused in Portland, Oregon, TRANSIMS will continue to pursue the goal of providing broader, more in-depth insight and information about the complex nature of transportation. Moreover, the intent remains to deliberately design a solution that is usable and affordable, and properly anticipates advances in computing and information technology available at the turn of the century. The project believes that the results of the DFW case study show that, while much remains to be done, the potential to achieve these ambitious goals is at hand.

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1. INTRODUCTION

The TRansportation ANalysis and SIMulation System (TRANSIMS) is part of the multi-track Travel Model Improvement Program sponsored by the U. S. Department of Transportation (DOT) and the Environmental Protection Agency (EPA). Los Alamos National Laboratory (LANL) is leading the development. TRANSIMS addresses issues resulting from the Intermodal Surface Transportation and Efficiency Act of 1991, such as considerations of intermodal connectivity and enhanced transit service. It supports analyses of potential responses to the stringent air-quality requirements of the Clear Air Act Amendments of 1990.

The objective of the TRANSIMS Project is to develop a set of mutually supporting realistic simulations, models, and databases that employ advanced computational and analytical techniques to create an integrated regional transportation system analysis environment. By applying forefront technologies and methods, TRANSIMS simulates the dynamic details that contribute to the complexity inherent in transportation issues, both today and tomorrow. The integrated results from the detailed simulations support transportation planners, engineers, and others who must address environmental pollution, energy consumption, traffic congestion, land use planning, traffic safety, intelligent vehicle efficacies, and the transportation infrastructure effect on the quality of life, productivity, and economy.

The TRANSIMS methods deal with individual behavioral units and proceed through several steps to estimate travel. It is an activity-based system. Trips are generated from these activities for individual households, residents, freight loads, and vehicles, rather than for zonal aggregations of households. The Household and Commercial Activity Disaggregation (HCAD) Module creates regional synthetic populations and activities from census and other data.

The Intermodal Route Planner involves the use of a demographically defined travel cost decision model particular to each traveler. Vehicle and mode availability are represented, and mode choice decisions are made during route plan generation. The method estimates desired trips not made, induced travel, and peak load spreading. This allows evaluation of different transportation control measures and travel demand measures on trip planning behaviors.

The Transportation Microsimulation executes the generated trips on the transportation network to predict the performance of individual vehicles and the transportation system. It attempts to execute the travel itinerary of each individual in the region. For example, each passenger vehicle has a driver whose driving logic attempts to execute the plan, accelerates or decelerates the car, or passes as appropriate in traffic on the roadway network.

The Transportation Microsimulation produces traffic information for the Environmental Models and Simulations to estimate motor vehicle fuel use, emissions, dispersion, transport, air chemistry, meteorology, visibility, and resultant air quality. The emissions model accounts for both moving and stationary vehicles.

Figure 1 is a schematic diagram of TRANSIMS and the connections among the TRANSIMS modules. Information flows in both directions among the modules. This feedback is extremely important. Without it, proper traffic dynamics cannot be achieved. This is shown in the methodology used to generate trips for the case study.

The case study involved a microsimulation of an area of Dallas-Ft. Worth, Texas. It was supported by the North Central Council of Governments (NCTCOG). The geographic area and the significance of the study are described in Section 2, *Case Study Description*.

TRANSIMS is being developed in stages. At any time, more effort is placed on one of the modules and less on the others. From this effort, an Interim Operational Capability (IOC) of one of the modules is developed. The microsimulation is the first IOC of TRANSIMS (IOC-1). The purpose of this case study is to demonstrate IOC-1, the microsimulation module, and the analysis capabilities possible when data on every traveler is available. IOC-1 considers only vehicular traffic; it does not consider freight or transit. The environmental module is not part of this study. These capabilities will be considered in future IOCs.

As shown in Figure 1, the TRANSIMS microsimulation depends on individual routes; these routes, in turn, depend on a set of household activities. Therefore, a rudimentary set of algorithms for the generation of activities from production-attraction matrices and a slightly more sophisticated set of algorithms for the determination of routes for individual travelers were developed for this study. These methods are preliminary and are not intended to be the standard TRANSIMS methodology.

The following sections of this report contain descriptions of the case study and the methods used for each of the TRANSIMS modules. Techniques for calibration of the microsimulation and validation of the microsimulation results with respect to Dallas-Ft. Worth roadway volumes are presented. An experimental design is outlined which allows for the investigation of the effects of three infrastructures on the travel characteristics of multiple populations.

TRANSIMS differs from the traditional methods for traffic analysis. These differences are in both the approach to the problem and in the resulting studies made with these tools. Traditional analysis relies on the average traveler and equilibrium solutions to estimate the average travel characteristics on a network. TRANSIMS, on the other hand, focuses on local interactions among the travelers to produce global traffic dynamics. Because TRANSIMS collects information on each traveler, in addition to conventional analysis techniques, important avenues of study that are not available with conventional tools become possible. Many of these avenues of study are based on the concept of a measured quantity, such as travel time, across a population. The two most important avenues are the study of uncertainty and the measurement of network reliability.

Understanding variability and uncertainty is critical for both decision makers and researchers. All models produce results that are not absolutely true. It is imperative for decision makers to comprehend this and to have some knowledge of the uncertainty in any result derived from models. Also, researchers must understand the components of model uncertainty in order to push their research efforts to the most profitable areas of study. Therefore, the first study presented in this paper demonstrates a methodology for determining the total uncertainty in a TRANSIMS analysis. This investigation includes a study of the components of TRANSIMS uncertainty: the uncertainty induced by the activities, the planner, and the microsimulation. These comparisons are detailed in Section 10, *Base Case: Uncertainty.*

Having information about individual travelers leads to interesting studies of network reliability. Because measures such as individual travel times and speeds are a function of local congestion and traffic signal timing, small differences in trip starting times and local interactions among vehicles causing different lane changes and vehicle velocities can produce large differences in these measures. For individual travelers, these differences measure day-to-day variability in travel times and speeds caused by the network. Hence, they are a measure of network reliability. Section 11, *Base Case: Network Reliability*, presents a methodology for the study of this effect. In Section 11, two techniques for estimating reliability are explained. It is shown that the median, or average, difference in travel times and speeds is not necessarily the best gauge of traveler dissatisfaction with the network. The 5 to 25% of travelers with the largest travel time or speed differences are also investigated, because it is these travelers who are most dissatisfied with the existing travel conditions. It is shown that these measures of network reliability may be used to analyze the effectiveness of infrastructure changes.

The remainder of the report involves equity analysis, which is an important aspect of any travel network study. In these investigations, the gains and loses by subpopulations of travelers are analyzed. The subpopulations may be based on any traveler characteristics such as the trip origins or destinations, length of trips, or traveler demographics. Once again, the availability of information on individual travelers in TRANSIMS makes partitions of the populations based on any of these factors extremely simple and measures of variability possible. The equity analysis presented in this report concerns the costs and benefits of infrastructure changes to the subpopulation of travelers that travel to or from a major mall in the study area. An additional analysis is made of those travelers who pass through the study area compared to local travelers.

The report concludes with a summary of the results of this study. The results depend on the planner and the generation of a true set of activities, neither of which are the focus of IOC-1; therefore, absolute reliance on the results shown in this study is unwarranted. However, the analysis methodologies shown in the report are a realistic representation of those possible with TRANSIMS. The population, activity, planner, and microsimulation methodologies used in the case study are described in Section 3, *Activities and Populations*; Section 4, *The Planner*; and Section 5, *Microsimulation*.

TRANSIMS is not a completed product. Because it is in a research and development stage, a section on parametric studies is presented. This section outlines a series of studies that are necessary for future TRANSIMS development. The goal of these studies is to delineate the network detail and the minimal data requirements for successful TRANSIMS studies.

2. CASE STUDY DESCRIPTION

The case study was jointly developed by Los Alamos National Laboratory and the North Central Texas Council of Governments. The intent was to develop a design that was "robust enough" to fully challenge the interim TRANSIMS programs, but yet not be so complex that a typical Metropolitan Planning Organization (MPO) or other agency would find the setup procedures too difficult to implement in their own region.

Both objectives were met with a case study derived from a recent NCTCOG travel model application known as the I.H. 635 (LBJ) Major Investment Study:

- The initial travel model *stick* network (i.e., a network with no shape points between the end nodes of a link) consisted of the 1990 base validation network. This was a *focused* model network that had small analysis zones within the LBJ corridor and larger zones elsewhere (the zone size increased as the distance from the corridor increased). The level of network detail (i.e., inclusion of collector and arterial streets) reflects what was needed to properly connect the centroid of each zone to the network. Within the LBJ corridor, collector streets and higher classifications were coded; for the largest zones outside the corridor, only freeway links were coded.

- The initial 800-by-800 zone production-attraction vehicle trip tables (for home-based work, home-based nonwork, nonhome based, and other trip purposes) were obtained by dividing the 1990 person trip tables by the model-calculated zone-to-zone occupancy factors.

While the 3,218-square-mile Metropolitan Planning Area network and trip tables were used for traveler disaggregation and route planning, a smaller -mile study region was the focus for the traffic microsimulation. Table 1 shows the demographic characteristics of the planning area and study region for the case study.

Table 1: Demographic Characteristics of Case Study

	Microsimulation Study Region	Dallas-Ft. Worth Metropolitan Planning Area	Ratio, Study Region/ Planning Area
Area (Square Miles)	25	3,218	0.0078
Households – 1990 – 2010 – 2010/1990	38,472 47,709 1.24	1,350,667 1,910,199 1.41	0.0285 0.0250 ----
Population – 1990 – 2010 – 2010/1990	82,108 93,052 1.13	3,544,397 4,728,997 1.33	0.0232 0.0197 ----
Employees – 1990 • Basic • Retail • Service • Total	 20,269 24,083 56,433 100,785	 660,368 366,002 1,017,558 2,043,928	 0.0307 0.0658 0.0555 0.0493
Employees – 2010 • Basic • Retail • Service • Total	 24,670 33,126 74,428 132,224	 969,014 518,583 1,578,082 3,065,679	 0.0255 0.0639 0.0472 0.0431
Employees – 2010/1990 • Basic • Retail • Service • Total	 1.22 1.38 1.32 1.31	 1.47 1.42 1.55 1.50	 ---- ---- ---- ----

Note that,

- In 1990, the study region had 82,108 people and 100,785 employees, which represents 2.3% of the planning area population and 4.9% of the planning area employment.
- In 2010, the study region is forecasted to have 93,052 people and 132,224 employees, which represents 2.0% of the planning area population and 4.3% of the planning area employment.
- Employment in the study region is primarily service (office) oriented: 56.0% of all employees in 1990 and 56.3% of all employees in 2010.

The selection of the 25-square-mile microsimulation study region was based on a number of factors:

- There is a good mix of residences and work places, which allows for both low-volume and high-volume driveway locations to be represented.
- There is a full range of roadway types, from alleys and cul-de-sacs in residential areas to the east-west LBJ Freeway and the north-south Dallas North Tollway.
- There is both recurring and non-recurring peak period traffic congestion on LBJ Freeway.

- Current transit and pedestrian activities are minimal (this is significant because the initial TRANSIMS testing focuses only on traffic microsimulation).

- There is a major multi-use activity center (Galleria area, with large office buildings and an up-scale shopping mall) near the center of the study region, which makes it easy to conduct a meaningful equity analysis of subpopulation groups (e.g., Galleria Area versus non-Galleria Area travelers).

Equity analysis refers to who benefits from and who pays for a transportation improvement (i.e., the "winners and losers"). This ability to partition the benefits and costs of a transportation infrastructure change among subpopulations of travelers was a central theme for the entire TRANSIMS case study application.

Figure 7 (see Appendix A) shows the procedures used to convert the initial travel model network and trip tables to the *TRANSIMS format*. The steps for modifying the initial 1990 travel model network included the following:

1) **Resolve network geometrics**. NCTCOG's travel model network was not always *literally coded*. For example, the entry point for an eastbound ramp onto a freeway may actually be located along a frontage road to the east of a four-leg intersection, but yet was coded as if originating at the intersection. The remedy was to modify the base network so that real-world geometrics were depicted.

2) **Add local streets**. Since TRANSIMS deals with individual travelers rather than zonal aggregations of travelers, the decision was made to add local streets onto the existing base travel model network for the 25-square-mile microsimulation study region. ARC/INFO was used to incorporate Census TIGER streets onto the base network:
   - Remove all freeway and ramp links from the TIGER network.
   - Overlay the remaining TIGER network onto the travel model network.
   - Delete the TIGER links that are already represented by a model link (buffering).
   - Merge all remaining TIGER links onto the model network by creating new nodes (concatenation).
   - Subdivide existing link segments so they utilize the new node numbers (conflation).
   - Review the new network and make manual adjustments.

The initial attempt consisted of working with a GIS-based TIGER network and a non-GIS *stick* travel model network. The end result was a number of *buffering problem* situations in which a portion of a TIGER link was calculated by ARC/INFO to be a new link, even though it should have been deleted (see Figure 8, Appendix A). This problem was lessened by replacing the initial *stick* travel model network with a GIS-based travel model network. [Note: an alternative approach would be to convert the TIGER links to *stick* links prior to buffering].

- **Add intersection and signal details**. The network coding structure consists of a series of files (tables) maintained in an Oracle database. Separate tables are used for nodes, links, pocket lanes, and parking places (traffic loading points), lane connectivity, traffic signal phasings, and traffic signal timings (see

- Table 2). Although ArcView was used for network viewing, the initial coding for the case study was based on cumbersome non-GIS procedures (i.e., direct modifications of the individual database files). Most of the intersection and signal data was obtained through field checks (known as windshield surveys), information supplied by local traffic engineers, and professional judgment.

- **Add traffic loading nodes (parking locations)**. The final network coding activity consisted of placing one or more nodes along the non-freeway links, so that individual trips could be loaded onto (or removed from) the TRANSIMS network.

Table 2: Network Coding Details (Information Used for Microsimulation)

File	Information to be Coded
Node	Location (X-Y coordinate)

Link	• End nodes (node A and node B)
	• Length
	• Setback distance from center of intersection to stop line, by direction
	• Number of permanent lanes in each direction
	• Pocket lanes in each direction
	  - Number that are left of the permanent lanes
	  - Number that are right of the permanent lanes
	• Speed limit in each direction

Pocket Lane	• Node into which the pocket lane leads • Link ID on which the pocket lane lies; lane number of the link • Type: turn, pull-out, or merge • Starting position and/or length
Parking Places	Location of traffic loading nodes/points
Lane Connectivity	Identification of all allowed movements through an intersection
Unsignalized Node	Sign control on each incoming link (stop, yield, or none)
Signalized Node	• Seconds of offset from a base intersection • ID# of the timing plan • Start time for the timing plan
Phasing Plan	• ID# of the timing plan • Incoming link, outgoing link, and turn protection indicator (protected or unprotected) for each movement allowed in a particular phase number
Timing Plan	Length of green, yellow, and red clearance interval for each signal phase number

The steps for modifying the four initial 24-hour production-attraction person trip tables included the following:

1) Convert the 24-hour person trip tables to vehicle trip tables by applying the travel model-calculated occupancy factors.

2) Convert the 24-hour production-attraction vehicle trip tables to time-sliced origin-destination tables by applying time-specific P-A and A-P factors obtained from NCTCOG's regional travel survey data.

3) Allocate each zone-based trip end to a random point (X-Y coordinate) within the zone boundary.

In addition to the base network, two infrastructure changes were coded:

1) **Freeway infrastructure change**. The 1990 base network was modified by adding one eastbound main lane on LBJ (I.H. 35E to U.S. 75) and one westbound main lane on LBJ (U.S. 75 to I.H. 35E). No changes were made to ramp configurations or frontage road/arterial signal timings.

2) **Local infrastructure change**. The 1990 base network was modified by a series of non-freeway improvements:
   - new roadways (three segments, two of which were frontage road links);
   - widened roadways (four long routes);
   - new signalized intersections (three locations);
   - median closures (four unsignalized intersections); and
   - intersection improvements (double left turns, free right turns, and a grade separation).

3. ACTIVITIES AND POPULATIONS

The TRANSIMS structure requires a population of travelers and their activities. A list of demographic characteristics represents an individual in a population. A set of activities is assigned to each individual. These activities have both a spatial and a temporal component to signify the location of the activity and the time it takes place. Individuals are subsequently routed to fulfill their activities. The microsimulation then executes the individual routes. Because activities and populations are not the focus of this case study, pseudoactivities and populations were created and routed. The populations were generated by using data from the National Personal Transportation Survey (NPTS) and the Public Use Microdata Samples (PUMS) from the Census Bureau. Activities were created to match the Production-Attraction (PA) matrices from NCTCOG.

In TRANSIMS, a trip is inferred when two separate activities are schedule at two different times and two distinct locations. Therefore, a list of known trips can generate a set of pseudoactivities by scheduling two activities for each trip. One activity takes place at the trip origin; the other takes place at the trip destination. The NCTCOG PA matrices list the number of trips, over 10 million in total, for 800 Traffic Analysis Zones (TAZ) in the Dallas-Ft. Worth area, by trip type, for a 24-hour period. The NCTCOG trip types are: home-based work, home-nonwork, nonhome-based, and other. A set of pseudoactivities was produced for the trips represented in these trip tables. Additionally, a separate traveler was generated for each pair of activities or trip in the PA matrices. PUMS and NPTS were used to construct demographics for each traveler.

Each link in the simulation network, except for freeway links, ramps, and bridges, was given at least one TRANSIMS parking place. All vehicles enter or depart the simulation at these locations. The activities derived from the PA tables were each scheduled to occur at a unique parking place. Trips with origins or destinations within a particular TAZ were assigned a parking place at random from all parking places within the TAZ. Parking places on more major roads or streets were given a higher probability of being assigned a trip origin or destination.

Unexpected congestion on certain local streets resulted from a microsimulation of the trips derived from activities generated with these parking places. This congestion was the result of multiple land uses in some of the TAZs. A TAZ that encompasses both residential and commercial land use has too many trip destinations assigned to the residential areas and too many trip origins from the commercial parking places in the morning. This problem was alleviated by changing the probability of selection for a particular parking place to account for both land use and the trip type.

For mixed land use TAZs, the following parking place allocation scheme was used.

- The parking places were divided into commercial and residential locations.
- Residential parking places were selected, with higher probability for trips representing home-based work and home-nonwork productions.
- Higher probabilities were given to the selection of commercial parking places for home-based work and home-nonwork attractions.

The start time of the activities was determined differently for each of the two activities that constitutes a trip. The start time for the activity that corresponds to the trip origin was determined from start time distributions for the four trip types that were supplied by NCTCOG. The start time for the activity that corresponds to the trip destination was obtained by adding an estimated trip time to the trip origin start time. This simple scheme of assigning activity start times also leads to unexpected congestion in the microsimulation. First, the NCTCOG trip start time distributions are uniform in one-hour segments. For example, 35% of all home-based work attractions occur between 7:00 and 8:00 a.m., while 17% are scheduled between the hours of 8:00 and 9:00 a.m. These abrupt changes in the proportion of trip start times lead to abnormalities in the microsimulation. Therefore, the start time distributions for the various trip types were smoothed while maintaining the relative proportion of trips over the one-hour periods.

NCTCOG does not distinguish between shopping and non-shopping trips in their home-based non-work trip table. As a result, it was determined that the microsimulation had too many trips arriving at the shopping centers in the 7:30 to 9:00 a.m. time period. Hence, parking places associated with shopping centers were identified, and the NPTS data was used to estimate the start time distribution of home-based non-work trips to these parking places.

A set of demographics was generated for every pair of activities (trip) in the activity list. The minimal demographics—age, gender, education, worker, and income—were obtained from a combination of NPTS and PUMS data. The four demographics—age, gender, education, and worker—were obtained by random selection of drivers from the NPTS. Income was produced by fitting data from the PUMS to these demographics. This methodology is used here as a temporary measure. The TRANSIMS methodology for generating full households will follow Beckman, Baggerly, and McKay (1996) [1].

The four trip types from NCTCOG were matched with trip purpose and the type of transportation from the NPTS (Table 3).

Table 3: Trip Type Matching

NCTCOG Trip Type*	NPTS Trip Type*	NPTS Transportation Type
HBW	HBW	Auto, Passenger Van, Cargo Van, Pickup, Other Truck, RV
HBO	HBO: Shop, Social, Other	Auto, Passenger Van, Cargo Van, Pickup, Other Truck, RV
NHB	NHB	Auto, Passenger Van, Pickup, RV
OTHER	NHB	Cargo Van, Other Truck, Bus, School Bus, Other

* HBW = Home-based work, HBO = Home-based other, NHB = Non-home-based

Drivers in the NPTS database who matched the trip and transportation types in Table 3 were collected for each of the four NCTCOG trip types. For each trip created from the NCTCOG trip tables, one of the NPTS driver's demographics was selected at random to represent the age, gender, work status, and education of the TRANSIMS traveler.

The traveler's income was generated from PUMS data that covers the Dallas-Ft. Worth area. Personal income was statistically fit to the person's age, gender, work status, and education. Using this fit, income was assigned to individuals created from the NPTS data set.

The TRANSIMS router uses demographics to weight network link characteristics, link travel times, tolls for the links, and link length. Combining these weighted characteristics produces a link cost. Because only link travel time is considered in the case study, the generated demographics have no effect in the route choice. The demographics are included so that future parametric studies can judge their importance.

The case study requires multiple routes and microsimulations. In all cases except for one of the base case runs, the activities and the populations remained constant.

4. THE PLANNER

For transportation planning questions, the first and most important feature is to predict the spatial and temporal characteristics of traffic delays. For example, air pollution models are wrong if the traffic model incorrectly predicts congestion. Also, optimization of the transportation system might be based on these results and, therefore, would be incorrect.

A conventional way of driving traffic simulation models is the use of turn counts. For each intersection and each incoming direction, a (possibly time-dependent) table contains information on the number of vehicles that go left, straight, or right. This approach is not useful for planning questions, because, for example, there would be no turn counts directing traffic on a new road. Additionally, the cost of collecting turn counts for all intersections in a city, possibly for different scenarios, is prohibitive.

TRANSIMS uses individual route plans to satisfy individual activities. Here, each individual vehicle in the simulation *knows* the sequence of streets it is intending to use. It is necessary to have time-dependent origins and destinations available for each vehicle. As described in the previous section, PA matrices are used for this purpose in the case study. Data collection for these tables may be a problem. In addition, PA matrices are also subject to change under infrastructure changes, although to a lesser degree than turn counts. For example, the introduction of a public transit system may greatly change vehicular trip patterns.

PA matrices are not the proper long-term solution for a transportation planning model. The TRANSIMS design, for that reason, starts with demographic data. It first derives *synthetic* households from the data, including activities and locations of activities. The activities are then combined (*chained*), and their transportation is planned and executed in the microsimulation.

The preliminary router used for this case study consists of two parts: an initial planner and a replanner. Currently, TRANSIMS runs on fixed route plans; a traveler cannot change the planned sequence of links once the simulation has started – even if the vehicle is stuck in a traffic jam. The initial planner generates such a set of plans based only on the free speeds and capacity values provided by NCTCOG. The microsimulation is run on this initial plan set. The replanner then changes the routing of a certain percentage of the trip using the link speeds from the microsimulations, and the microsimulation is rerun on this new set of trips. This run is followed by several more iterations between microsimulation and replanner, which are described below.

The method in the initial planner is similar to a standard assignment procedure except that the trips are routed on an individual basis. That is, a trip is routed, the (time-dependent) link travel times are updated according to a demand-dependent link travel time function, and the next trip is routed. The router used here is a time-dependent, fastest-path algorithm. More detail on the routing algorithm is found in Nagel and Barrett (1997) [4].

The well-known problem with the initial router is that a simple demand-dependent link travel time function is not realistic during congestion. Therefore, the replanner uses more realistic link travel time information from the microsimulation to correct for these effects. The current TRANSIMS replanning module is based on an imaginary simplified model of human behavior. The principal idea is that people run day-to-day simulations, and that *over night*, a certain number of people reevaluate their route choice. More precisely, the following steps are performed:

1) An initial set of routes that use the basic routing algorithm are obtained.

2) The microsimulation is run on the set of routes.

3) Link travel times are obtained from the microsimulation run for each 15-minute time interval.

4) A new set of routes is generated by allowing a percentage of all travelers to reroute their trips.

5) Iteration is accomplished by returning to Step 2.

Figures 9, 10 and 11 (see Appendix A) show the status of the network at 10:00 a.m. after a microsimulation of the initial plan set (iteration 0), the plan set of the first iteration, and the plan set of the tenth iteration, respectively. The black dots on these plots are individual vehicles, and the entirely black links indicate congestion. Initially there is massive congestion on the local streets (Figure 9). Figure 10 shows that the previous congestion in the Northeast and Southwest quadrants has cleared in the first iteration. By the tenth iteration, (Figure 11), all local congestion has cleared.

This procedure can be seen as a straightforward extension of the second phase of a dynamical assignment during which, trips that have already been routed are rerouted based on an updated version of the cost function (link travel times). Traditionally, the link travel times are obtained by a simple equation from demand. For the replanner described in this section, the simple cost function calculation is replaced by the microsimulation, which is more capable of dealing with complicated situations such as queue spillback and complicated geometries.

The number of iterations and the percentages of replanned trips are parameters of the router. Different router parameters produce different plan sets. The acceptability of a set of plans is determined by the number of lanes blocked for more than ten minutes at 10:00 a.m. and the number of *off-plan* vehicles. A vehicle becomes *off-plan* in the microsimulation when congestion prevents it from following its plan.

For the case study, router parameters were determined from the results of a designed experiment. The initial plan set had 22% *off-plan* vehicles and 270 lanes blocked at 10:00 a.m. After five iterations, the first two iterations with 20% replanned trips and the last three with 10%, had 75 lanes blocked and 7% *off-plan* vehicles. This plan set was reduced at random to 95% of the total number of trips and iterated three more times with 5% replanning. The last microsimulation of this series had 45 lanes blocked and 7% *off-plan* vehicles. This iteration scheme was used in all of the case study runs.

5. MICROSIMULATION

The TRANSIMS microsimulation component simulates the movement and interactions of travelers in the transportation system of a metropolitan region. Using a trip plan provided by the TRANSIMS route planner, each traveler attempts to execute the plan on the transportation system. The combined traveler interactions produce emergent behaviors such as traffic congestion.

The microsimulation used for IOC-1 simulates vehicular travelers in which each vehicle contains one traveler. Intermodal travel plans and multiple travelers per vehicle will be represented in future IOCs. Roadway transportation was chosen for the initial emphasis because of its high use, complexity, and importance to air quality. The roadway network includes freeways, highways, streets, ramps, turn pocket lanes, and intersections (signalized and unsignalized). Vehicles executing trip plans accelerate, decelerate, turn, change lanes, pass, and respond to other vehicles, traffic signs, and signals.

A cellular automata approach is used in the microsimulation to provide the computational speed necessary to simulate an entire region at the individual traveler level. Cellular automata microsimulation provides a means to simulate large numbers of vehicles and maintain a fast execution speed. Each link in the transportation network is divided into a finite number of cells. At each timestep of the simulation, each cell is examined for a vehicle occupant. If a vehicle is present in the cell, the vehicle may be advanced to another cell using a simple rule set. Increasing the fidelity by decreasing the cell size, adding vehicle attributes, and expanding the rule set results in slower computational speed. The fidelity and performance limits of the cellular automata microsimulation are being explored to establish the computational detail and the fidelity necessary to meet analysis requirements.

The microsimulation creates vehicles from a set of travel plans produced by the interim TRANSIMS router. Each plan begins and ends at a parking place. The TRANSIMS router produces plans on the regional transportation network. The microsimulation for the case study uses a study area that is a subset of the regional network. The plan set produced by the planner is preprocessed to

- limit it to plans that enter the microsimulation study area during the simulation time interval,
- truncate the plans to the series of links in the microsimulation study area, and
- sort the plans by time of entry into the microsimulation study area.

The microsimulation uses the preprocessed and sorted plan set to obtain the starting link of each plan. The plan is then placed in a parking place queue on the starting link. As simulation time advances, the microsimulation removes a plan from the parking place queue at the appropriate starting time, creates a vehicle from information in the plan, and places the vehicle on the link. The vehicle then traverses the roadway network following the links in its plan until it reaches a destination parking place in the study area or until it completes the sequence of links in its plan that are in the microsimulation study area.

Traffic dynamics in the microsimulation are produced by interactions of individual vehicles on the transportation network. The position of vehicles on the roadway is determined by applying a rule set that governs movement and lane changes. This rule set is as simple as possible in order to maintain the computational speed necessary to update positions of the large number of vehicles that could be present in a regional traffic microsimulation. The rule set imposes a no-collision strategy on the vehicles. Vehicle interactions based on the following rules combine to produce emergent driver behavior that creates traffic dynamics.

The movement rule is:

Accelerate when you can; slow down if you must; sometimes do not accelerate.

The rule is executed to update the speed and position of each vehicle on the roadway.

The distance between a vehicle and the next car ahead is called the *gap*, which is measured by the number of cells between the two vehicles. Each vehicle accelerates if the gap is greater than the desired speed. The desired speed is limited to the speed limit posted on each link. If the gap is smaller than the current speed, the vehicle will slow down until its current speed is equal to the gap, thus imposing the no-collision condition. Each vehicle also has a random probability of being slower than possible, which is called the *deceleration probability*; it was set to 0.2 for the case study. Randomness is essential to produce realistic traffic dynamics, such as jam waves, from the individual vehicle interactions.

The cells used in the microsimulation correspond to 7.5 meters. The timestep is one second. Therefore, the velocity is measured in the number of cells moved per timestep. The maximum velocity allowed in the microsimulation is five cells per timestep, which corresponds to 85 mph. This maximum velocity is reduced by the speed limit on the link. Further information on the characteristics of the microsimulation may be found in Nagel (1996a) [2] and Nagel (1996b) [3].

Vehicles change lanes for two reasons:

1) To pass a slower vehicle in the current lane

2) To make turns at intersections in order to follow its plan

The decision to make a lane change in order to pass a slower vehicle is based on the gap on the current lane, the gap backward on the new lane, and the gap forward on the new lane. Rickert, Nagel, Schreckenberg, and Latour (1996) [5] show the lane change logic for two-lane traffic simulated with a cellular automata.

A vehicle that must make a turn at the next intersection in order to follow its plan starts to consider a lane change when it is within a set distance from the intersection. As the vehicle approaches the intersection, the urgency to change into an appropriate lane for plan following increases. Vehicles that fail to make the required lane changes for plan following are marked as *off-plan* and removed at the nearest parking place.

Unsignalized intersections with stop/yield traffic controls require vehicles to consider oncoming traffic before they can move onto the next link. The vehicles use the gap between the oncoming vehicles and the intersection to determine whether the intersection can be entered. If the gap is acceptable, the vehicle traverses the intersection and arrives on the destination link during a single update step.

Vehicles at signalized intersections have different behavior from those at unsignalized intersections. After a vehicle enters an intersection, it is placed in a queue where it resides for a specified time before exiting to the destination link. The time that vehicles spend in the queue imitates the time necessary to traverse the intersection. Vehicles with permitted, but not protected, movements from the intersection traffic control, must consider the oncoming traffic before entering the intersection.

The TRANSIMS microsimulation runs on multiple CPUs to maximize the computational speed. Updating of vehicle positions is done in parallel on the individual CPUs, which is faster than updating on a single CPU.

The transportation network is partitioned among the CPUs with each CPU receiving a set of nodes and links, which results in some links that are split in the middle between two CPUs. The partition algorithm tries to minimize the number of these split links. Vehicles are transferred between the CPUs as they traverse these split links. Each split link introduces a message passing delay during the update sequence because messages must be passed between the CPUs for vehicles that are crossing the split links. A view of the network split used in the case study is shown in Figure 12 (see Appendix A). Here the dark links are split between two CPUs and delineate the portion on the network *owned* by each CPU.

The case study microsimulations were run on five networked SUN SPARC workstations. The five-hour microsimulation of traffic between 5:00 and 10:00 a.m. runs in real time with this configuration.

6. MICROSIMULATION CALIBRATION

The previous section described the TRANSIMS microsimulation logic. Various parameters in the microsimulation, such as deceleration and lane changing probabilities, are fixed in advance of any simulation. These parameters control the emergent traffic dynamics produced by the microsimulation. To study the effects of these parameters in a systematic way, TRANSIMS includes a traffic flow characteristics test suite, which tests certain aspects of driving behavior in isolation. Situations are selected to be comparable to similar real world measurements, to the Highway Capacity Manual, and to other simulations.

The test suite presented here is restricted to quantities most relevant for traffic planning applications. These quantities are all related to *flow cutoffs*, or capacity, such as the capacity of a freeway, the capacity of a traffic light, or the merge capacity of a minor road for a given flow on the major road.

The most important traffic flow feature is demand exceeding capacity, which leads to queue build-up and delays that are relevant for rush hour traffic. Rush hour traffic is usually relaxed to a situation where actual demand rarely exceeds capacity by large amounts; thus, dynamics for traffic near capacity become important. These dynamics are investigated in the test suite.

The four simplified situations that TRANSIMS currently tests are:

1) *One-lane traffic in a circle*, which tests simple car-following behavior. The outputs of these runs are the standard fundamental diagrams (i.e., the relation between density, flow, and velocity).

2) *Three-lane traffic in a circle*, which tests the addition of lane-changing behavior. The outputs of these runs are lane occupancy and the standard fundamental diagrams.

3) *Unsignalized junctions* (stop signs, yield signs, freeway ramps, and unprotected left turns), which test gap-acceptance behavior. Figure 13 (see Appendix A) is a diagram of these networks, where blue vehicles travel around the inner circle, and red vehicles merge into traffic from the minor road on the left side of the figure and are removed on the right side. The outputs of these runs are the flow from the minor road as a function of the flow on the major road.

4) *Three-lane signalized intersection* (where one lane is for left turns, one lane goes straight, and one lane is for right turns), which fulfills two functions: testing of traffic light capacity and testing of plan-following behavior. The latter is achieved by vehicles entering on randomly selected lanes with a plan to turn or to go straight. Vehicles that fail to be in the correct lane at the signal are counted as *off-plan* vehicles. Outputs of this test case are two values: the number of vehicles that traverse an intersection during a green phase of a given length, and the number of *off-plan* vehicles.

Figure 14 (see Appendix A) depicts the typical flow against density fundamental diagram recorded in a simulated freeway situation with a speed limit of 75 mph. The flow through a stop sign going into a three-lane road versus the flow on that three-lane road is shown in Figure 15 (see Appendix A). The gap acceptance that was used in this calibration run was used for the case study. Figure 16 (see Appendix A) shows the flow through a stop sign going into a one-lane road versus the flow on the one-lane road for an enhanced gap acceptance logic. This enhanced gap acceptance logic will be used in future studies. The curve from the Highway Capacity is added in Figure 16 for comparison.

7. TRAVEL VALIDATION

The previous section presented the results of a TRANSIMS calibration study. Calibration relates only to the behavior of the microsimulation in test networks. Validation compares characteristics of simulated traffic to traffic actually seen. In the case study, travel behavior involves the trip tables, the activity generation from these tables, and the router, in addition to the microsimulation. The microsimulation is the focus of IOC-1 and the case study, not the activity generation and the router; therefore, we do not expect traffic counts produced by the microsimulation to exactly emulate traffic patterns seen in Dallas.

We validate the base case simulation by obtaining vehicle counts from the microsimulation on specific links from 7:00 to 8:00 a.m. These counts are compared with the volumes over the same time period that is modeled by NCTCOG. The model uses 24-hour counts as a basis. Figure 17 (see Appendix A) contrasts the Dallas estimated volumes with the microsimulation counts for freeway, principal arterial, minor arterial, and collector links. The solid lines in the graphs of Figure 17 mark the equality line. The dashed lines depict plus or minus 50% of the Dallas volumes. The results for freeways, principal arterials, and minor arterials are reasonable, with slightly fewer freeway trips in TRANSIMS than modeled by NCTCOG. TRANSIMS sees more traffic on collectors than was predicted by the NCTCOG model, which is probably caused by the use of centroid connectors in the NCTCOG model.

Fewer volumes are available from NCTCOG for local streets, frontage roads, and ramps. Plots of simulation counts against NCTCOG-modeled volumes on these links are not shown. They are very similar to the plots for freeways, principal arterials, and minor arterials shown in Figure 17.

Because the goal of this case study is to demonstrate the microsimulation and not the activity generation or the planner, the set of plans producing Figure 17 is adequate for this purpose.

8. THE EXPERIMENTAL DESIGN AND RUN STATISTICS

Traffic on three networks was simulated. Each of the simulation networks covers 25 square miles around the Galleria Mall. Trip routes for each traveler were planned over the entire Dallas-Ft. Worth Metro area, then truncated to the study area. As previously mentioned, the three networks are:

1) BC – the base case with the network as it was in 1990

2) IC1 – an infrastructure change to the base case network with the addition of an extra lane both east and west on the LBJ Freeway

3) IC2 – a set of local changes to the arterial roads of the base case infrastructure

Because additional capacity is added in the infrastructure changes and trip planning takes place across the entire network, a new set of plans is generated for simulations IC1 and IC2. The activity sets, however, remain constant in all but one base case simulation.

The case study highlights three analysis capabilities of TRANSIMS. Information on individual travelers and the TRANSIMS modular structure make possible studies of model uncertainty, network reliability, and equity. Each of these studies uses a different aspect of variability and requires a different experimental design or set of microsimulations.

The base case was simulated four times under different conditions to investigate uncertainties in the system.

1) BC-1-1-1 – initial plan set

2) BC-1-1-2 – identical plan set to BC-1-1-1, but different random number seeds were used in the microsimulation

3) BC-1-2-1 – a new set of plans

4) BC-2-1-1 – a new set of activities

The implications of these microsimulations in terms of the uncertainty in the simulations are discussed in Section 10, *Base Case: Uncertainty*.

To estimate network reliability, two simulations were carried out for each of the three networks. the original simulation is supplemented with a second simulation where the travelers' start times are perturbed a small amount. Differences in travel characteristics between the two simulations are then measured. Complete details on network reliability are given in Section 11, *Base Case: Network Reliability*.

The third area of investigation in the case study is equity analysis. To illustrate the versatility of TRANSIMS in conducting equity studies, the effect of the infrastructure changes on differing populations of travelers is investigated. The population of travelers simulated in the study area is partitioned into two groups.

1) Galleria – travelers whose origins or destinations are in the Galleria Mall

2) Non-Galleria – travelers whose origins and destinations are outside the Galleria Mall area

A study of these groups of travelers determines the costs and benefits of the infrastructure changes attributable to the two populations.

For each of the three networks (BC, IC1, and IC2), three simulations were made. Initially, all travelers on the network were simulated. In the first of two additional simulations, the Galleria travelers were removed, and the travel plans of the others were simulated (Non-Galleria Only). Also, the Non-Galleria travelers were removed, and the Galleria travelers alone were simulated (Galleria Only). Because the trips are not replanned, these two simulations determine a baseline cost for each population with reference to the other.

The measures of effectiveness for the simulations, such as the individual travel times, with the Galleria Only plan sets can be compared with the same measures for the Galleria population from the simulation with all the travelers. This measures the cost the Non-Galleria population imposes on the Galleria travelers. Suppose a measure of effectiveness for the Galleria travelers in an infrastructure change simulation with all of the travelers is equal to the same measure of effectiveness for the Galleria population when simulated alone in the base case. Then, the cost exacted by the Non-Galleria population on the Galleria travelers is the cost of the infrastructure change. This comparison can, of course, be made in the opposite direction.

To show the flexibility of TRANSIMS, a secondary analysis of the data was completed. In this analysis, the population of travelers was partitioned into three groups:

1) Thru – travel is through the study area

2) Local-Into – either the trip origin or the destination parking place of the trip is in the study area, but not both

3) Local – both the trip origin and the destination are in the study area

The number of completed trips differs for each of the simulations. Trips are planned across the entire Dallas-Ft. Worth region. Because a network change requires a new set of trip plans, the number of trips scheduled to start in the study area between the simulation hours of 5:00 to 10:00 a.m. differs for each network. Also, each trip originates at a parking place either on a link in the study area or in the buffer area. No vehicle appears in the simulation at a parking place if the place is blocked by another vehicle; it is queued until the parking place is free. Therefore, even with identical plan sets, the number of vehicles that enter the simulation may change slightly if the random number seed is changed in the microsimulation. Additionally, the number of completed trips differs for the same plan set under microsimulations with differing random number seeds. A vehicle may complete its trip before the simulation ends in one microsimulation and not in the other.

The number of trips completed before 10:00 a.m. for the four base case runs (BC-1-1-1, BC-1-1-2, BC-1-2-1, and BC-2-1-1) and the two infrastructure runs (IC1 and IC2) are shown in Table 4, which also includes the number of completed trips for the subpopulations under investigation.

Table 4: Completed Trips

	BC-1-1-1	BC-1-1-2	BC-1-2-1	BC-2-1-1	IC1	IC2
Full	194,174	193,727	201,752	198,920	204,779	199,657
Galleria	11,700	11,658	12,325	12,190	11,963	12,082
Galleria Only	12,945	n/a	n/a	n/a	13,290	13,435
Non-Galleria	182,474	182,069	189,427	186,730	192,843	187,575
Non-Galleria Only	183,010	n/a	n/a	n/a	196,080	189,101
Thru	41,958	41,857	43,708	42,384	47,022	45,211
Local-Into	117,307	117,008	121,525	120,156	122,324	118,666
Local	34,909	34,862	36,519	36,380	35,433	35,780

Figure 18 (see Appendix A) shows the percentage increase in the number of trips relative to the BC-1-1-2 run, which is the simulation with the smallest number of completed trips. The BC-2-1-1 run is not in the plot because it is based on a different set of activities. Figure 18 also shows that the largest increase in completed trips (6%) comes with the addition of extra freeway lanes in IC1. These additional trips come as trips through the study area. There are 12% more through trips with this infrastructure than in the basecase (BC-1-1-2). There is also a significant increase in the number of trips through the study area in the IC2 simulation. All other increases in completed trips are within the range of the increase for BC-1-2-1, the base case with a second set of plans; hence, they are not significantly different from the base case.

9. MEASURES OF EFFECTIVENESS AND STATISTICAL DISPLAYS

Each simulation allows multiple measures of effectiveness. For populations, the four measures used in the case study are:

1) Vehicle miles traveled

2) Vehicle hours traveled

3) Travel time – the total time the traveler expends in the study area

4) Speed – the average speed of the traveler while in the study area

Travel time and speed are estimated for each of the subpopulations discussed in the previous section, as well as for the entire population of travelers. Because data is collected on each traveler, the variability in these quantities for each population is also estimated. Additionally, summary data is collected on each link in three-minute time intervals. Flows, speeds, and densities are computed on a link-by-link basis from the data. Variances of travel times are also available for each link over the three-minute period.

The hours between 5:00 and 10:00 a.m. were simulated in the case study. Population statistics are computed only for those travelers who complete their trips before 10:00 a.m. Each of the population statistics is displayed as a function of the time the trip either originates in, or enters, the study area. Also, the measures of effectiveness, such as speed or travel times, pertain only to data collected over the study area. To avoid anomalies caused by end conditions, displays of the statistics are given for trips starting between 6:00 and 9:00 a.m.

Measures of effectiveness are displayed in two ways.

1) Data for a population is collected in five-minute start time intervals. Percentiles of the statistics, such as the 75th percentile and the median travel times, are computed for all of the data in each five-minute interval. The data is then smoothed as a function of trip start time and is plotted. Figure 19 (see Appendix A) is an example of the median travel times in five-minute intervals and the smoothed function fit to them.

2) A statistic such as travel time is displayed in a boxplot. Boxplots are used to display the data when comparisons between distributions are needed; for example, comparison of the distributions of travel times of two populations are needed. Histograms are not suited for this purpose. Figure 20 (see Appendix A) shows a histogram of a set of travel time data and the corresponding boxplot. The outer bars of the boxplot are the 95th and 5th percentiles of the distribution. The box encloses the 50% of the distribution between the 25th and 75th percentiles. The bar in the middle of the box marks the median, and the "x" marks the mean of the distribution.

10. Base Case: Uncertainty

No complex model gives the absolutely correct answer. To make informed decisions, it is imperative that decision makers understand the uncertainty inherent in the results of models used to make these decisions. In TRANSIMS, this uncertainty can be quantified. It is the result of the uncertainty in the components of TRANSIMS – the activities, the routes, and the microsimulation.

The base case was used to estimate the variability, or uncertainty, in the basic measures of effectiveness caused by the microsimulation, the planner, and the generation of activities. In this study, the number of trips from TAZ to TAZ in a 24-hour period remains constant in all of the runs. However, each component of TRANSIMS adds variability to the measures of effectiveness. The starting times of individual trips were drawn from the modified NCTCOG start time distributions. Therefore, multiple sets of activities may be generated where the resulting trips have different starting times but statistically follow the modified NCTCOG start time distributions. Variability is also induced in the planning process. The individual trips that are replanned are drawn at random from the existing trips. Consequently, for the same set of activities, and even with the interim optimal router used here, multiple execution of the planner produces multiple sets of plans. Lane changes and deceleration are among the quantities that vary according to random distributions in the microsimulation. Hence, two runs of the microsimulation with the same set of plans but with different random number seeds give different results.

Figure 21 (see Appendix A) illustrates a complete experiment to investigate the magnitude of variability induced by the components of TRANSIMS. The top level of the chart depicts two sets of activities generated with different starting times. For each set of activities, two sets of plans are produced, where the random selection of those trips to be replanned is changed (middle level). Each set of plans is microsimulated twice using a different random number seed in the microsimulation (bottom level).

Running the entire experiment shown in Figure 21 is extremely time consuming. In this study, four of these runs are completed: BC-1-1-1, BC-1-1-2, BC-1-2-1, and BC-2-1-1. Differences in the two simulations (BC-1-1-1 and BC-1-1-2), measure the effect of changing the random number seed in the microsimulation. This effect is expected to be small. Comparison of BC-1-1-1 or BC-1-1-2 with the BC-1-2-1 simulation show the effect the planning process has on the measures of effectiveness. This variability is relevant in the case study where comparisons of the infrastructure changes with the base case are made, and each of these microsimulations is computed with a different plan set. The effect of changes in the activity start times is gauged with the comparison of BC-2-1-1 and any of the other simulations. In terms of variability in the case study, BC-2-1-1 is included here only out of interest because each of the case study simulations is based on the same set of activities.

Figure 22 (see Appendix A) shows the median travel times and the median average speeds for the population of travelers in the uncertainty simulations. Differences in these plots occur for those travelers whose trip starts between 7:30 and 9:00 a.m. As expected, there is very little difference between the two simulations with the same plans and activities, BC-1-1-1 and BC-1-1-2. Likewise, the largest differences occur between simulations where there are different activities and different plans, for example BC-1-1-1 and BC-2-1-1. There are intermediate differences when the activities are held fixed and the plans change.

Infrastructure changes require plan sets different from the plan set used for the base case. Also, the microsimulation random processes differ in these cases. Therefore, displays of results that present differences in the measures of effectiveness between the new infrastructures and the base case always show the results from BC-1-1-1, BC-1-1-2 and BC-1-2-1. To be significant, measures of effectiveness from infrastructure changes must be outside the uncertainty envelope produced by these three microsimulations.

11. BASE CASE: NETWORK RELIABILITY

Large day-to-day differences in individual travel times and speeds for travelers following the same routes at approximately the same time of day is frustrating to the traveler and may lead to unhappiness with the planning organization in charge of the transportation network. TRANSIMS allows an analyst to estimate these day-to-day variabilities or network reliability.

Two methods for estimating network reliability using TRANSIMS simulations are presented in this section. These methods may be used, and are used in this paper, as a measure of effectiveness in assessing changes in travel characteristics when changes are made to the infrastructure. The measures concentrate on those travelers with the greatest variability in travel times and speeds.

The reliability of a traffic network can be appraised by determining the day-to-day difference in quantities like travel times and speeds for an individual traveler on the same route. The BC-1-1-1 and BC-1-1-2 simulations can assess a portion of the network reliability. Because each traveler has the same route in the two simulations, differences or variability in the individual travel times or average speeds are a measure of the network reliability. These differences measure random perturbations in lane changes and decelerations from the microsimulation.

A better measure of network reliability is derived from differences in the travel times and average speeds of individual vehicles when the same routes are maintained but minor perturbations are made to the travelers' start times. In addition to random perturbations in lane changes and decelerations, these perturbations cause vehicles to be involved in different congestion regimes and to arrive at traffic control devices at different times. This, in turn, causes differences in average speeds and travel times.

A set of travel plans was constructed by changing the start times of the plans used in the BC-1-1-1 simulation. The starting time for each trip was changed by adding or subtracting a time drawn at random between zero and five minutes. The average absolute difference in start times between the vehicles in this plan set and the plan set for the BC-1-1-1 simulation is 2.5 minutes. The simulation based on this plan set is called BC-1-1-1R.

The travel time and the average speed for each individual in BC-1-1-1 were differenced from that in BC-1-1-R. The absolute value of the differences was taken, and the percentiles of these differences as a function of average starting time was computed. These percentiles are shown in Figure 23 (see Appendix A). It is interesting to note the change in the upper percentiles (75th and 95th) as the start time changes between 7:00 and 9:00 a.m. The variability in individual travel times gets much larger for a proportion (25 to 5%) of the population over this time period (Figure 23a). On the other hand, the variability in individual travelers' average speed remains relatively constant over the entire time period of 5:00 to 9:00 a.m. (Figure 23b)

It is apparent from Figure 23 that a measure of network reliability should be one of the upper percentiles of the distribution of absolute differences rather than the median. The median measures the network satisfaction or dissatisfaction of only 50% of the travelers. High values of the 75th and 95th percentiles of the travel time or speed differences indicate dissatisfaction of the network by 25% to 5% of the travelers. While not a majority, it is these travelers who would be most likely to voice dissatisfaction with the system. The upper percentiles shown in Figure 23 imply that as many as 25% of the travelers have variability in times of over one minute and in average speeds of 4 mph during the peak hour. The 95th percentile indicates 5% of the population has a four-minute variability in travel time and 9 mph variability in average speeds.

It is interesting to compare the network reliability estimated by the two runs (BC-1-1-1 and BC-1-1-1R), with that estimated by the comparison of BC-1-1-1 with BC-1-1-2. As stated previously, the first comparison includes a more realistic measure because it accounts for small perturbations in travelers' start times, whereas the second estimate includes only the effects of the randomness in the microsimulation.

Figure 24 (see Appendix A) shows the differences in the 75th (24c and 24d) and 95th (24a and 24b) percentile estimates of travel times and average speeds for these two cases. As expected, the perturbed start time simulations have higher percentiles and, hence, more variability. It is noteworthy that the difference between these pairs of percentiles decreases as congestion increases between the hours of 7:30 and 8:30 a.m. This implies that during congestion, lane changing and speed fluctuations have almost the same effect on travel time and average speed differences as do small changes in the traveler start times.

12. INFRASTRUCTURE COMPARISONS: ALL TRIPS

The next technical sections of this paper illustrate the ease with which TRANSIMS may be used in equity studies. The costs and benefits that infrastructure changes impose on subpopulations of travelers are analyzed in these studies. These studies concern the behavior of only a few of the subpopulations that could be investigated as a function of infrastructure changes. Analysis of the effects of the infrastructure changes on different subpopulations of travelers could readily be accomplished by using the data from the TRANSIMS microsimulation that has already been run.

Travel behavior on three networks was investigated:

1) BC – the base case with the network as it was in 1990

2) IC1 – an infrastructure change to the base case network with the addition of an extra lane both east and west on the LBJ Freeway

3) IC2 – a set of local changes to the arterial roads of the base case infrastructure

Figure 25(a) (see Appendix A) displays the total vehicle hours for the three infrastructures with three curves given for the base case to show the uncertainty in these results. The total vehicle hours are given in Figure 25(b). The curves in these plots are obtained by smoothing the total vehicle miles and the total vehicle hours of all travelers whose start times in the study area are in five-minute intervals from 5:00 to 9:00 a.m. It is apparent from Figure 25(a) that more vehicle miles are traveled in IC1 than in the other simulations. This is a reflection of the increased number of trips for IC1 as was shown in both Table 4 and Figure 18.

The total vehicle hours in Figure 25(b) are more interesting. In this case, there are differences among all three of the infrastructures. Between 7:30 and 8:00 a.m., the total vehicle hours are less for IC1 and IC2 than for the base case simulations. Also, there is a shift in the time at which the maximum vehicle hours occur, with the maximum for IC2 shifted to the left of the base case, and the maximum for IC1 shifted to the right.

The two graphs in Figure 25 are scaled by the number of travelers and shown in Figure 26 (see Appendix A). Figure 26(a) displays the average vehicle miles for the travelers in five-minute intervals. Figure 26(b) gives the average vehicle hours or travel times as a function of the trip starting time in the study area. In Figure 26(a), it is interesting to note the precipitous drop in average trip lengths between 6:00 and 8:00 a.m. This drop in average trip lengths is a result of the planned trips. Figure 27(b) (see Appendix A) shows the average planned trip lengths. This mimics the microsimulation trip lengths given in Figures 26(a) and 27(a). The drop in planned trip lengths occurs when congestion is heavy in the study area. The line marked "ITO" in Figure 27(a) shows the average trip lengths for the initial plan set before it is iterated. Figure 28(a) (see Appendix A) displays the total number of trips, and Figure 28(b) displays the percentage of these trips that go completely through the study area. This percentage as a function of starting time follows both the planned trip lengths (Figure 27(b)) and the trip lengths as a result of the microsimulation (Figures 26(a) and 27(a)). It is obvious from these figures that the planner iterations make the trip lengths shorter, and that they route some of the longer trips around the study area.

The effect of the infrastructure changes on the average travel times can clearly be seen in Figure 26(b). The average vehicle hours is clearly less for travelers with starting times between 7:00

and 8:00 a.m. in the two infrastructure changes (IC1 and IC2). The decrease in trip times is well outside the variability induced by the planner and shown by the three base case results. There is also a temporal shift in the average vehicle hours. The shifts in maximum trip times are the same as those seen in Figure 25(b).

The median travel times and the median speeds of the travelers are presented in Figure 29 (see Appendix A). The median travel times reflect the pattern of the average travel times seen before. The speeds in Figure 29(b) are interesting. In this case, the speed decreases as the number of trips and, hence the congestion, is increasing. The maximum difference in speeds among the three infrastructures is the increased speed of travelers on IC2 after 8:00 a.m

One of the important aspects of TRANSIMS is the capability to look at the entire distribution of measures of effectiveness, such as travel times and speeds. In traditional analysis, improvements in travel time or speed are computed for the *average traveler* by calculating the mean travel time or mean speed. In addition to the mean, the percentiles of travel times and speeds are important. It is possible for the average travel time to decrease, while the travel times of those on the roadway the longest increase. This situation can only be ascertained through investigation of the complete travel time distribution.

The travel time and speed distributions are displayed by boxplots in Figures 30 and 31 (see Appendix A) for the base case runs (BC-1-1-1 and BC-1-2-1) and the infrastructure changes (IC1 and IC2). These figures show subtle changes in the distributions between the hours of 7:00 and 9:00 a.m. In particular, the infrastructures cause interesting differences between the upper percentiles of travel times and the lower percentiles of speeds.

The greatest improvements in the total travel network can be made by reducing the longest travel times and increasing the slowest speeds. To investigate the changes that infrastructure modifications make to the longest travel times and increase the slowest speeds, the percentiles of the speeds and travel times are exhibited in Figure 32 (see Appendix A). Figures 32(a) and 32(b) give the 95th and 75th percentiles of travel times. The upper percantiles of travel times correspond to travelers with the longest travel times. These percentiles exhibit the same, but more pronounced, pattern as the medians shown in Figure 29(a). Both infrastructure changes (IC1 and IC2) reduce the travel time associated with long trips. The temporal shift seen in the medians is present in the upper percentiles, and IC2 makes the most improvement in long travel times for trips that begin after 8:00 a.m.

The lower percentiles of the speed distributions, which represent those travelers with the slowest speeds, are shown in Figures 32(c) and 32(d). The percentiles reveal a pattern consistent with the upper percentiles of the travel times. The same temporal shift is evident, and IC2 increases the speed of the very slow trips more than the other infrastructures. This increase is more pronounced in the percentiles than it is in the mean or the median speeds.

It is possible that an infrastructure change slightly increases the average travel time, but greatly reduces the individual's day-to-day variability. Therefore, network reliability should be used as one of the measures of the effectiveness of network improvements.

To estimate the network reliability for each of the infrastructure changes, the starting time in the study area of each traveler was perturbed at a random amount within five minutes of their original starting times. As before, the upper percentiles of the absolute differences in each traveler's travel time and speed were obtained. These percentiles are shown in Figure 33 (see

Appendix A). From Figure 33, it is clear that the arterial infrastructure change (IC2) decreases the day-to-day variability in both the longest travel times and the slowest speeds more than IC1.

In terms of all travelers, the infrastructure IC2 is more beneficial than IC1 after 7:45 a.m. Both infrastructures (IC1 and IC2) decrease travel times and increase speeds when compared to the base case; they are also more reliable than the basecase.

13. EQUITY ANALYSIS: GALLERIA AND NON-GALLERIA TRAVELERS

Several methods for the study of equity analysis are presented in this section. These methods involve the examination of the median travel time and speed for different populations. Techniques to draw inferences from the percentiles of these quantities are presented. The upper percentiles of travel times and the lower percentiles of speeds are critical, but unused, in traditional analyses. Before judging one infrastructure to have either an adverse or helpful effect on a particular portion of the population, it is wise to make sure that this effect pertains to a high percentage of the population. Studies of means and medians do not reveal these facts.

The case study is designed to study the effects of the infrastructure changes on two populations of travelers and the effects the populations exert on each other with reference to the infrastructures. These populations are those travelers whose origins or destinations are in the Galleria Mall area and those whose origins or destinations are not. From Table 4, one sees that the Galleria travelers are approximately 5% of all travelers in the study area. Travel times and average speeds are obtained for the individual travelers in the separate populations from the complete simulations of the three infrastructures. Additionally, different microsimulations are completed where:

1) The Galleria travelers are removed from the population of travelers, and the Non-Galleria travelers alone are microsimulated (Non-Galleria only).

2) The Non-Galleria travelers are removed, and the Galleria travelers alone are microsimulated (Galleria only).

These secondary simulations of isolated populations set the baseline for the combination of subpopulation and infrastructure. The results of these simulations are the best an individual subpopulation can expect from the infrastructure while the other subpopulation is present. The travelers' routes in these simulations are not replanned, as the simulations are, to measure the effect the second population has on the first. For example, if the travel times for a subpopulation of travelers with an infrastructure change are less than they are when the second population is removed from the original infrastructure, the cost that the second population imposes on the first is the cost of the infrastructure change. If there is no difference in these two cases, the subpopulations are completely separated from each other on the network.

The median travel times of the Non-Galleria and Galleria travelers are given in Figure 34 (see Appendix A). In each plot in Figure 34, the baseline simulation of Non-Galleria Only or Galleria Only is shown. The display of Non-Galleria travel times in Figure 34(a) is interesting. Both infrastructure changes improve the Non-Galleria travel times more than the removal of the Galleria travelers between 7:30 and 8:30 a.m. The now familiar temporal shift is present. The network with the additional freeway lanes (IC1) is more effective in reducing travel times of the Non-Galleria travelers until approximately 8:15 a.m. At that time, IC2 slightly dominates IC1.

In contrast to the Non-Galleria travelers, Figure 34(b) shows that before 8:00 a.m., the IC1 infrastructure is slightly better in reducing the travel times of the Galleria travelers. After 8:00 a.m. however, the local infrastructure (IC2) is much better for these travelers. For the Galleria travelers, neither of the infrastructure changes has the equivalent effect of removing the Non-Galleria travelers from the base case network.

The median of the average travelers' speeds of the two populations is shown in Figure 35 (see Appendix A). It is clear from these plots that, after 8:00 a.m., travelers on IC2 have higher speeds in both populations. Before 8:00 a.m., slightly higher speeds are seen on infrastructure IC1.

The upper percentiles of travel times and the lower percentiles for speeds of the Non-Galleria travelers are shown in Figure 36 (see Appendix A). They have a pattern different from the medians. Here the relative advantage of IC2 over the others starts earlier in the morning. The higher the travel time percentile or the lower the speed percentile, the earlier IC2 dominates. This means that IC2 is more effective in reducing long travel times and increasing the slowest speeds of the Non-Galleria travelers.

A similar but more pronounced result is in the upper percentiles of travel times and the lower percentiles of speeds for Galleria travelers. These percentiles are given in Figure 37 (see Appendix A). Once again, IC2 dominates the other infrastructures, and this domination begins at 7:30 a.m. There are no cases where the IC2 infrastructure is equivalent to the removal of the Non-Galleria travelers from the base case.

Overall, the IC1 infrastructure slightly improves the travel times and speeds of both the Galleria and Non-Galleria travelers in the early hours before 8:00 a.m. IC2, on the other hand, increases the speeds and decreases the travel times of both populations after 8:00 a.m. With the local infrastructure change (IC2), longer trips and trips with slower speeds are made better by 7:30 a.m. for Galleria travelers and by 7:45 a.m. for Non-Galleria travelers. Both infrastructure changes are better for the Non-Galleria travelers than is the removal of the Galleria travelers from the base case network. The same is not true for the Galleria travelers.

14. INFRASTRUCTURE COMPARISONS: SUPPLEMENTAL STUDIES

There is a wealth of data in the output of the case study microsimulations. The analyses shown so far have barely scratched the surface of the available possibilities. The purpose of this section is to amplify the results given so far and to suggest possible additional analyses to those who are interested in pursuing them.

The baseline simulations with one population removed from the simulation are available for the Galleria and Non-Galleria populations only. However, even in the absence of the baseline simulations, the effects of the infrastructure changes on other populations are interesting. This is demonstrated by looking at travelers who are local to the study area and those who travel through it. In this case, the total population is partitioned into three groups:

1) Thru – travel is through the study area

2) Local-Into – either the trip origin or the destination parking place of the trip is in the study area, but not both

3) Local – both the trip origin and the destination are in the study area

The median travel times and speeds for these three populations are given in Figures 38 and 39 (see Appendix A). Panels a in these figures show the Local travelers, Panels b show the Local-Into, and Panels c show the Thru travelers. Panels d in each of the figures are the previously displayed median travel times and speeds for the entire population. The difference in the effects of the infrastructure changes on these three populations is striking. The local infrastructure change (IC2) improves the travel characteristics of both the Local and Local-Into populations. This is true for both travel time and speed, but the largest effect is reduced travel time after 7:30 a.m. On the other hand, there is not much difference in the effects of the two infrastructure changes on the travelers passing through the study area. Both improve the median speeds and travel times of this population; and the improvements are approximately the same, but shifted in time, regardless of the infrastructure.

Other partitions of the travelers could easily be studied. For example, one could partition the populations into those that use the LBJ freeway and those that do not. Or, the population could be divided into 800 subpopulations based on the traveler's zone of origin or destination. The population could also be partitioned by the traveler demographics such as income. Each of these partitions would give additional information about the travel characteristics of the three networks under consideration.

TRANSIMS output is collected on every link in small time intervals. The sampling and output times are determined by the investigator and are inputs in TRANSIMS. In the case study, link attributes were collected every three minutes. The data collected was the link travel time from which the average speed is determined, the travel time variability, the number of vehicles exiting the links, and the vehicle density in 150-meter segments on the link. This data may be used to investigate the effects of infrastructure changes on a particular link or a series of links.

A series of links on Alpha Road and the LBJ Freeway was chosen to demonstrate an analysis based on some of the link data. Additional lanes were added to Alpha Road in IC2, while IC1 has an extra lane in both directions on the LBJ Freeway. Figures 40 through 43 (see Appendix A) show the speeds and flows on these roadways. These plots are presented for two half-hour time periods, 7:30 to 8:00 a.m. and 8:00 to 8:30 a.m., and both directions. The complexity of this type of analysis is apparent from this figures. The four panels of the LBJ Freeway speeds in Figure 40 show different results depending on the time of day, the direction of travel, and the location on the roadway. There are two times, locations, and directions where one or the other of the infrastructure changes out performs the base case network. One improvement occurs in the west to east direction between 8:00 and 8:30 a.m. before the Dallas North Tollway. Here, speeds on the IC1 infrastructure are much greater than they are on either the base case or IC2. For both time periods in the east to west direction, both IC1 and IC2 improve the travelers' speeds on the links before Preston Road.

The flows on the LBJ Freeway are presented in Figure 41. As expected, the flows are greatest for the infrastructure with the additional lanes on the freeway (IC1).

The speeds and flows along Alpha Road are displayed in Figures 42 and 43 and show little differences between the infrastructures. The speeds on this road are controlled more by the delays at signal lights than anything else.

At this time, all link summary data should be viewed cautiously. The data is heavily influenced by the router. Even with the overall adequate vehicle counts shown in Figure 17, it is not clear if the links chosen for display have realistic counts. This is particularly true in the two infrastructure change cases where no data is available for validation.

Other interesting analyses could be done with the output data. Speeds, variances of speeds, flows, and densities could be studied for a particular link or an intersection. Also, a comparison of the travel times and speeds on the three infrastructures for the simulations where either the Galleria or the Non-Galleria travelers have been removed would be instructive. In particular, it would show whether the base case infrastructure is as good for the Galleria travelers as the other two structures when viewed alone.

15. CASE STUDY SUMMARY

The effects of three infrastructures on various populations of travelers were investigated in this study. The first infrastructure was a 1990 base case network around the Galleria Mall area in Dallas. The two other networks consisted of additional lanes on the LBJ Freeway (IC1) and a series of infrastructure improvements to the arterial roads (IC2). Two sets of subpopulations of travelers were constructed to study the effects of these networks on different populations:

1) Galleria and Non-Galleria travelers, the principal subpopulations

2) Local travelers and those passing through the study

Measures of the effectiveness of the infrastructure changes are constructed in a manner that is unique to transportation analysis methods like TRANSIMS, which consider each traveler. Network reliability is estimated by the absolute difference in travel times and speeds of individual travelers. Analysis of the complete distribution of travel times and speeds, in addition to the average values of these quantities, is shown to increase understanding of the transportation network. More is to be gained by reducing the travel time of those travelers with the longest trips and increasing the speeds of those with the slowest speeds. This was accomplished by investigating changes in the percentiles of the travel time and speed distributions of the three infrastructures. All of these methodologies were used in the case study.

Overall, the local infrastructure change (IC2) had the greatest potential for reducing travel times and increasing speeds for almost all of the subpopulations. The exception to this was for travelers passing through the study area; both infrastructure changes benefited these travelers.

Although the greatest reductions in travel times and increases in speeds occurred with the local infrastructure change, all of these improvements were after 7:30 a.m., with some of them as late as 8:00 a.m. Before 7:30 a.m., the extra lanes on the LBJ Freeway reduce travel times and increase speeds.

Both infrastructure changes reduced the travel times and increased the speeds of the Non-Galleria travelers more than they are improved by removing the Galleria travelers from the base case network. The same is not true for the Galleria travelers. Non-Galleria travelers made up 95% of the travelers in the study area. As expected, their removal from the base case had a great impact on the speeds and travel times of the Galleria travelers.

The distributions of travel times on the three networks were shifted in time. The longest travel times for the arterial infrastructure, IC2, occurred before 7:30 a.m. The longest travel times happened after 8:00 a.m. for IC1. The longest travel times for the base case were between these two times. This temporal shift among the infrastructures was unexpected, but it can be explained. A smaller percentage of vehicles traveled completely through the study area after 7:30 a.m.; yet the number of trips in the study area increased until 8:00 a.m. As a result, more travelers were leaving the freeways and were on the local streets between 7:30 and 8:00 a.m., which increased effectiveness in IC1 during the early period and provided better response of IC2 later in the morning.

16. PARAMETRIC AND SENSITIVITY STUDIES

Many of the TRANSIMS inputs have the potential to change the microsimulation output. Studies of the effects of these parameters will guide future development of TRANSIMS. Some of these inputs are the structure of the roadway network, the method of activity generation, the planner parameters, and the parameters of the microsimulation itself. This section outlines possible studies to judge the effect of some of these inputs. The base case of the case study is taken as the basis for these studies.

Most of the TRANSIMS parametric and sensitivity studies require microsimulation of a plan set. The results of the microsimulation with the new set of parameters are compared with the results from the original run. Differences in these comparisons are judged with respect to the uncertainty in the base case simulations. If the study requires a new set of plans, the statistics of the study must be compared with the results of BC-1-1-1 and BC-1-2-1. If a new set of plans is not required, the comparisons are with the differences in BC-1-1-1 and BC-1-1-2.

The case study networks each contain local streets. The characteristics of local streets are hard to acquire and will be burdensome if they are required in TRANSIMS. Additionally, TRANSIMS becomes computationally slower as the amount of roadway increases. Therefore, it is of great interest to study the effects of the addition of local streets to the simulations. It will take some thought to design an experiment to make the comparison between a network with local streets and one without them. The straight forward approach of fixing a set of activities and obtaining a set of routes for each network may not answer the question. This scheme will have the variability of the planner in addition to the variability induced by the microsimulation. This variability may be large enough to mask differences between the local and non-local street networks.

Except for freeways, ramps, and bridges that have no parking places, every link on each network was given one parking place. There are a few exceptions where links in the Galleria area were given multiple parking places. The effect of placing multiple parking places on a link is unknown. It would easily be studied by randomly assigning activities to any one of the multiple parking places on the same link as the location of the original parking place. The variability between a simulation with the multiple locations and BC-1-1-1 should be no greater than the variability seen between BC-1-1-1 and BC-1-1-2 if there is no effect of multiple parking places.

As an experiment, the parking lot of the Valley View Mall, which is next to the Galleria, was modeled as a series of links in a loop with access to the four roads on the boundary. This model is displayed in Figure 44 (see Appendix A). A small amount of traffic travels through the Valley View Mall. This traffic pattern is unrealistic, but its consequences are unknown. This situation could be studied by rerouting those few vehicles that pass through the mall.

Signal timings and offsets must be set for each signalized intersection in the simulation network. This is a difficult task; however, it is possible to create a generic algorithm to do this. A contrast of a simulation of a network with generic signalization and the network with actual ones would be made. Without replanning, differences in the two networks must be more than the difference of BC-1-1-1 and BC-1-1-2 to be significant.

Another general question is the effect of the length of turn pockets. It is unknown whether turn pockets of short lengths significantly change the behavior seen in the microsimulation. This could be tested with a series of calibration networks and with modifications to the base case network.

The case study microsimulation covers a 25-square mile study area surrounded by a buffer area. Routes were determined for every traveler over the entire Dallas-Ft. Worth metropolitan area. For those trips that start outside the study area, starting times in the buffer area are estimated from the expected travel times of the links outside the study area. An expanded microsimulation area would change the vehicle's arrival time at what was previously a buffer link. The consequences of this are unknown.

The desirability of taking one link rather than another is measured in the planner by a cost function. This cost function weights the monetary cost of taking the link, the link length, and the link travel time. The weights are derived from the traveler demographics. The case study used only the travel time in the planner cost function. Hence, in the case study, traveler demographics were ignored. The effects of producing a new set of plans based on the weighted cost function and the traveler demographics are unknown.

New methods for breaking gridlock in the microsimulation have been developed. The impact of these methods on the replanning process is not clear. A sensitivity experiment needs to be designed to evaluate the significance of these changes on both the microsimulation output and the planner characteristics.

The sensitivity and parametric studies listed in this section are not complete. The modules of TRANSIMS continue to evolve. As changes are made to each of the TRANSIMS components, sensitivity tests will be performed to judge the effectiveness of these changes. Many other sensitivity tests are possible. However, the tests listed here have the most immediate direct impact on the future development of TRANSIMS.

17. Conclusions

This paper presents a case study based on the first Interim Operational Capability (IOC) of TRANSIMS, which is the microsimulation. The microsimulation was exercised on three networks supplied by the North Central Texas Council of Governments (NCTCOG). A 25-square mile area of highly congested roadway around the Galleria Mall in Dallas-Ft. Worth, Texas was simulated. The networks represented

- a 1990 base case,
- a global change to the network with the addition of lanes to the LBJ Freeway, and
- a local network with increased capacity on the arterial roads in the study area.

The simulation was carried out for the hours between 5:00 and 10:00 a.m. Approximately 200,000 vehicle trips were simulated for each network. Each of these simulations executed in real time on a network of five Sun SPARC workstations.

TRANSIMS tracked each traveler in the simulation. The availability of information on individual travelers led to innovative analysis methodologies, including new methods for the study of uncertainty, network reliability analysis, and equity studies.

The microsimulation was calibrated using simple networks, which included a circle, an on-ramp, a left turn, and a signalized intersection. Simulations on each of these networks mimicked the results seen on real networks of a similar type.

The microsimulation of TRANSIMS moved individual vehicles on a predetermined route. The determination of these routes is not a part of this IOC, but routes for each individual are necessary inputs to the microsimulation. A preliminary method of determining routes based on iterative replanning with an optimal routing algorithm was developed. The origins and destinations of these trips were established from trip tables supplied by NCTCOG. Because the structure of TRANSIMS required a population of travelers and their activities, the trip tables were converted to pseudoactivities to be used by the router. Vehicle counts based on microsimulations using these routes and pseudoactivities were compared with volumes modeled by NCTCOG. This comparison showed the routed trips to be in agreement with NCTCOG.

An experimental design was exploited to assess the effects of the infrastructure changes on subpopulations of travelers. The full set of travelers was simulated on each of the three networks. The experimental design included the simulation of two populations, Galleria travelers and Non-Galleria travelers, in the absence of the other. These simulations allowed for the development of a baseline for the full microsimulations. The baseline simulations were compared with the two populations of travelers from the full microsimulations.

All models produced results that are uncertain. In TRANSIMS, this uncertainty is quantified. Randomness in the activity starting times, the rerouting algorithm, and the microsimulation led to uncertainty in the final results. An experimental design was developed to appraise this uncertainty. Microsimulation uncertainty was assessed by two simulations with different random number seeds but the same base case plan set. The same set of activities was replanned to determine the uncertainty from the replanning algorithm. Uncertainty induced by the activities was ascertained with the microsimulation of a plan set based on a different set of activities. The estimated uncertainty in simulations was used as a base line to judge the significance of differences among the simulations of the three networks.

Multiple measures of effectiveness were used in this study. These measures included the usual measures total vehicle miles, total vehicle hours, travel time, and average speeds. Information and important measures that are unique to models like TRANSIMS, which track the individual travelers, were advanced. Of greatest importance may be the estimation of network reliability, which was developed and presented as a measure of effectiveness. Because individual travelers are simulated, the starting time of each individual was perturbed a small random amount. The original simulation and one with the same traveler routes but with the starting time perturbed, mimicked the day-to-day variability of travelers on the network. To measure network reliability, the absolute differences in individual travel times and speeds from two simulations were computed. The average, or median, differences of individual travel times or speeds may be of interest. However, the travelers with the largest day-to-day variability in speed or travel times are potentially the most dissatisfied with the transportation network. To judge dissatisfaction with the network, the measure of network reliability was presented as the upper percentiles of travel time differences and the lower percentiles of individual speed differences.

Differences in the distributions of travel times and speeds across the three networks for the two populations, Galleria travelers and Non-Galleria travelers, showed that the local infrastructure change (IC2) benefited both populations after 7:30 a.m. This was true whether the effects were measured with the mean or median, or with percentiles of the distribution. Both infrastructure changes improved the travel characteristics of the Non-Galleria travelers more than the removal of the Galleria travelers from the base case network. Therefore, the cost imposed on the Non-Galleria travelers by the Galleria travelers was less than the cost of the infrastructure changes. The same was not true for the Galleria travelers. The new infrastructures were not equivalent to the removal of the Non-Galleria travelers in the base case.

Supplemental analyses were made based on all travelers and travelers being divided into three subpopulations: Local, Local-Into, and Thru travelers. The results based on these populations demonstrated almost the same pattern as seen in the Galleria and Non-Galleria travelers. The infrastructure change IC2 benefited both the Local and Local-Into travelers after 7:30 a.m. Both infrastructure changes benefited the Thru travelers.

Network reliability studies also showed the same infrastructure effects. The local infrastructure was more reliable than the other two infrastructures after 7:30 a.m. This was particularly true when the reliability was estimated with travel times.

The results of the case study were easily explained. Traffic passing through the study area represented only 20% of the total trips, which primarily occurred before 7:30 a.m. when the extra lanes on the LBJ Freeway made through trips more efficient. At 7:30 a.m., the local infrastructure become more efficient. At that time, just as congestion was increasing, local travelers were leaving the freeways and using the local streets, which made the local infrastructure changes more efficient after 7:30 a.m.

A set of parametric studies was presented. All modules of TRANSIMS were evolving. The importance of many of the finer points of the networks, the activities, the planner, and the microsimulation are unknown. The parametric studies will help to answer some of these questions.

The case study has successfully demonstrated the first IOC of TRANSIMS, the microsimulation. The simulations were based on a rudimentary set of routes and trips that were not the focus of this IOC; however, they were adequate to demonstrate the capability of TRANSIMS and the analysis potential when complete histories of individual travelers were available. The next IOC will focus on activity generation, planning and routing, and the environmental modules of TRANSIMS.

18. REFERENCES

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APPENDIX A

Dallas-Ft. Worth Case Study Figures

Figure 1	This schematic diagram displays the four modules of TRANSIMS: activity and population generation, planning and routing, microsimulation, and air quality analysis. The arrows show that information flows in both directions among the first three modules.
Figure 2	The four-step process is contrasted with the TRANSIMS modules used in the case study. The four-step Generation module was used in the case study to develop the number of vehicle trips. Distribution in the four-step process is related to Disaggregation in TRANSIMS. In the Case Study, there is iteration between the TRANSIMS Route Planner and Microsimulation.
Figure 3	Trips are planned on the Dallas-Ft. Worth network shown. They are microsimulated over a 25-square mile area around the Galleria and Valley View Malls.
Figure 4	The median travel times for the three infrastructures as a function of trip starting times are shown. The solid line represents the base case; the dotted line, IC1; and the dashed line, IC2.
Figure 5	The upper 5^{th} percentile of travel time differences estimate the day-to-day variability in travel times for the most variable 5% of the population. In this figure, the solid line represents the base case; the dotted line, IC1; and the dashed line, IC2.
Figure 6	The median travel times for the three infrastructures as a function of trip starting times are shown. Here, the three base case results are displayed to show the uncertainty in the simulations. The solid lines represent the base cases; the dotted line, IC1, and the dashed line, IC2.
Figure 7	This schematic diagram shows the procedures used to convert the initial travel model network and trip tables to TRANSIMS format.
Figure 8	This figure represents a *buffering* problem in which a portion of a TIGER link was calculated by ARC/INFO to be a new link, even though it should have been deleted.
Figure 9	The status of the network before replanning (iteration 0) is shown. Individual dots are vehicles; solid black links indicate congestion.
Figure 10	The status of the network after one iteration is shown. Individual dots are vehicles; solid black links indicate congestion.
Figure 11	The status of the network after the tenth iteration is shown. Individual dots are vehicles; solid black links indicate congestion.
Figure 12	The dark links denote those links split between four CPUs in the microsimulation.

Figure 13 The merge calibration network is shown where red vehicles merge with blue vehicles. The intersection controls are yield, stop, signal light, and none. The blue vehicles travel around the circle. The red vehicles merge from the left side and exit on the right.

Figure 14 A plot of vehicle flow (vehicles/lane/hour) verses the vehicle density (vehicles/lane/Km.) is given for a three-lane calibration circle.

Figure 15 The dual flows of blue and red vehicles (vehicles/lane/hour) for the merge calibration network with a stop sign are plotted.

Figure 16 The flows of blue and red vehicles for a one-lane merge calibration network are compared with similar data from the Highway Capacity Manual. The dots are from the calibration simulation. The line is from the Highway Capacity Manual.

Figure 17 These plots compare the microsimulation peak hour counts from the microsimulation with Dallas estimated volumes for freeways, principal and minor arterials, and collector links. The solid line is the equality line. The dashed lines denote ± 50% of the Dallas volumes.

Figure 18 The simulation with the least number of trips is BC-1-1-2. This histogram shows the percentage increase in trips above BC-1-1-2 for the other microsimulations – BC-1-1-1, BC-1-2-1, IC1 and IC2. The increase in trips given for the subpopulations of travelers, Galleria, Non-Galleria, Thru, Thru-Into, and Local are also shown. The largest increase is for Thru travelers in IC1.

Figure 19 The dots on the plot are the median travel times of travelers whose trips start in five-minute intervals between 5:30 and 9:00 a.m. The solid line is a smoothed curve fit to these points.

Figure 20 An example histogram of travel time with a smoothed density function is shown on the left. A corresponding boxplot showing the 95th, 75th, 25th, and 5th percentiles is shown on the right. The median and the mean of the distribution are also shown.

Figure 21 This schematic outlines an experimental design for the uncertainty experiment. Two activity sets are at the top of the design. Two sets of plans are generated for each activity set, and two microsimulations are run for each set of plans. The dark boxes show the activities, plans, and microsimulations completed in the uncertainty experiment.

Figure 22 The travel times (Panel A) and speeds (Panel B) for the travelers in the uncertainty experiment are given in these plots. The dark lines are for the two microsimulations with the same set of plans: BC-1-1-1 and BC-1-1-2. The dotted line is for microsimulation BC-1-2-1, which has the same activity set as BC-1-1-1 and BC-1-1-2, but a different set of plans. The travel times and speeds for the microsimulation with the second set of activities, BC-2-1-1, are given by the dashed line.

Figure 23 The distributions of travel time (Panel A) and speed (Panel B) differences assess base case network reliability. The differences are caused by differing the starting times of the travelers. The 5^{th} and 95^{th} percentiles of the difference distribution are given by the dashed lines. The 25^{th} and 75^{th} percentiles are shown by dotted lines. The solid line is the median of the distribution.

Figure 24 Network reliability can be judged by either perturbing the starting times or running the microsimulation using different random numbers. The solid lines in the plots denote perturbed starting times; the dashed lines denote new random number seeds. Panels A and D are the 95^{th} and 75^{th} percentiles of travel times. Panel B and D are the 95^{th} and 75^{th} percentiles of speeds.

Figure 25 These two figures show the total vehicle miles (Panel A) and the total vehicle hours (Panel B) in five-minute intervals for all travelers in the base cases (IC1 and IC2). The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2.

Figure 26 The total vehicle miles and the total vehicle hours of Figure 25 are divided by the number of travelers to give the average vehicle miles (Panel A) and the average travel time (Panel B). The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2. There is a steep drop in average trip length as congestion increases at 7:30 a.m.

Figure 27 Panel A is the same figure as Figure 26(a) showing the drop in average trip length from the microsimulation. This is compared with the planned trip lengths in Panel B. The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2. The long dashed line in Panel B gives the average trip length before replanning. The longer trips are decreased by replanning.

Figure 28 The total number of trips and the percentage of trips through the study area in five-minute intervals are given in Panels A and B, respectively. The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2. The percentage of Thru trips decreases as congestion increases at 7:30 a.m.

Figure 29 The median travel times (Panel A) and the median speeds (Panel B) of all the travelers are shown for each of the microsimulation runs. The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2. Both infrastructures improve the travel times and speeds. A temporal shift in the maximum travel times and speeds between the infrastructures is evident.

Figure 30 Boxplots of the travel time distributions for two of the base case runs, IC1 and IC2, are shown for 15-minute intervals from 5:45 to 9:15 a.m. The outer points are the 95^{th} and 5^{th} percentiles of the distribution. The ends of the box are the 75^{th} and 25^{th} percentiles. The median is shown by the line; the “x” marks the mean of the distribution.

Figure 31 Boxplots of the speed distributions for two of the base case runs (IC1 and IC2) are shown for 15-minute intervals from 5:45 to 9:15 a.m. The outer points are the 95^{th} and 5^{th} percentiles of the distribution. The ends of the box are the 75^{th} and 25^{th} percentiles. The median is shown by the line; the “x” marks the mean of the distribution.

Figure 32 The 95th and 75th percentiles of travel time (Panels A and B) and the 5th and 25th percentiles of speeds (Panels C and D) are displayed as a function of starting time for the base cases (IC1 and IC2). The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2. IC2 shortens the long trips and increases the slowest speeds compared to the other infrastructures.

Figure 33 Network reliability as measured by the 95th and 75th percentiles of travel time (Panels A and C) and speed (Panels B and D) variability are given. The solid line represents the base case; the dotted line, IC1, and the dashed line, IC2. IC2 is the most reliable network.

Figure 34 The two panels in this figure display the median travel times for the Non-Galleria travelers (Panel A) and the Galleria travelers (Panel B). The solid lines signify the base cases; the dashed lines represent IC1 and IC2. The dotted line is the median travel time for travelers when only the Non-Galleria travelers are simulated (Panel A), or only the Galleria travelers are simulated (Panel B).

Figure 35 The two panels in this figure display the median speeds for the Non-Galleria travelers (Panel A) and the Galleria travelers (Panel B). The solid lines signify the base cases; the dashed lines represent IC1 and IC2. The dotted line is the median travel time for travelers when only the Non-Galleria travelers are simulated (Panel A), or only the Galleria travelers are simulated (Panel B).

Figure 36 The 95th and 75th percentiles of travel time (Panels A and B) and the 5th and 25th percentiles of the speed distributions (Panels C and D) are given for Non-Galleria travelers. The solid lines signify the base cases; the dashed lines represent IC1 and IC2. The dotted lines are the travel time percentiles for travelers when only the Non-Galleria travelers are simulated

Figure 37 The 95th and 75th percentiles of the travel time distributions (Panels A and B) and the 5th and 25th percentiles of the speed distributions (Panels C and D) are given for Galleria travelers. The solid lines signify the base cases; the dashed lines represent IC1 and IC2. The dotted lines are the travel time percentiles for travelers when only the Non-Galleria travelers are simulated

Figure 38 The four panels display the median travel times for travelers local to the study area (Panel A), travelers whose trips either start or end in the study area but not both (Panel B), travelers who travel through the study area (Panel C), and all travelers (Panel D). The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2.

Figure 39 The four panels display the median speeds for travelers local to the study area (Panel A), travelers whose trips either start or end in the study area but not both (Panel B), travelers who travel through the study area (Panel C), and all travelers (Panel D). The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2.

Figure 40 Average speeds for links along the LBJ freeway for two time intervals and in two directions are displayed in the four panels. Panel A shows the average speeds in the time interval 7:30 to 8:00 a.m. in the East-to-West direction. Average speeds from 8:00 to 8:30 a.m. in the same direction are given in Panel B. Panels C and D display the average speeds in the East-to-West direction between 7:30 and 8:00 a.m. and 8:00 to 8:30 a.m., respectively. The solid lines represent the base cases; the dotted line, IC1; and the dashed line, IC2.

Figure 41 Average flows for links along the LBJ freeway for two time intervals and in two directions are displayed in the four panels. Panel A shows the average flow in the time interval 7:30 to 8:00 a.m. in the East-to-West direction. Average flows from 8:00 to 8:30 a.m. in the same direction are given in Panel B. Panels C and D display the average flows in the East-to-West direction between 7:30 and 8:00 a.m. and 8:00 to 8:30 a.m., respectively. The solid lines represent the base case; the dotted line, IC1; and the dashed line, IC2.

Figure 42 Average speeds for links along Alpha Road for two time intervals and in two directions are displayed in the four panels. Panel A shows the average speeds in the time interval 7:30 to 8:00 a.m. in the East-to-West direction. Average speeds from 8:00 to 8:30 a.m. in the same direction are given in Panel B. Panels C and D display the average speeds in the East-to-West direction between 7:30 and 8:00 a.m. and 8:00 to 8:30 a.m., respectively. The solid lines represent the base case; the dotted line, IC1; and the dashed line, IC2.

Figure 43 Average flows for links along Alpha Road for two time intervals and in two directions are displayed in the four panels. Panel A shows the average flow in the time interval 7:30 to 8:00 a.m. in the East-to-West direction. Average flows from 8:00 to 8:30 a.m. in the same direction are given in Panel B. Panels C and D display the average flows in the East-to-West direction between 7:30 and 8:00 a.m. and 8:00 to 8:30 a.m., respectively. The solid lines represent the base case; the dotted line, IC1; and the dashed line, IC2.

Figure 44 The network representation of the parking lot around the Valley View Mall is shown in this figure. The roads around the mall and the roads that access them were used to represent the parking lot in the case study simulations.

The TRANSIMS Modules

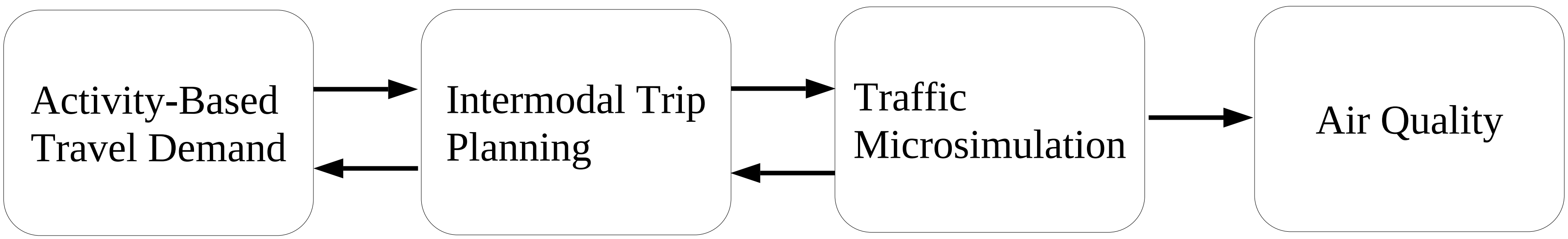


Figure 1

Four Step Model and TRANSIMS

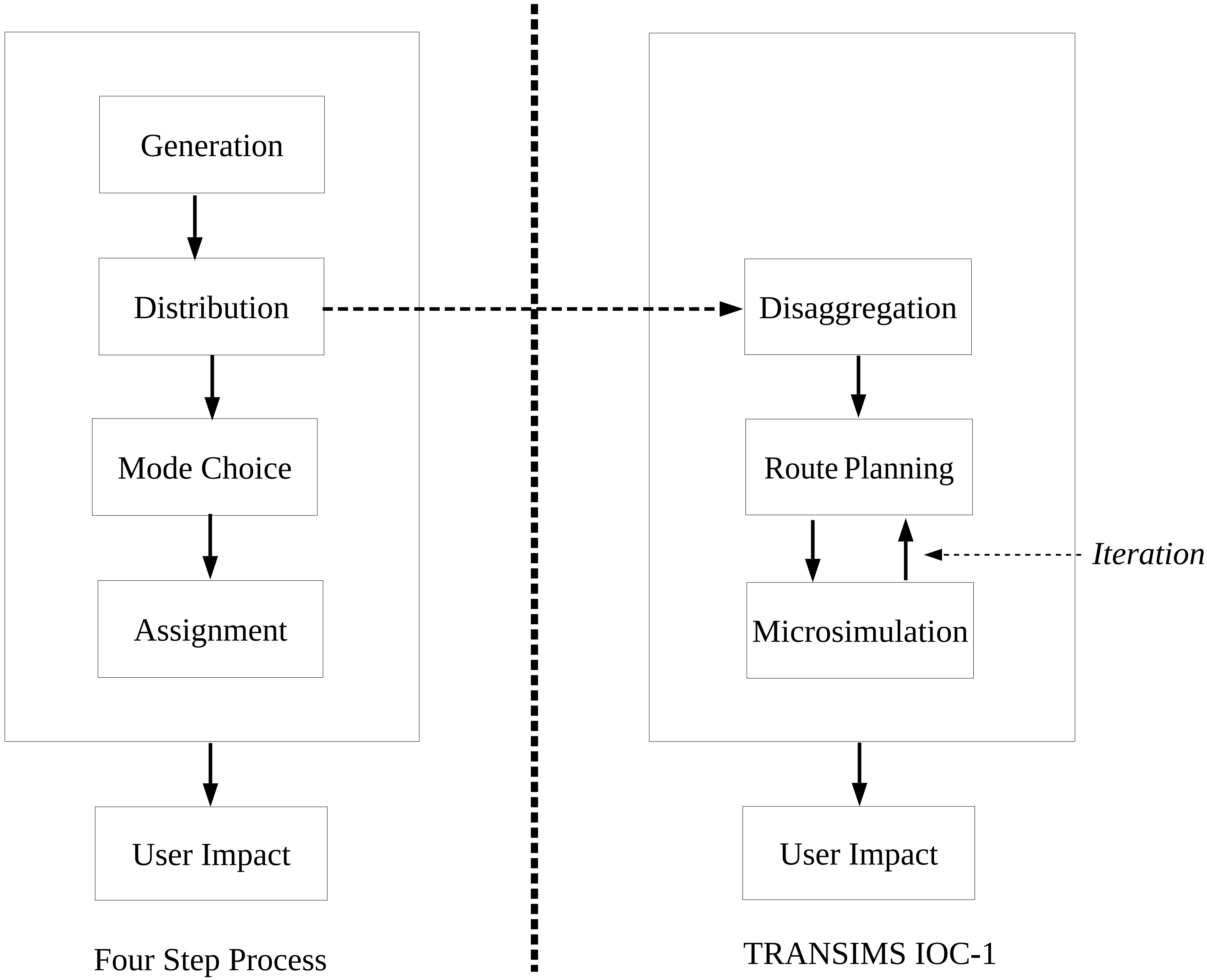


Figure 2

Planning Network

Figure 3

Median Travel Times

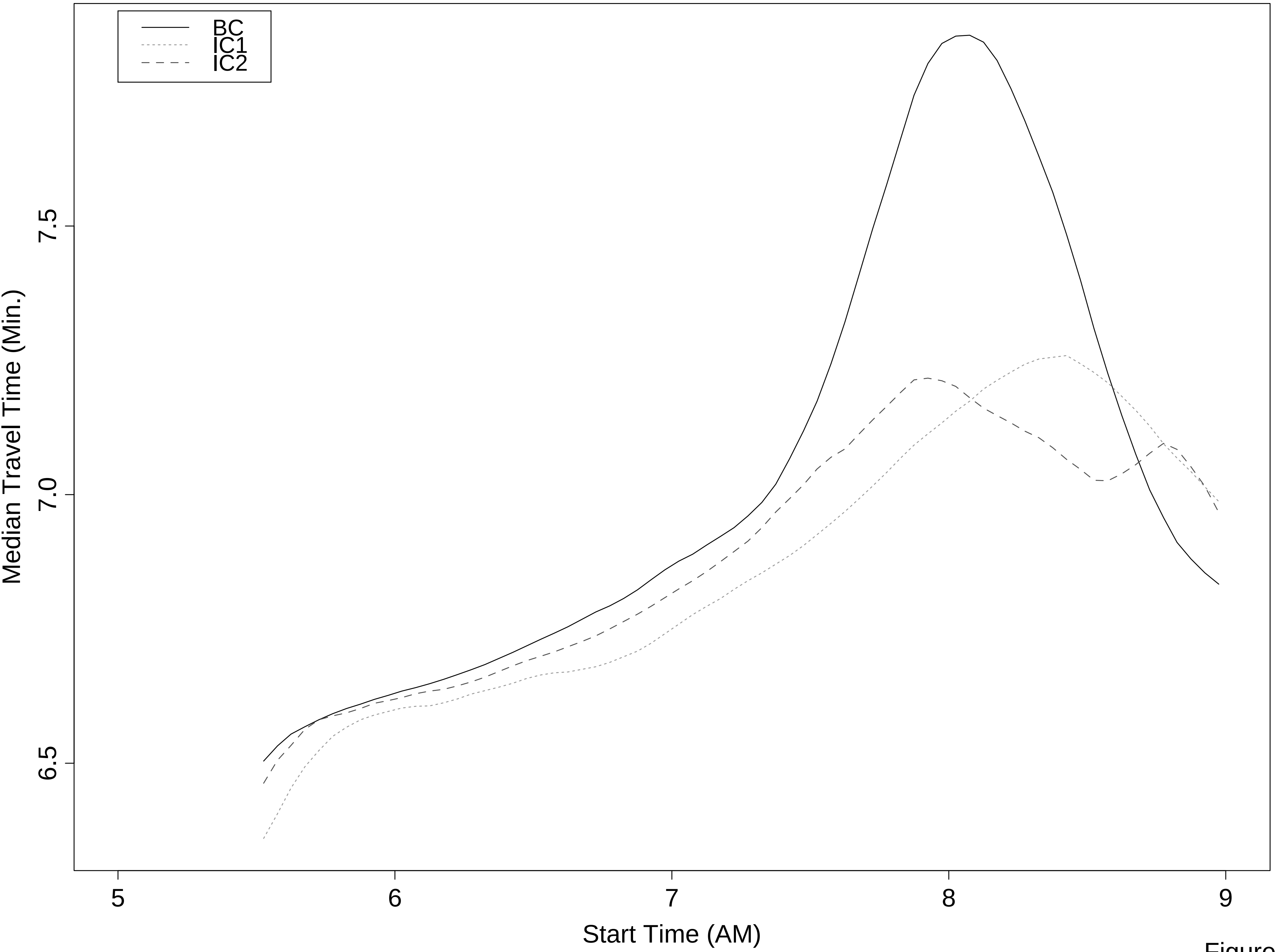
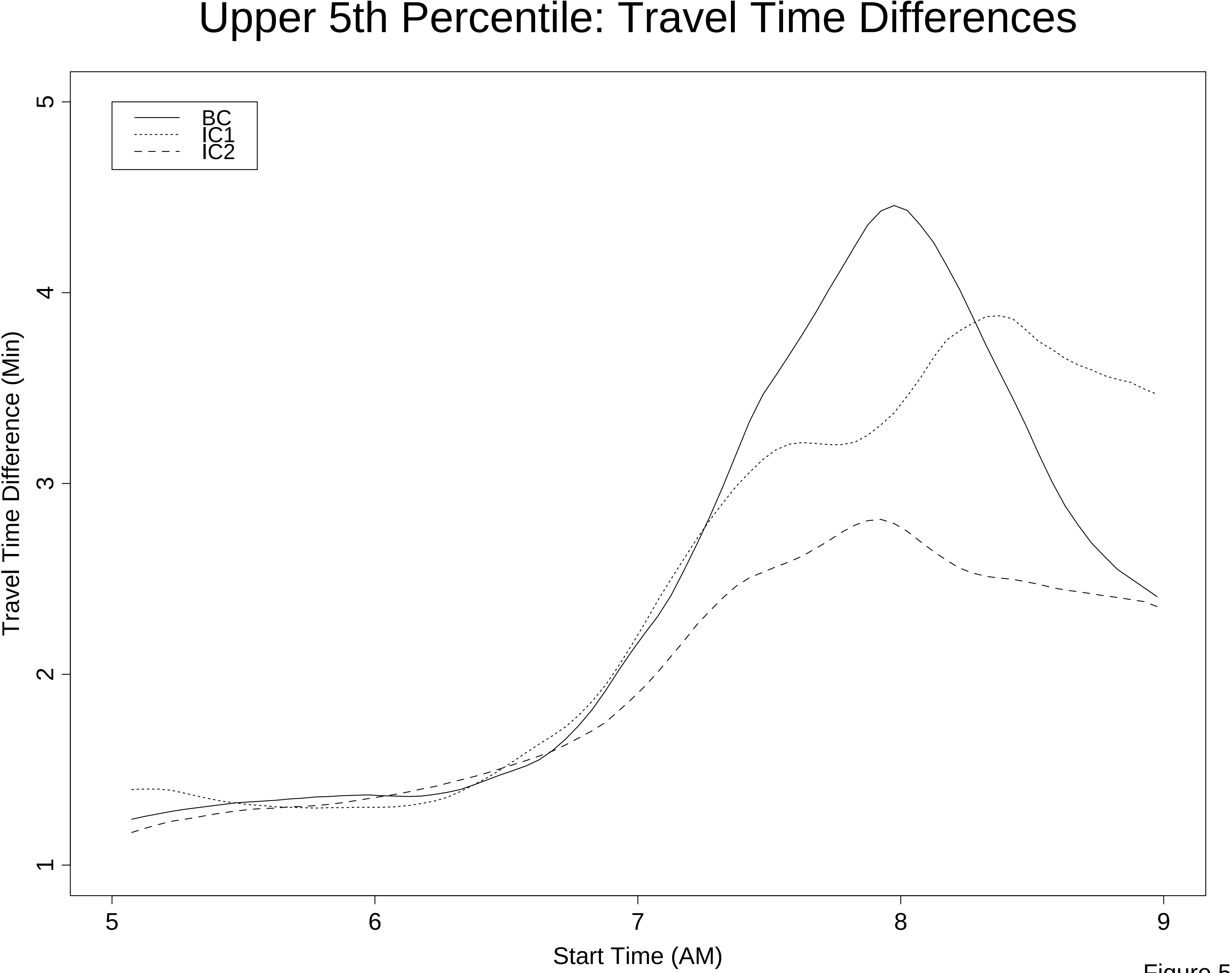


Figure 4



Upper 5th Percentile: Travel Time Differences
BC
IC1
IC2
Travel Time Difference (Min)
1
2
3
4
5
Start Time (AM)
5
6
7
8
9

Figure 5

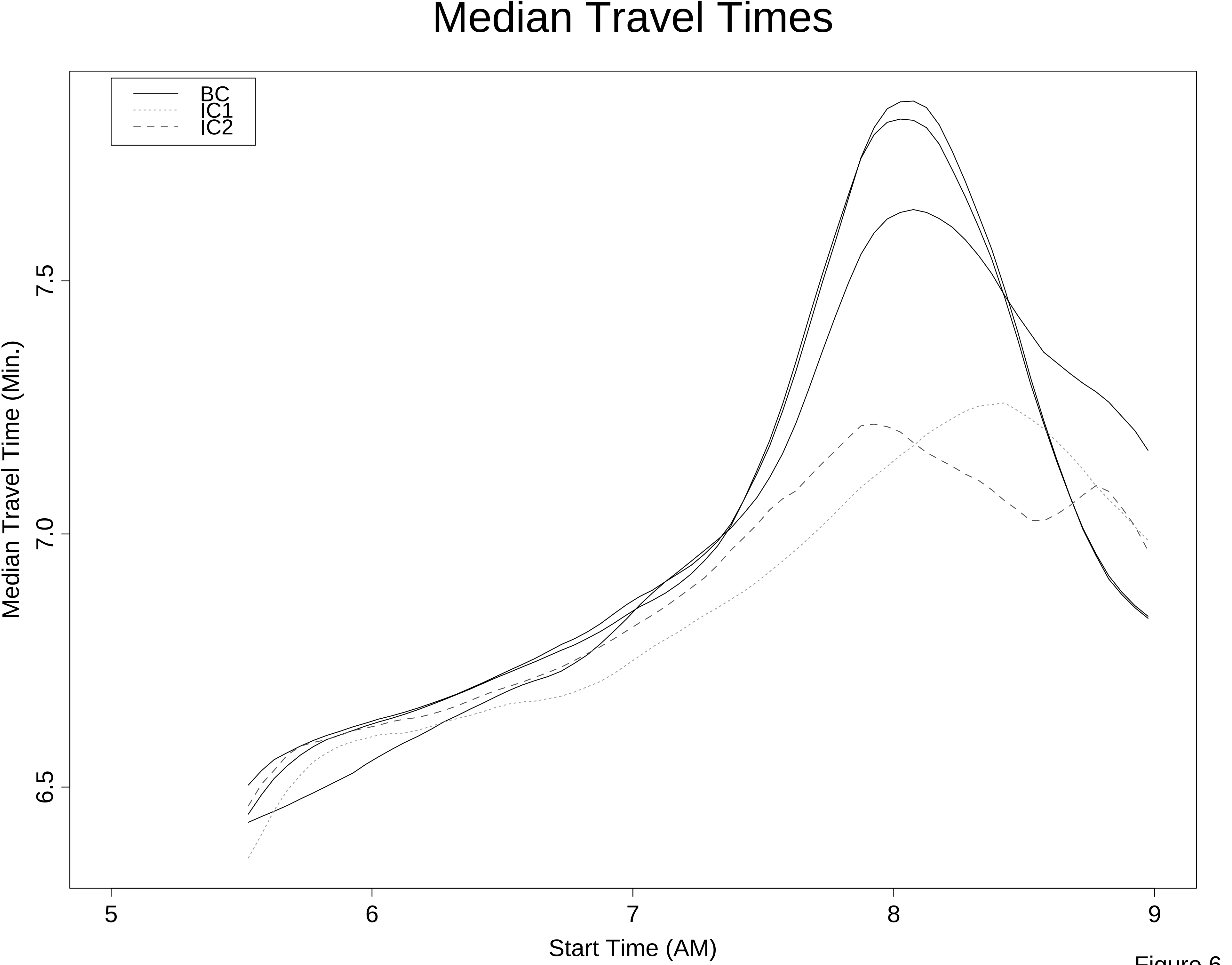

Median Travel Times
BC
IC1
IC2
7.5
7.0
6.5
Median Travel Time (Min.)
5
6
7
8
9
Start Time (AM)

Figure 6

Setup Procedures

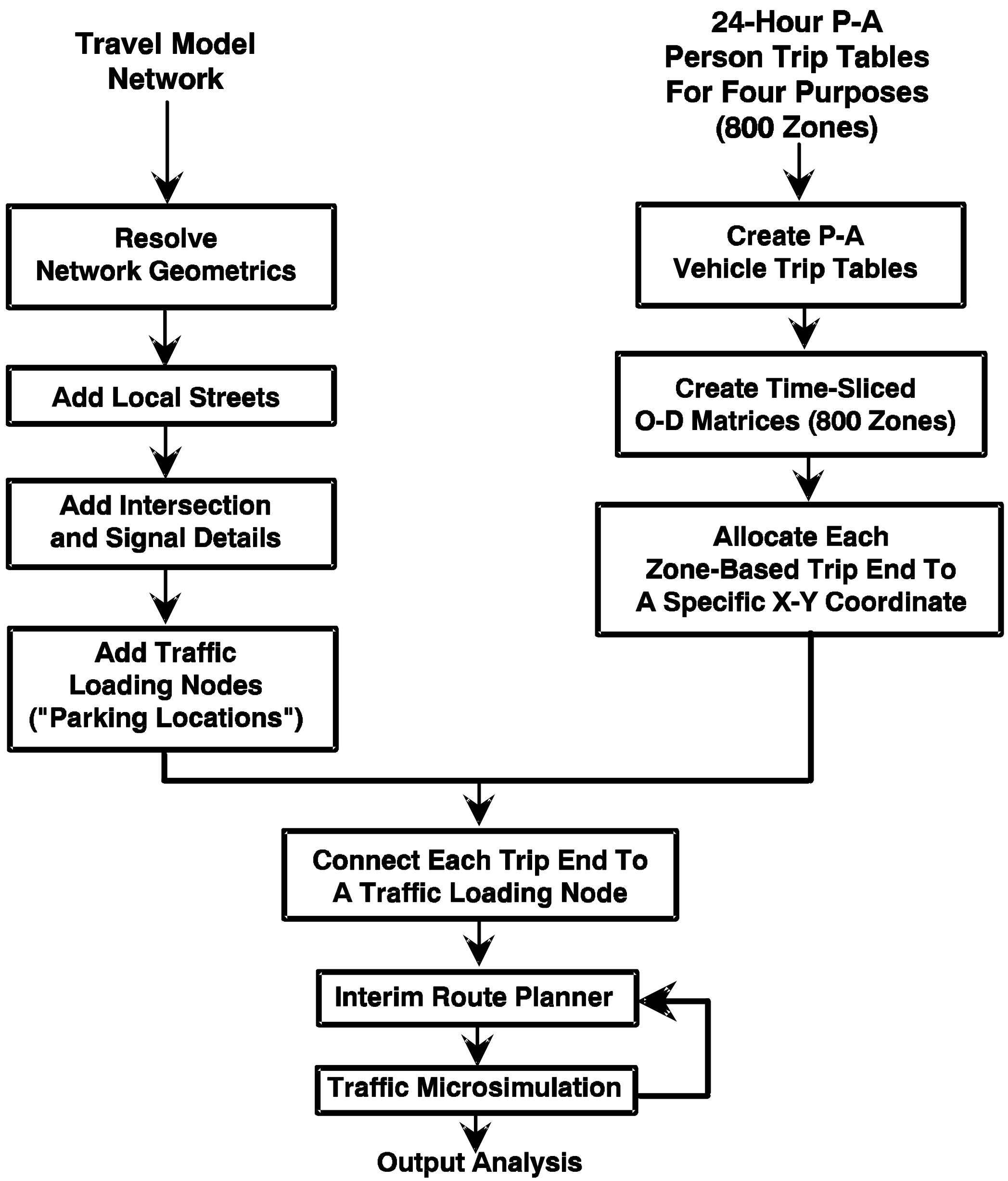


Figure 7

Local Streets: Buffering Problem

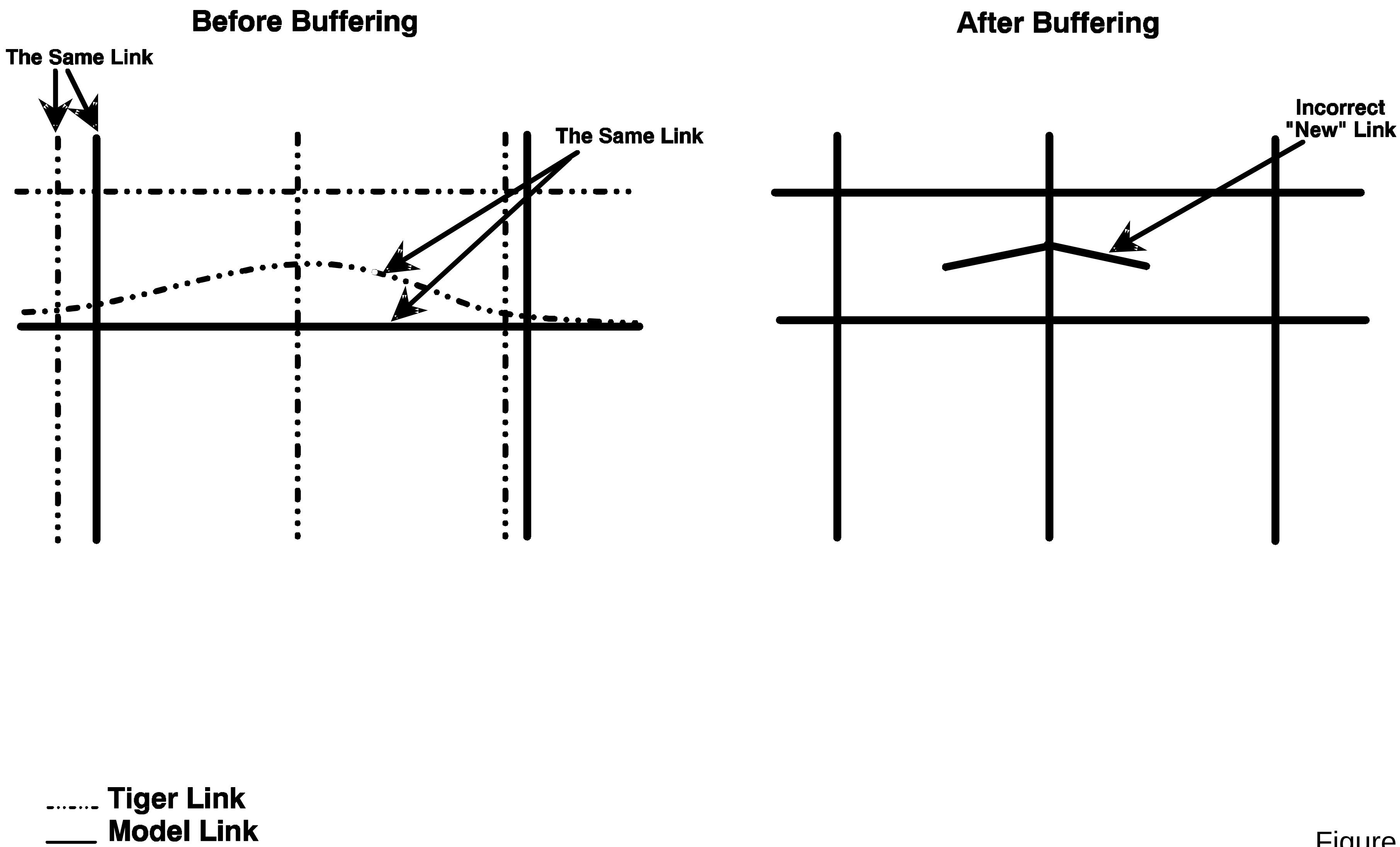


Figure 8

Replanner 0th Iteration

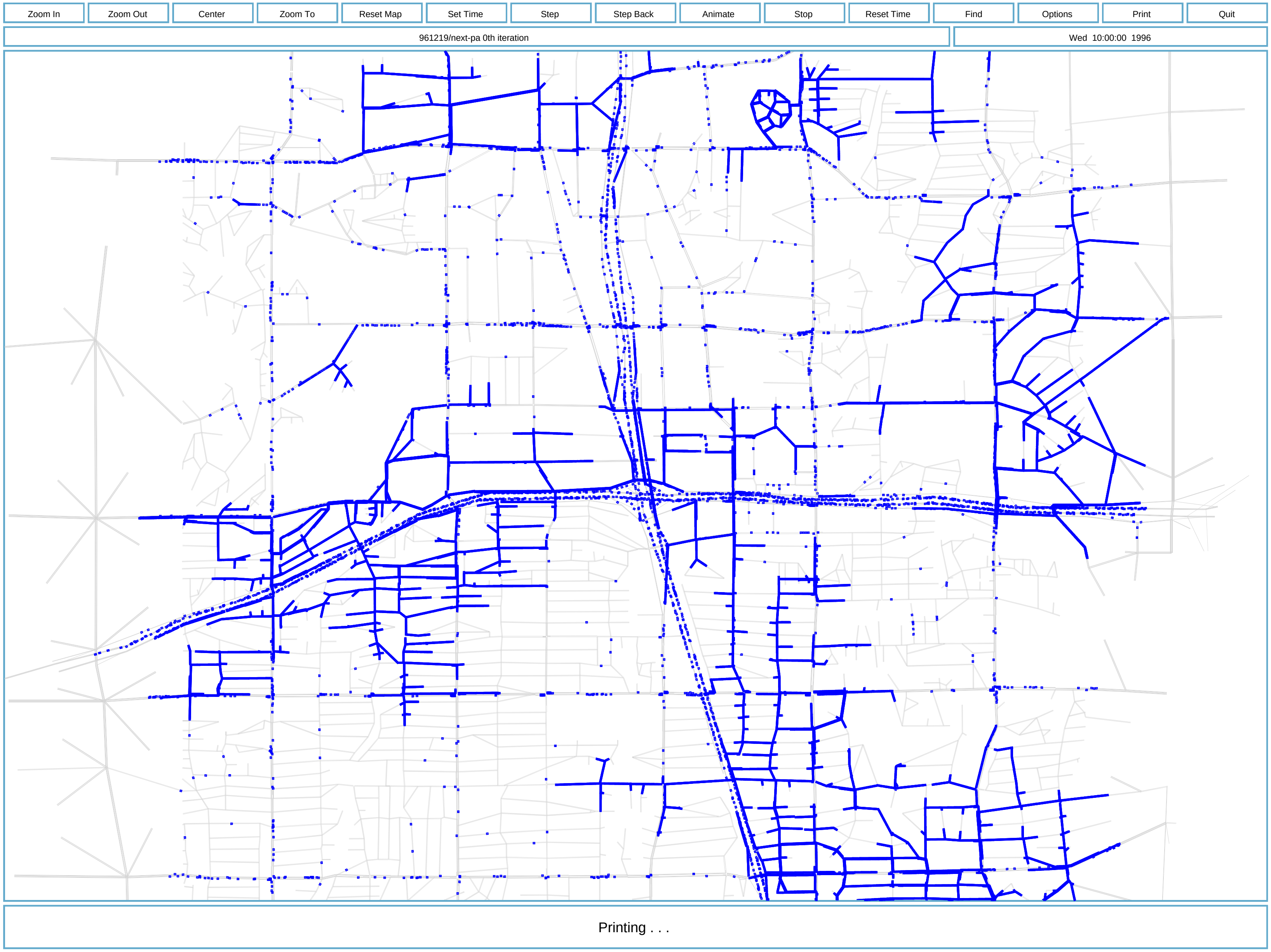


Figure 9

Replanner 1st Iteration

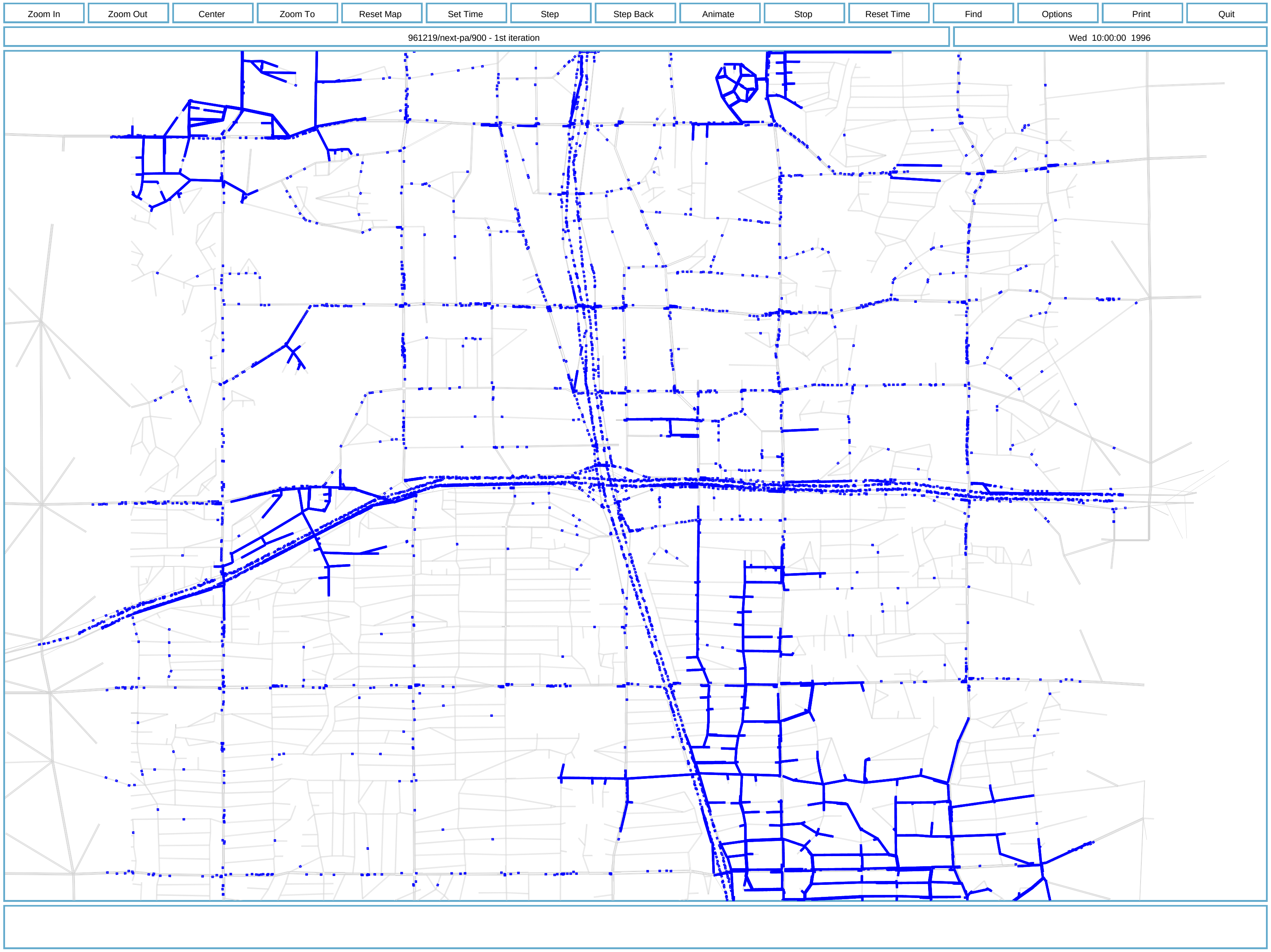


Figure 10

Replanner 10th Iteration

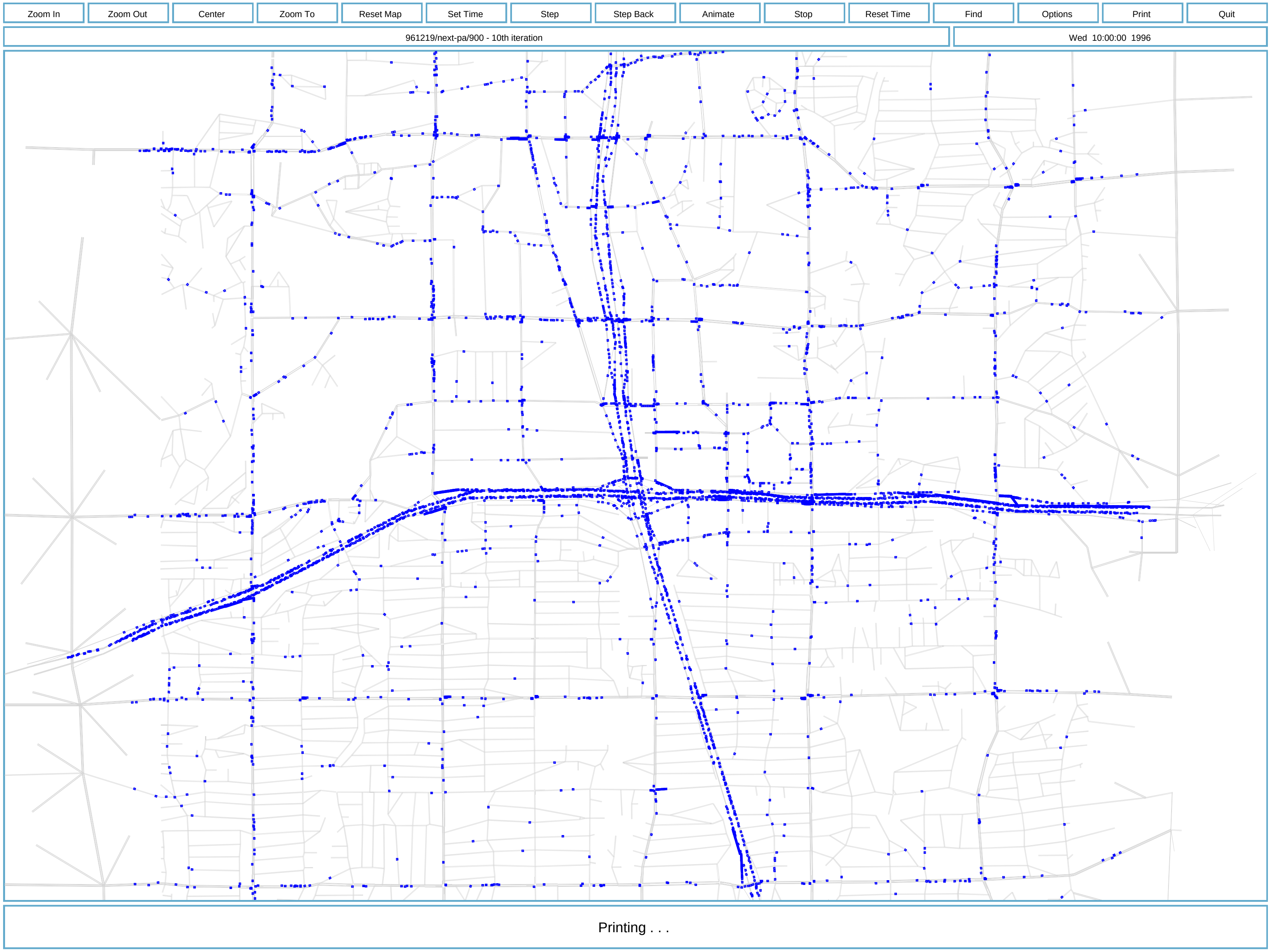


Figure 11

Split Links

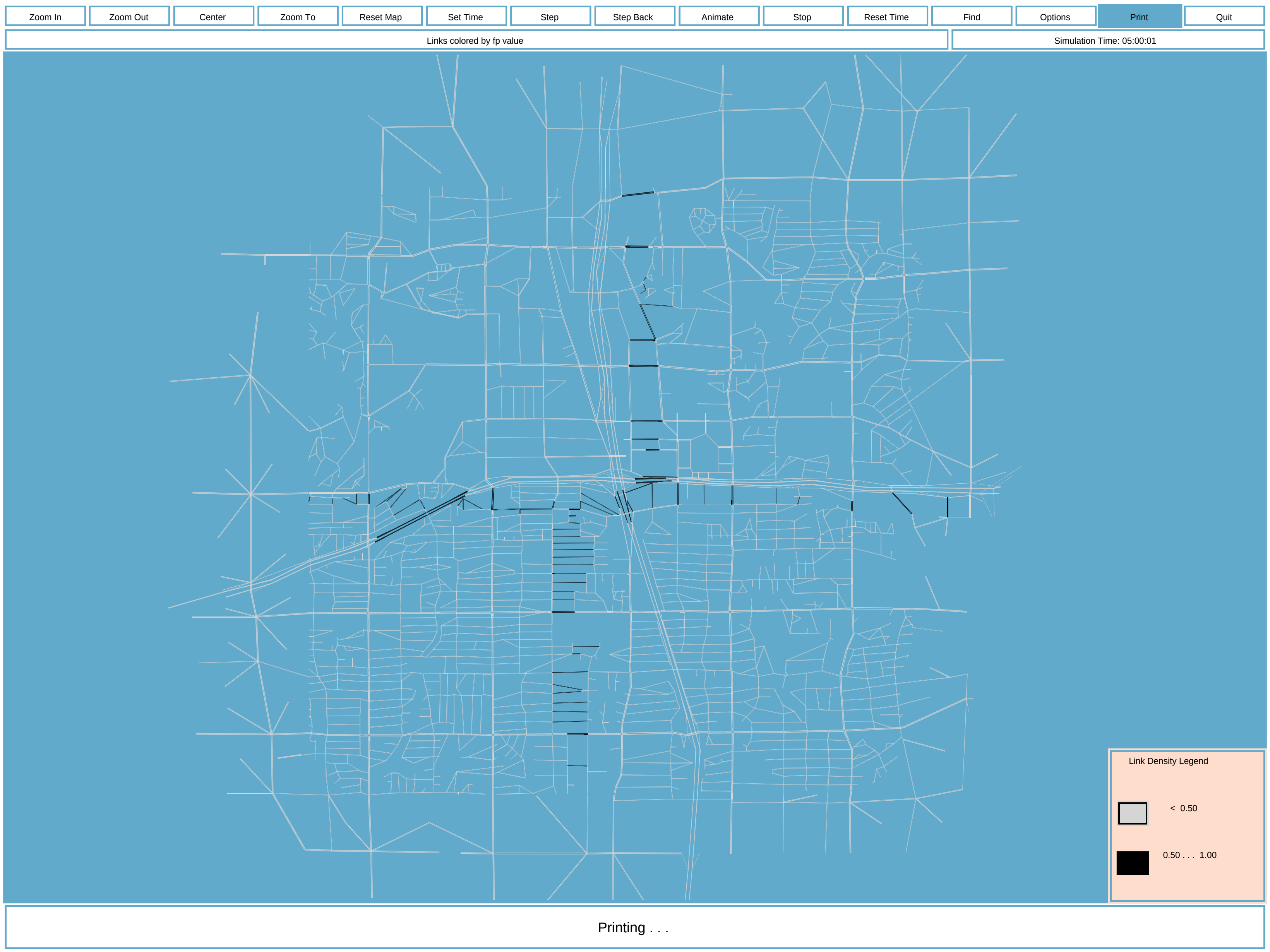


Figure 12

Merge Calibration Network

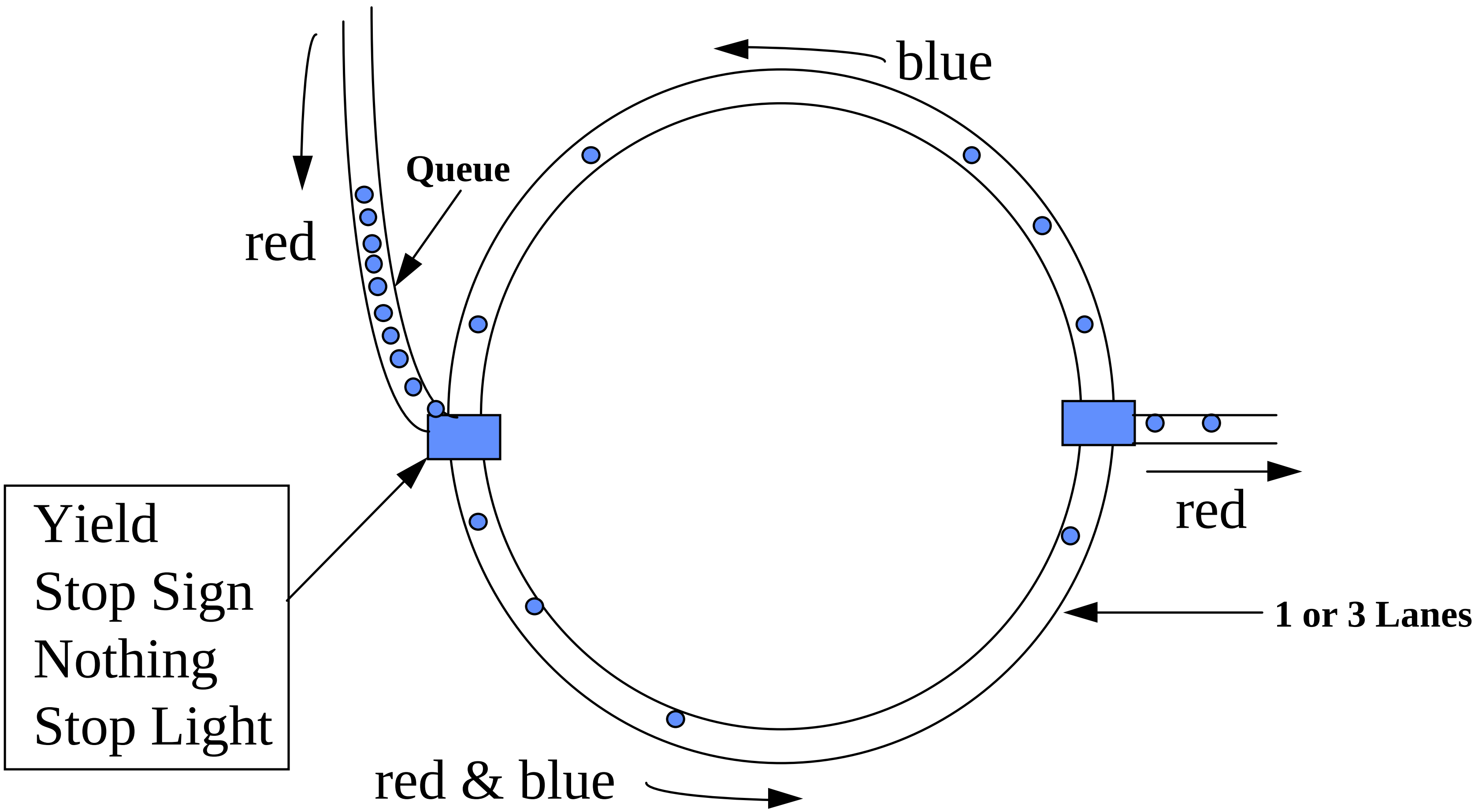


Figure 13

Fundamental Diagram: Three-lane Circle

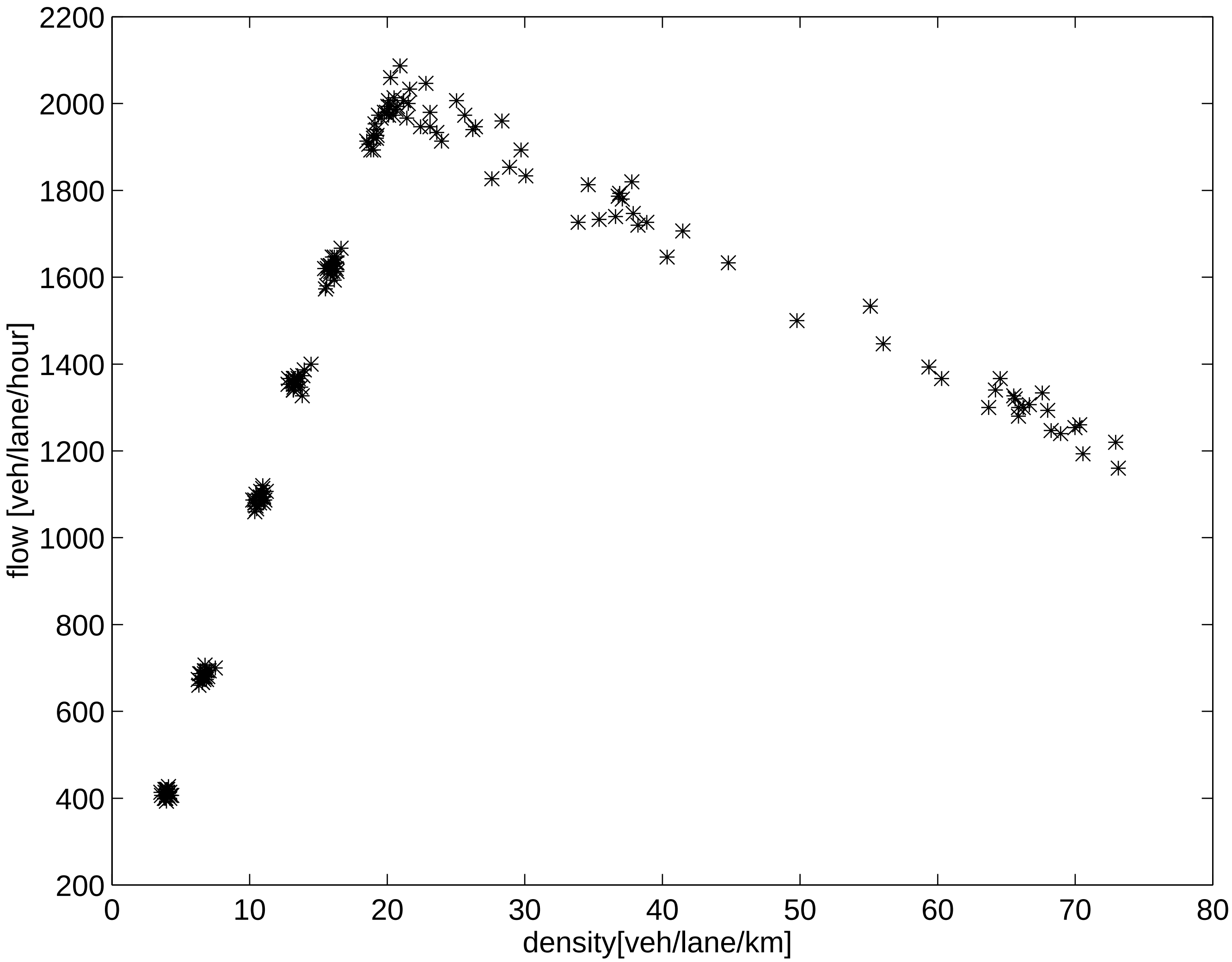


Figure 14

Stop Sign: Red v. Blue Vehicle Flow

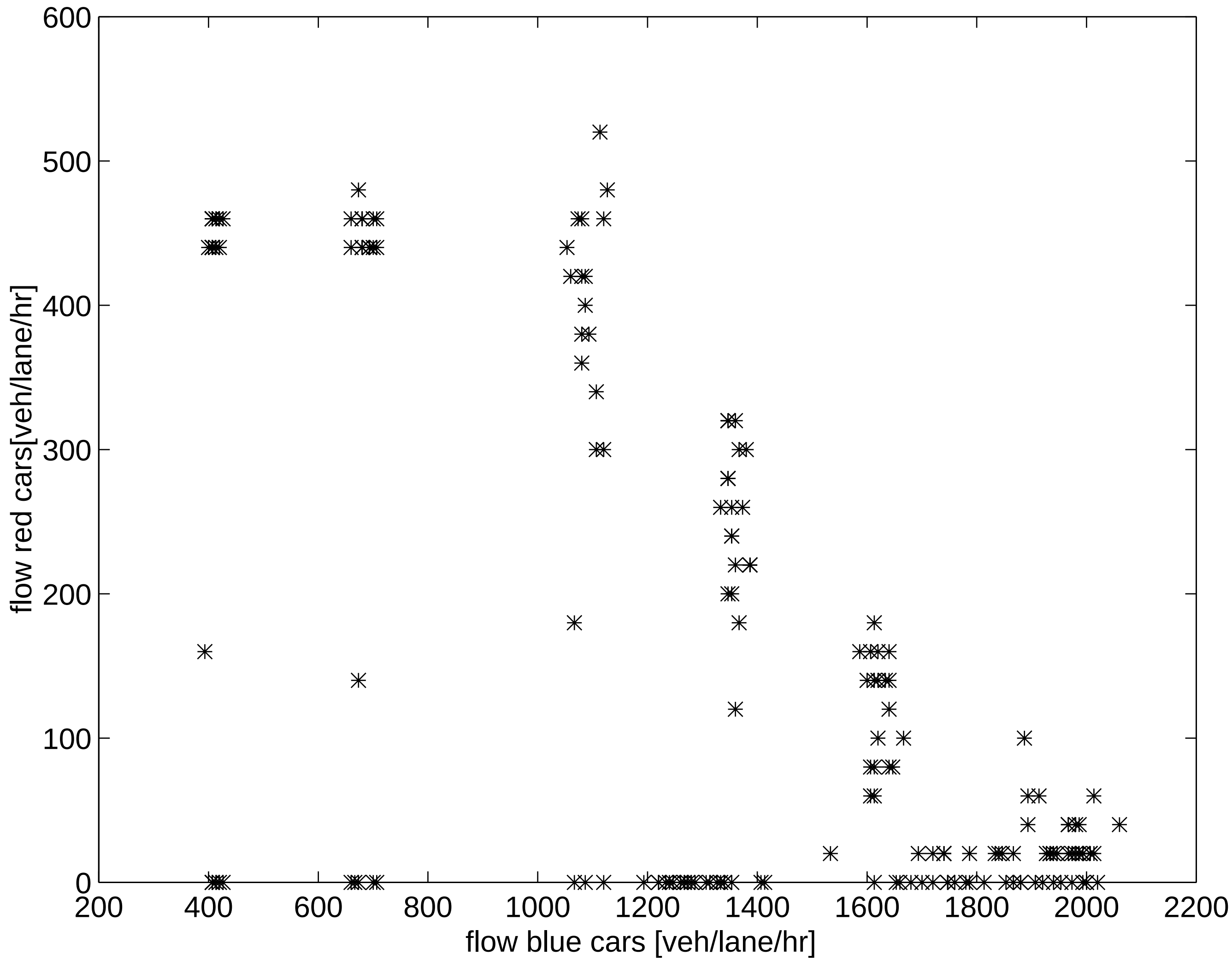


Figure 15

Flow: One-lane Circle

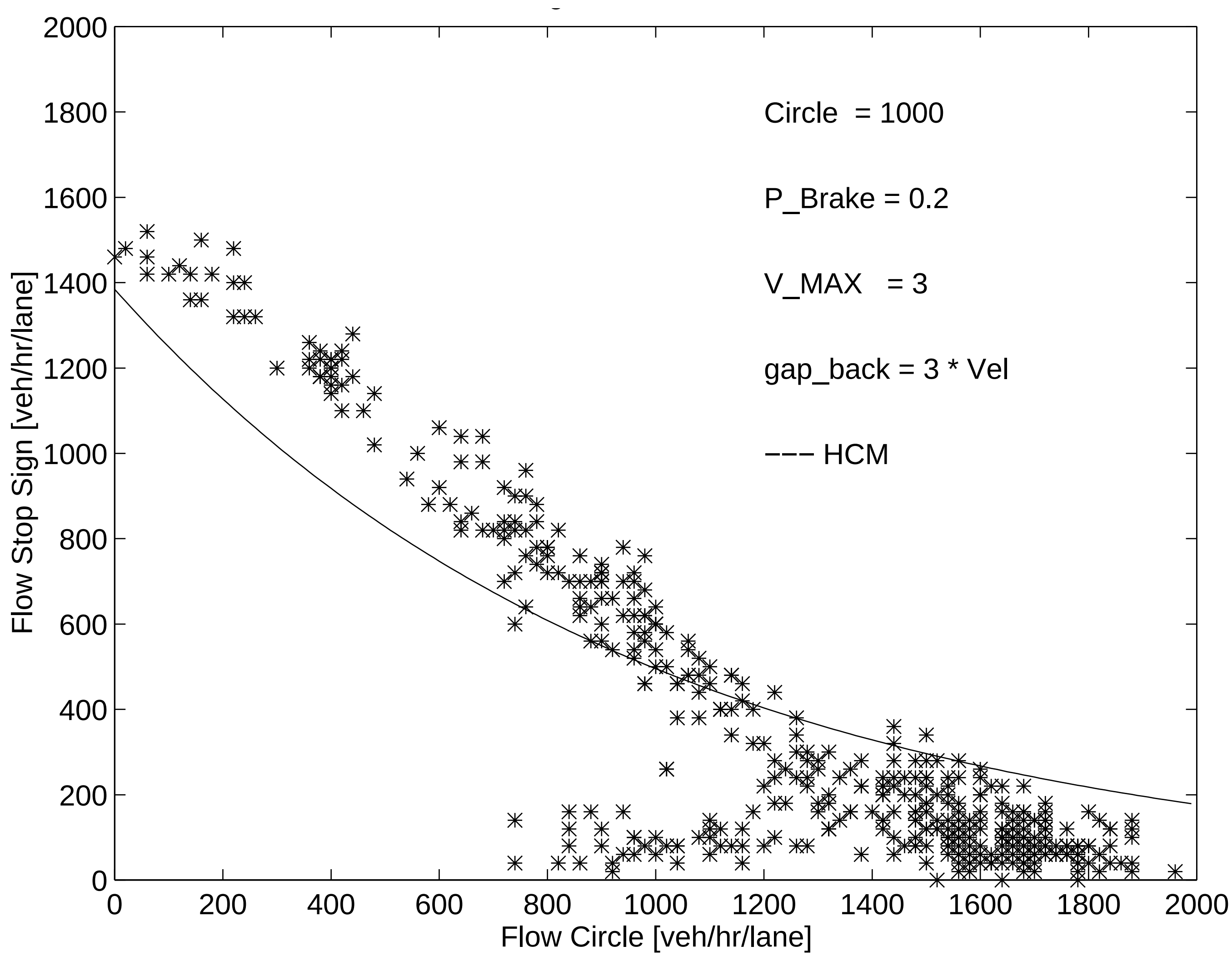
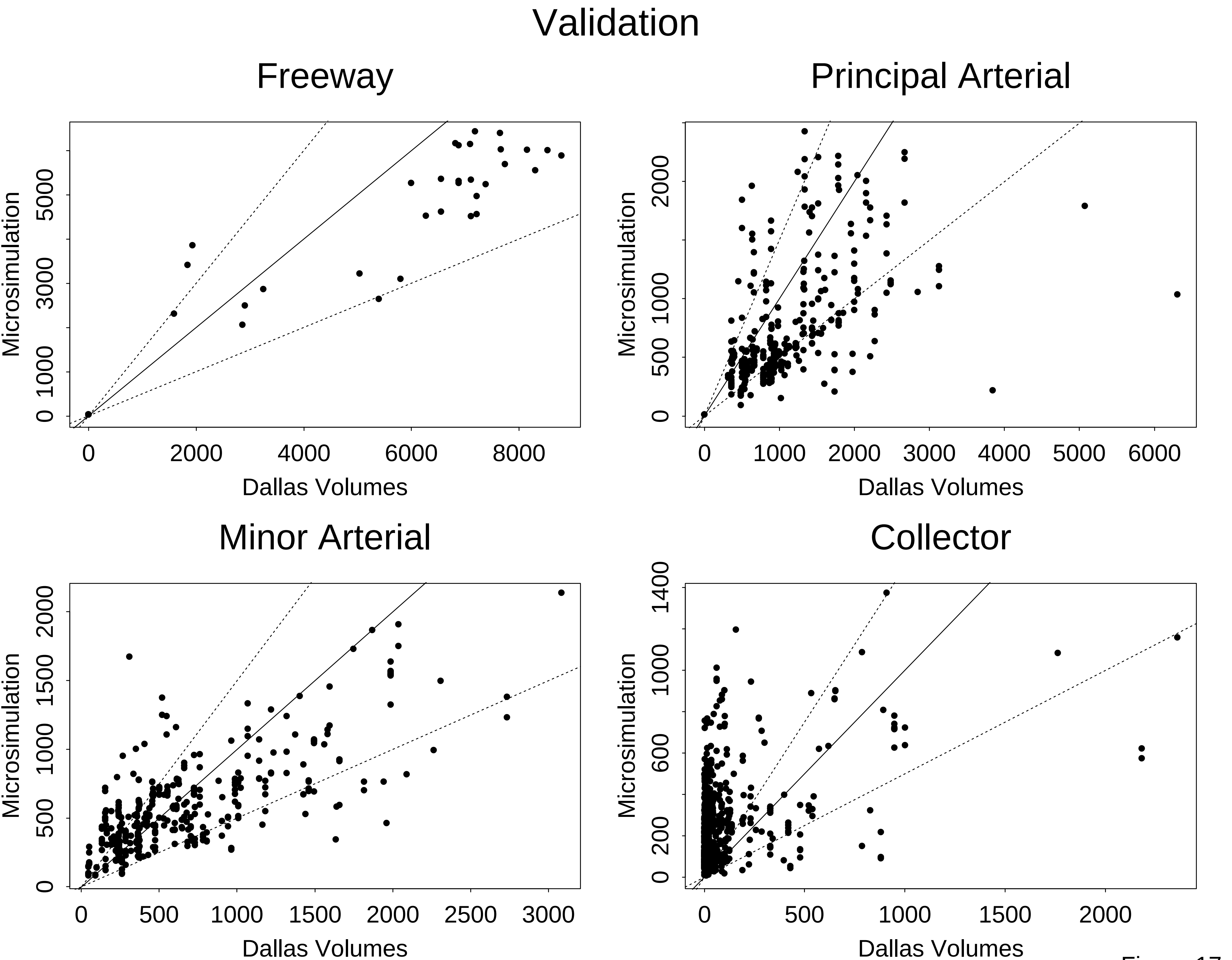


Figure 16



Validation
Freeway
Principal Arterial
Minor Arterial
Collector
Microsimulation
Dallas Volumes
0
1000
3000
5000
2000
4000
6000
8000
500
1000
2000
3000
5000
6000
1500
2500
200
600
1400

Figure 17

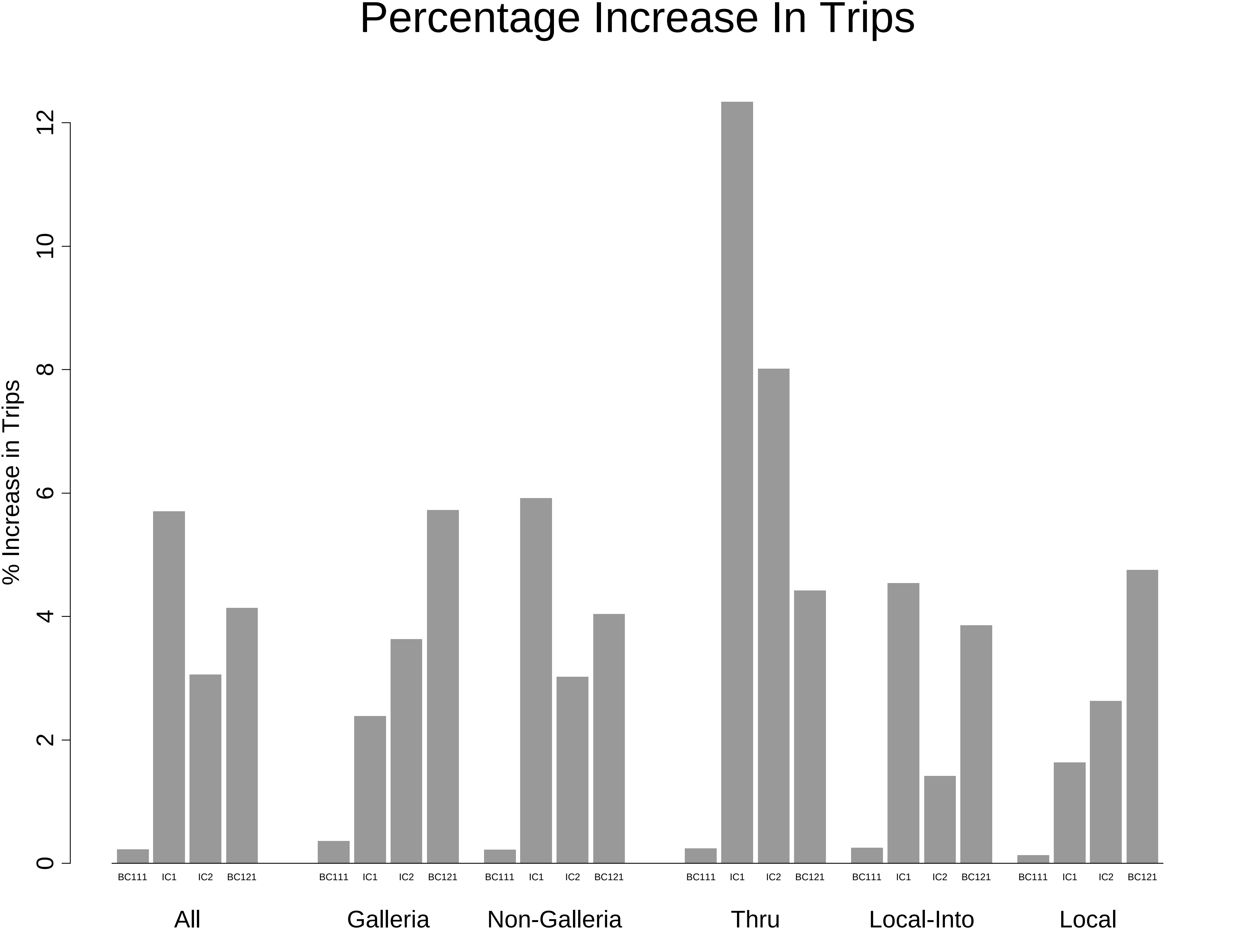
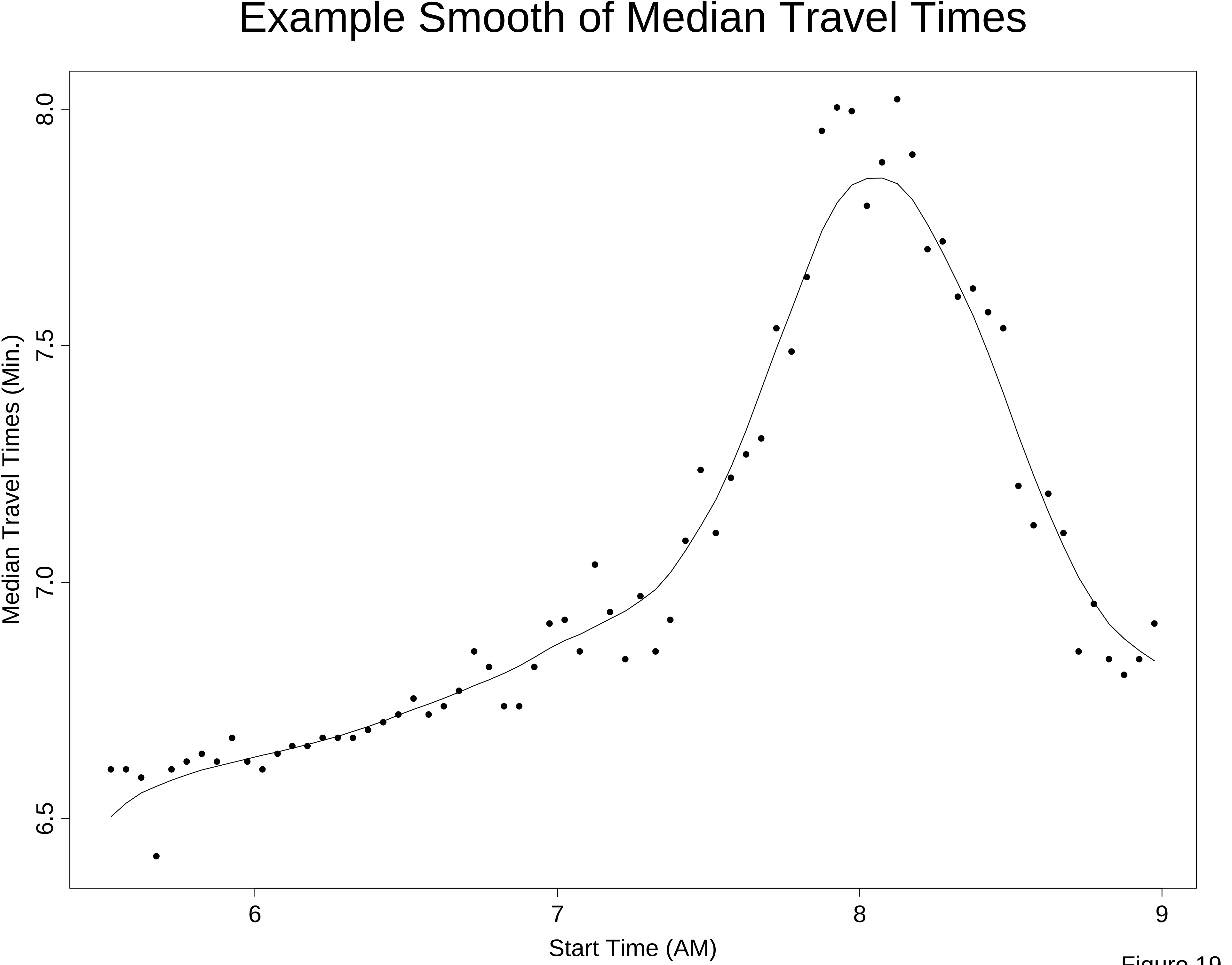

Percentage Increase In Trips
% Increase in Trips
0
2
4
6
8
10
12
BC111
IC1
IC2
BC121
All
Galleria
Non-Galleria
Thru
Local-Into
Local

Figure 18



Example Smooth of Median Travel Times
Median Travel Times (Min.)
8.0
7.5
7.0
6.5
6
7
8
9
Start Time (AM)

Figure 19

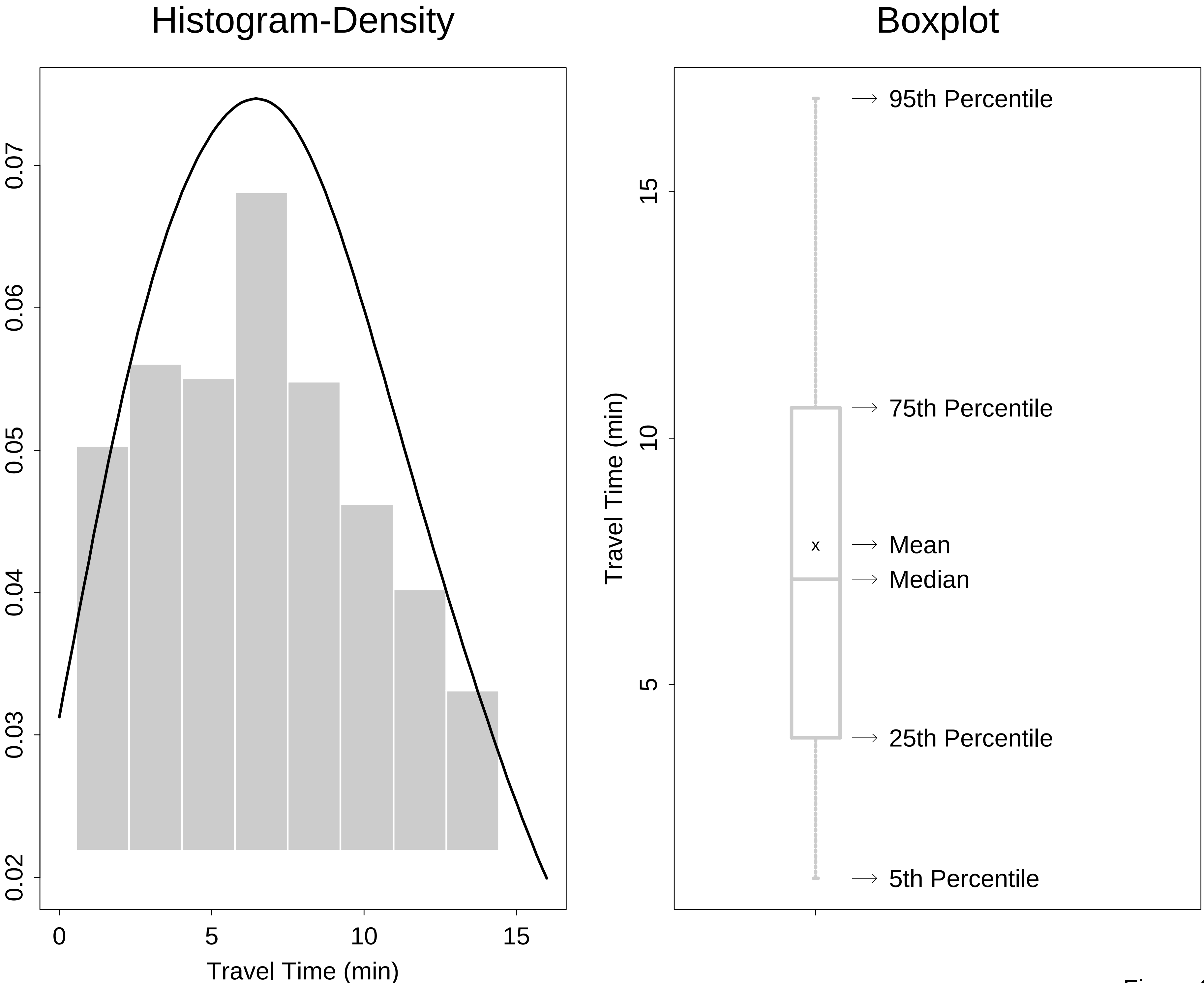

Histogram-Density
0.02
0.03
0.04
0.05
0.06
0.07
0
5
10
15
Travel Time (min)
Boxplot
Travel Time (min)
5
10
15
95th Percentile
75th Percentile
x
Mean
Median
25th Percentile
5th Percentile

Figure 20

Uncertainty Experimental Design

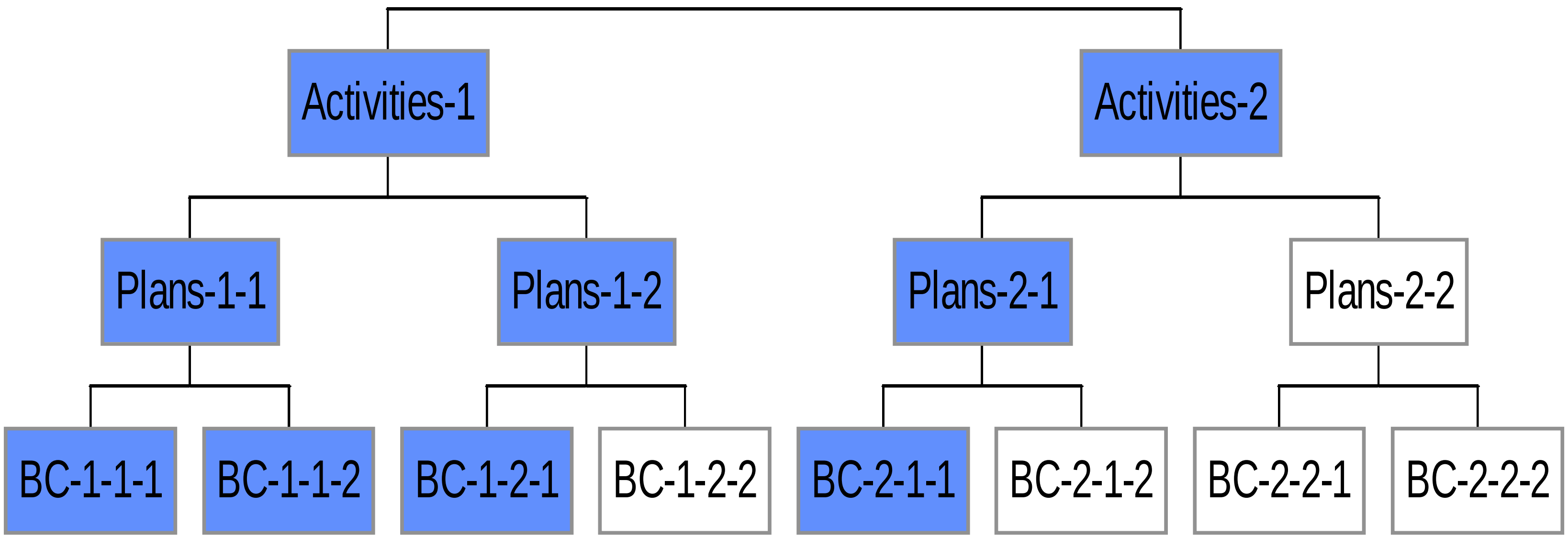


Figure 21

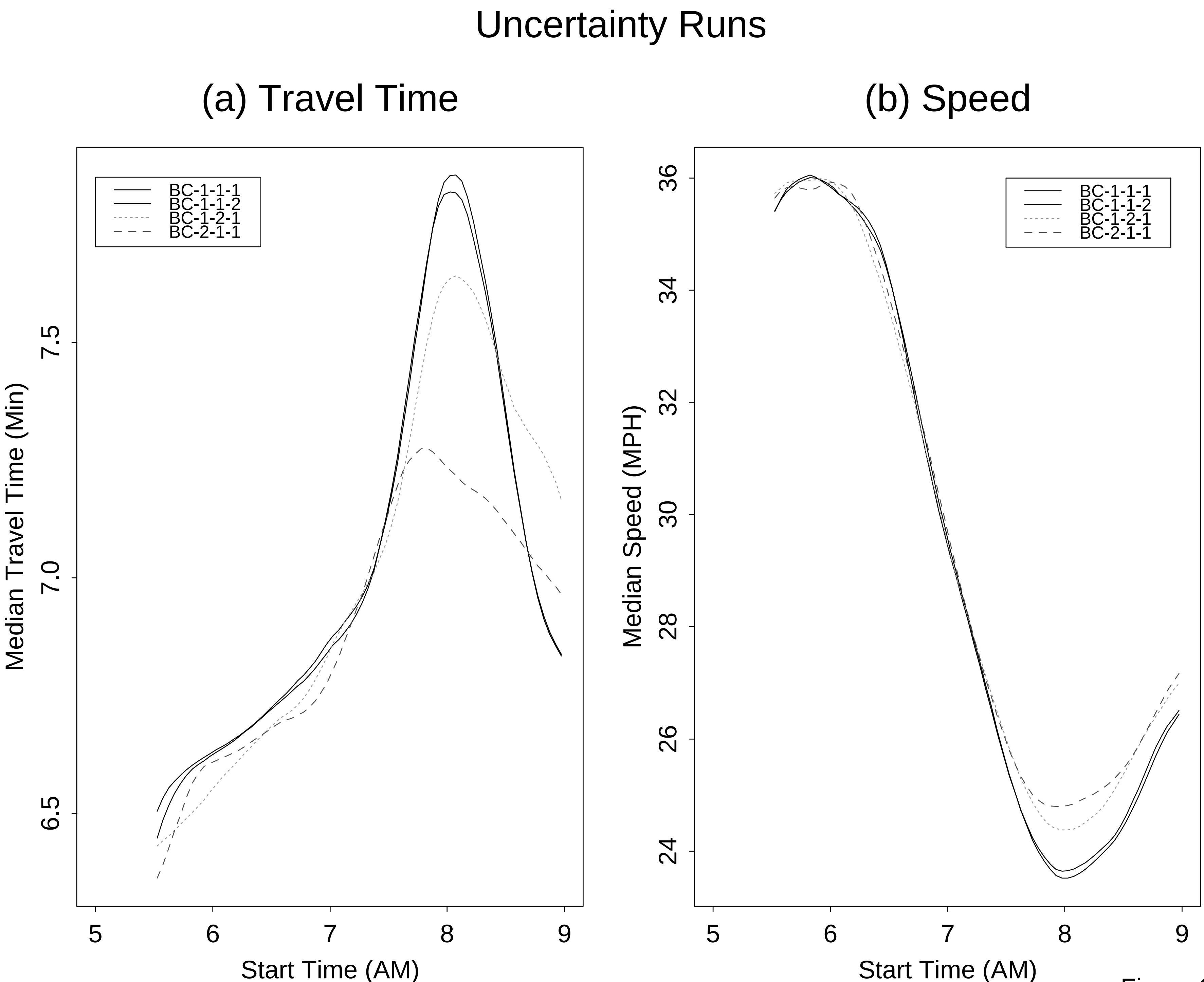

Uncertainty Runs
(a) Travel Time
Median Travel Time (Min)
Start Time (AM)
BC-1-1-1
BC-1-1-2
BC-1-2-1
BC-2-1-1
6.5
7.0
7.5
5
6
7
8
9
(b) Speed
Median Speed (MPH)
Start Time (AM)
BC-1-1-1
BC-1-1-2
BC-1-2-1
BC-2-1-1
24
26
28
30
32
34
36
5
6
7
8
9

Figure 22

Base Case Network Reliability

Different Start Times

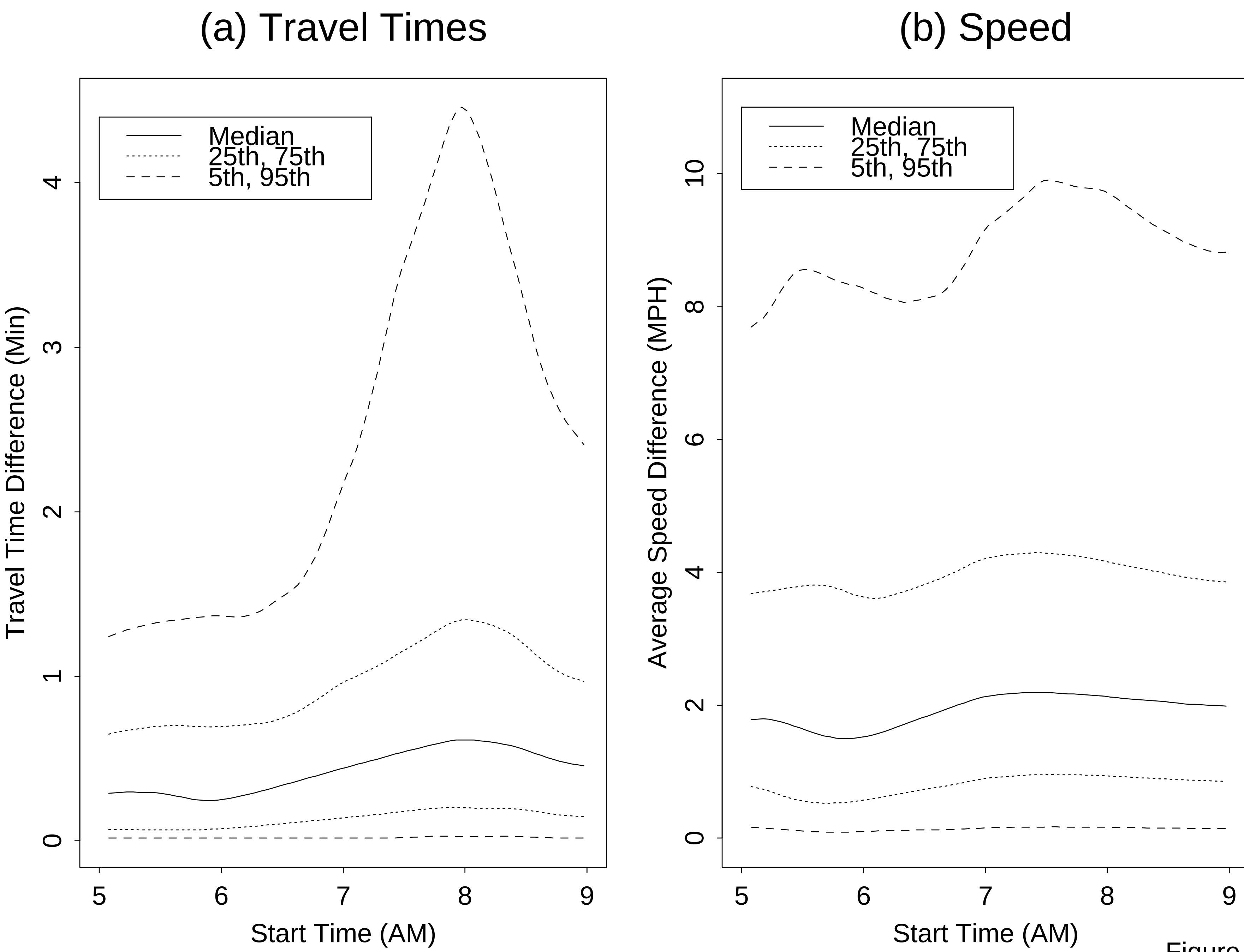


Figure 23

Base Case Network Reliability

Percentile Differences

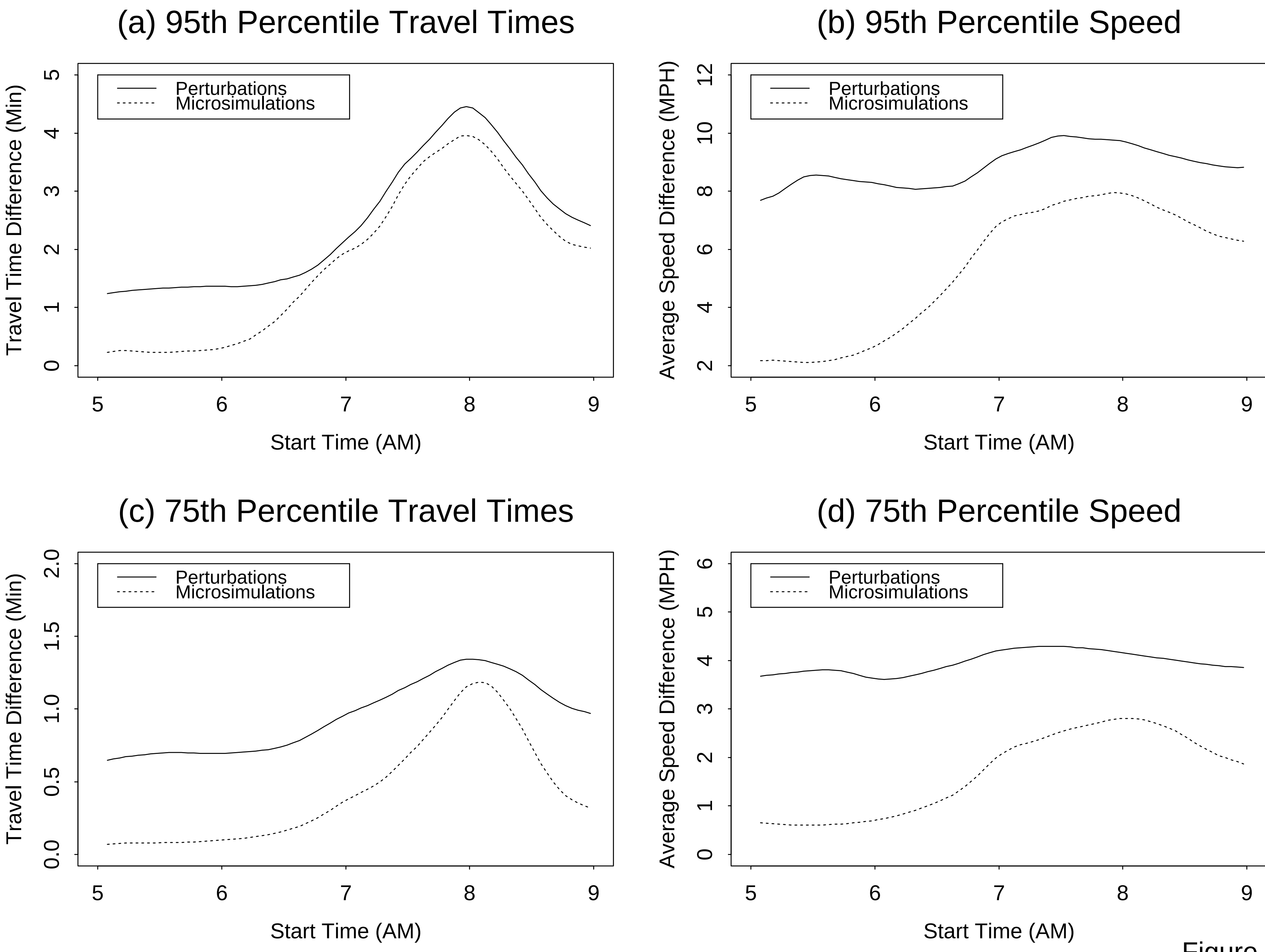


Figure 24

All Trips

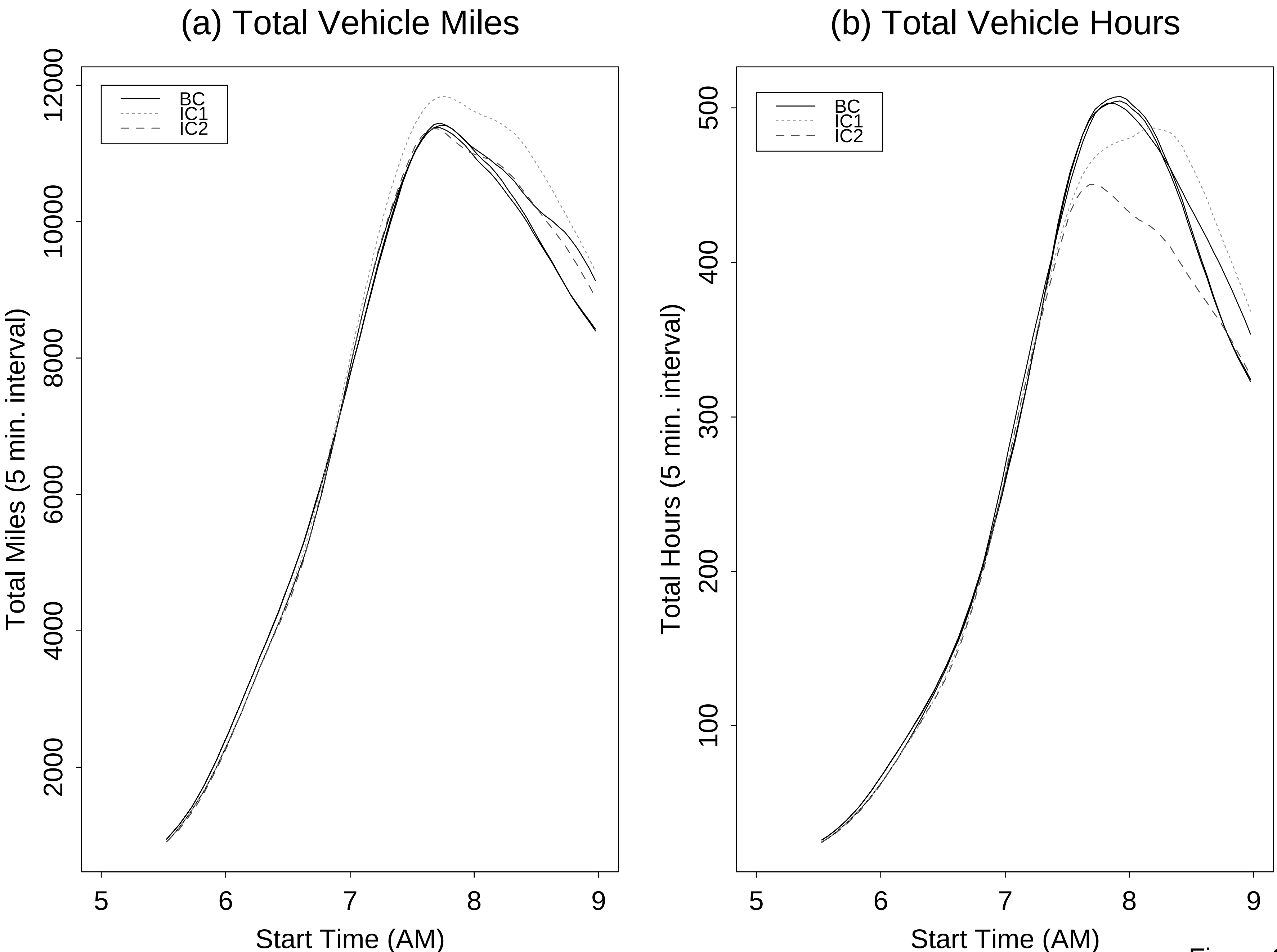


Figure 25

All Trips

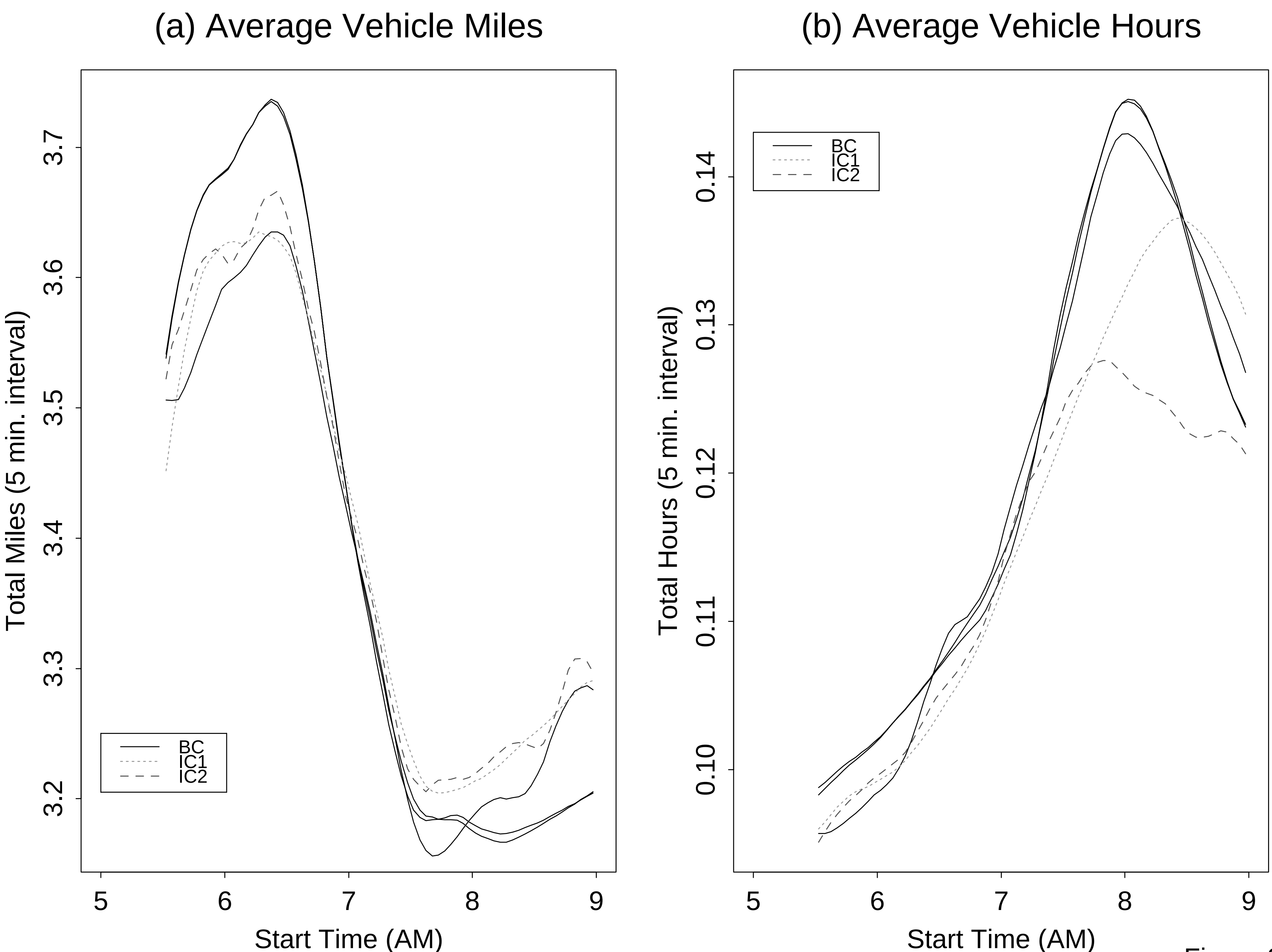


Figure 26

All Trips

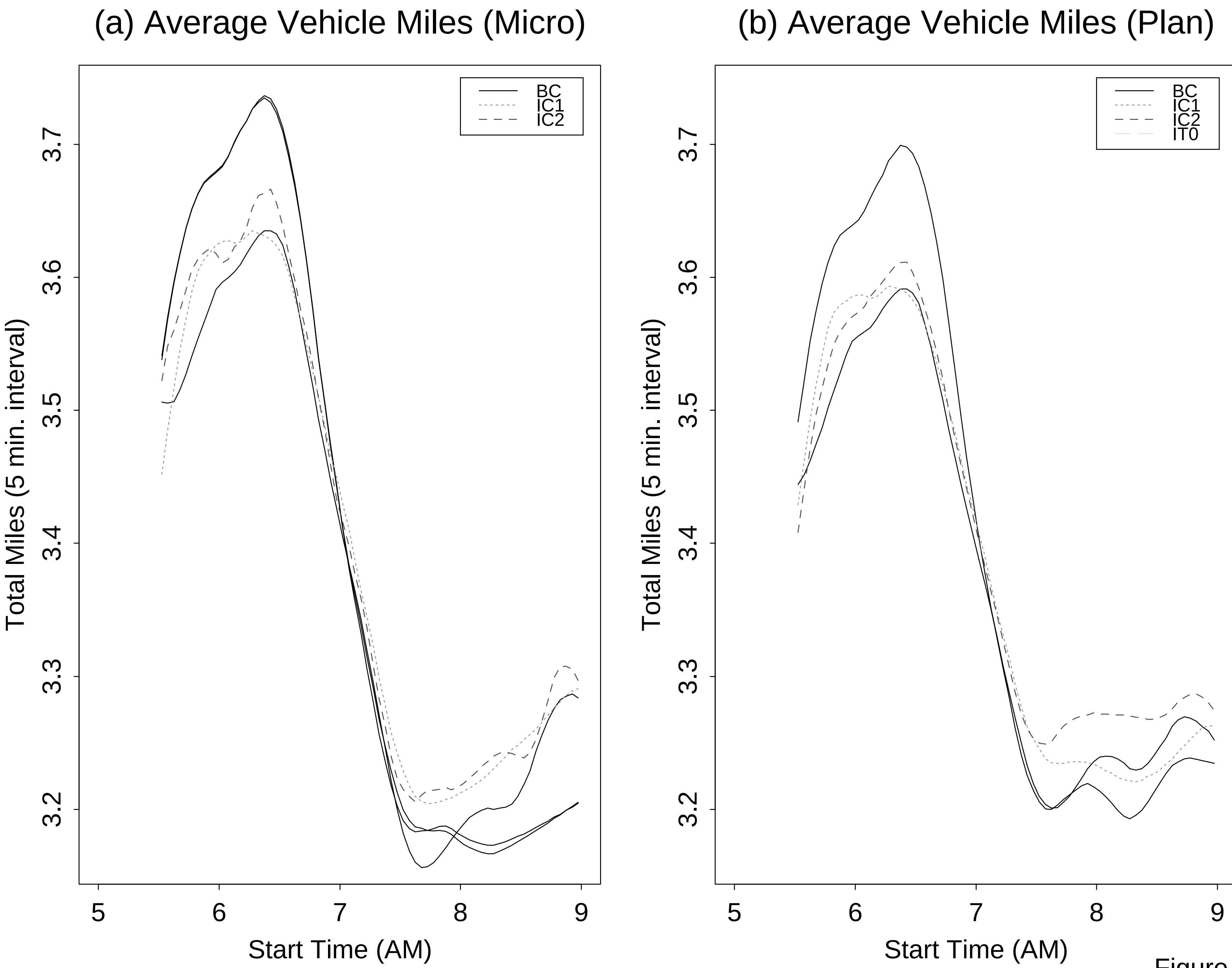


Figure 27

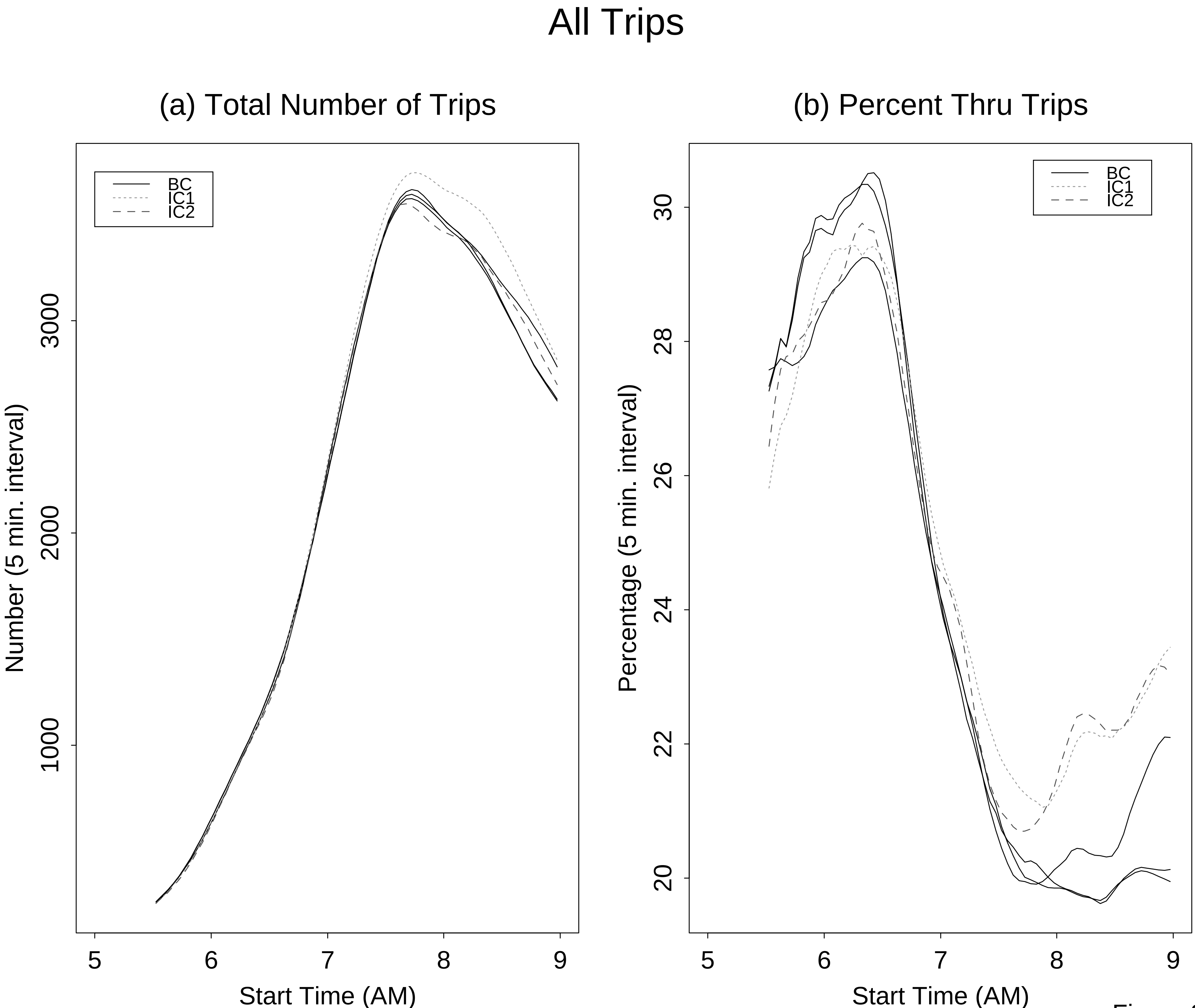

All Trips
(a) Total Number of Trips
BC
IC1
IC2
Number (5 min. interval)
1000
2000
3000
5
6
7
8
9
Start Time (AM)
(b) Percent Thru Trips
BC
IC1
IC2
Percentage (5 min. interval)
20
22
24
26
28
30
5
6
7
8
9
Start Time (AM)

Figure 28

All Trips

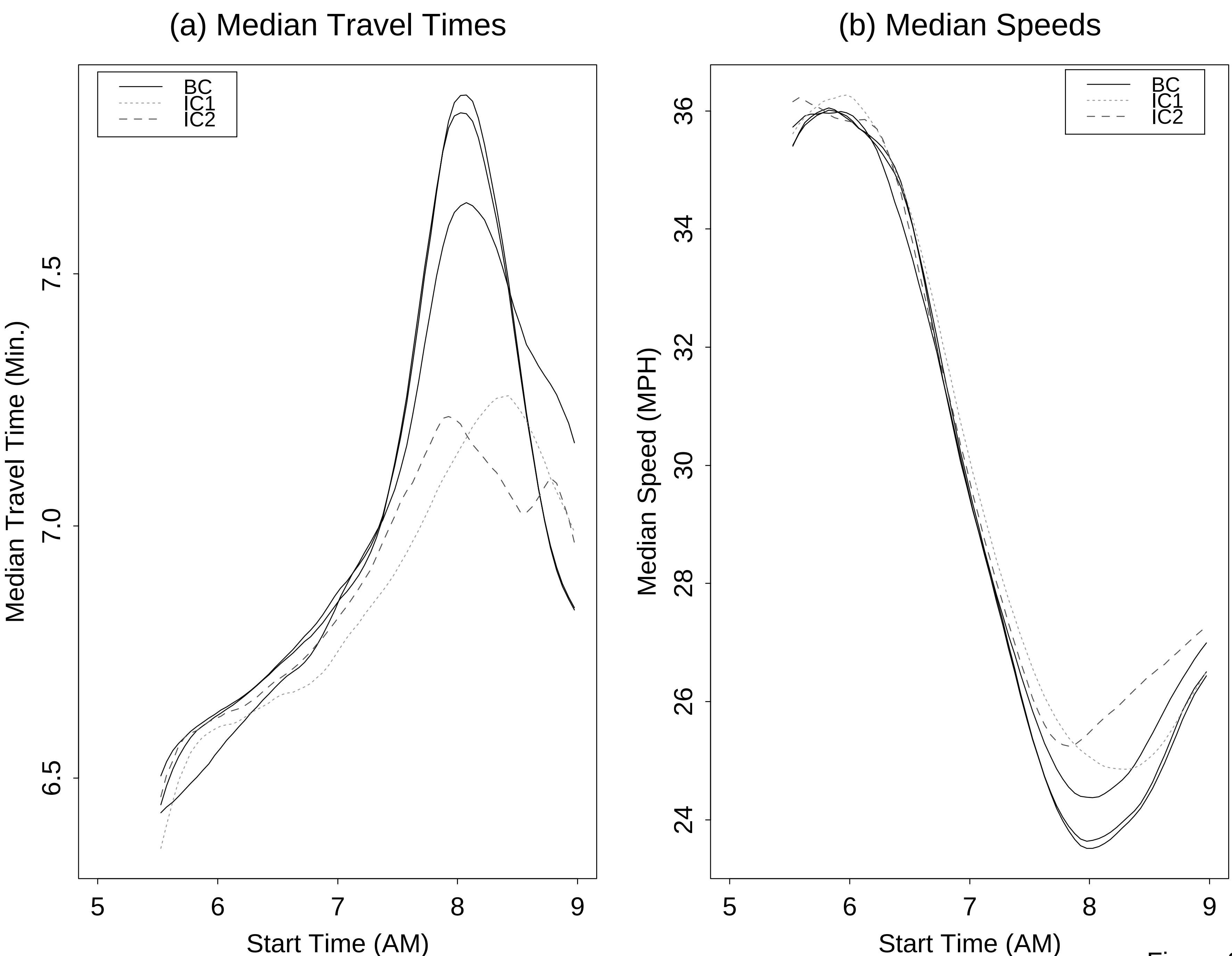
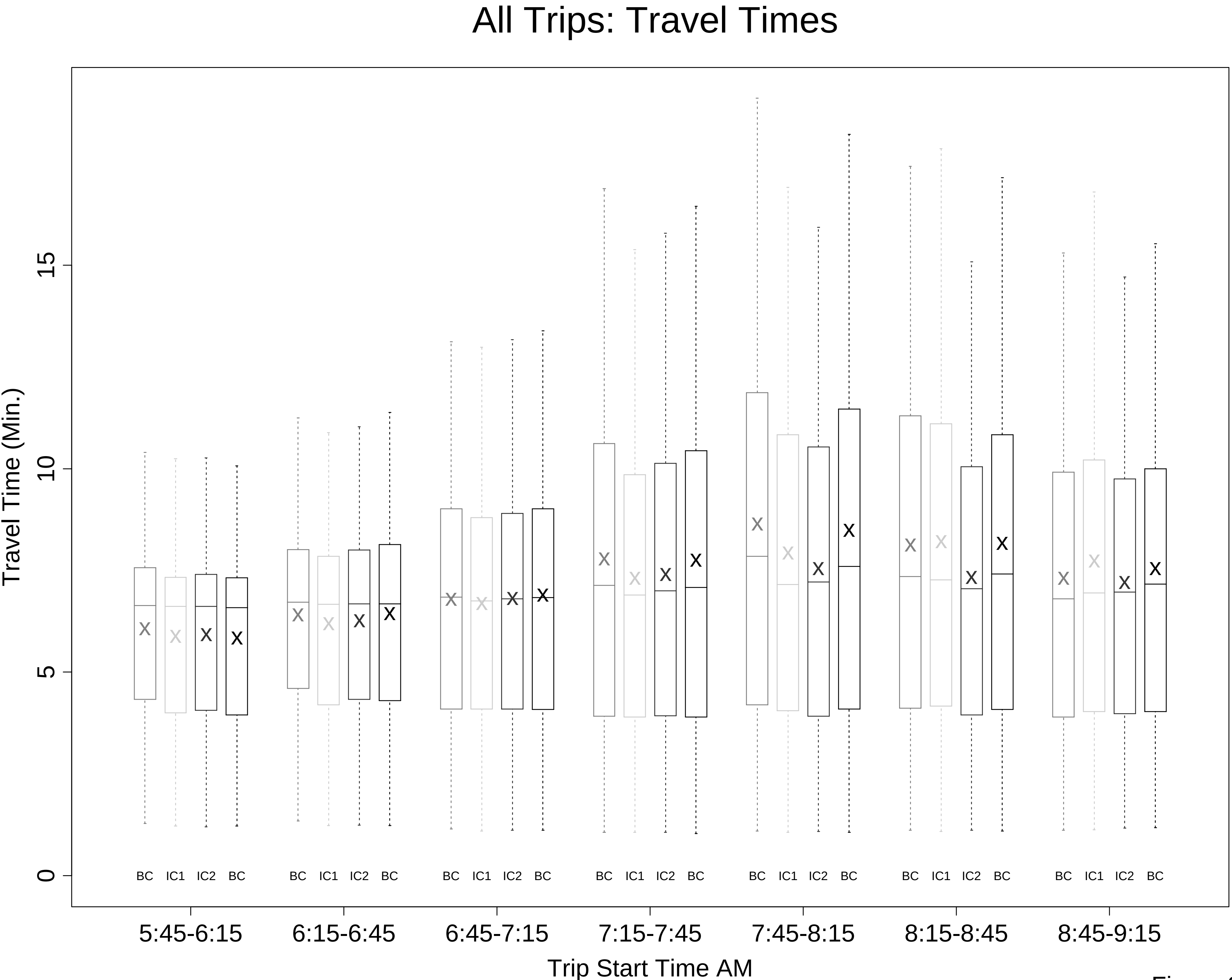


Figure 29



All Trips: Travel Times
Travel Time (Min.)
0
5
10
15
BC
IC1
IC2
BC
5:45-6:15
6:15-6:45
6:45-7:15
7:15-7:45
7:45-8:15
8:15-8:45
8:45-9:15
Trip Start Time AM

Figure 30

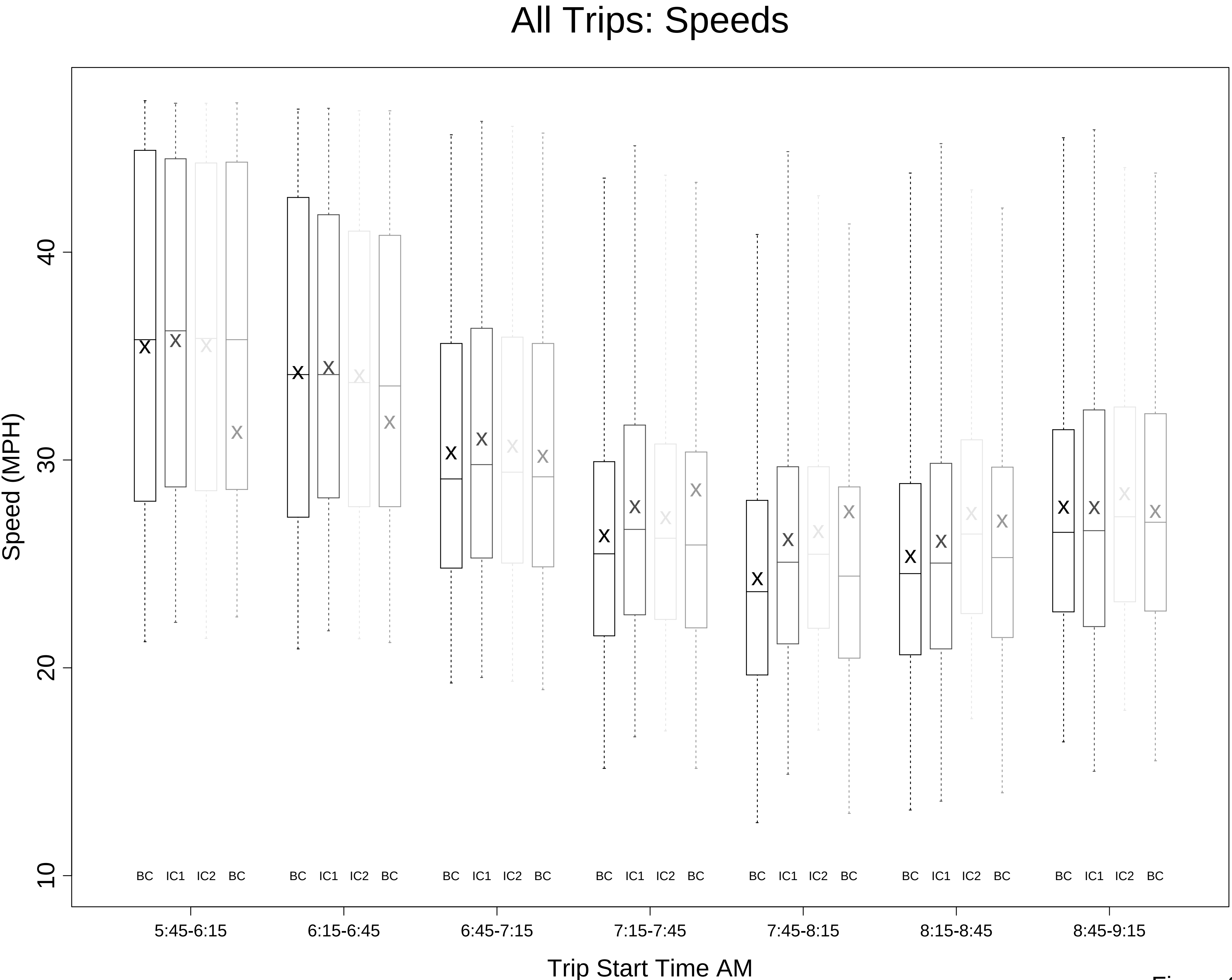

All Trips: Speeds
Speed (MPH)
10
20
30
40
BC IC1 IC2 BC
5:45-6:15
6:15-6:45
6:45-7:15
7:15-7:45
7:45-8:15
8:15-8:45
8:45-9:15
Trip Start Time AM

Figure 31

Percentiles

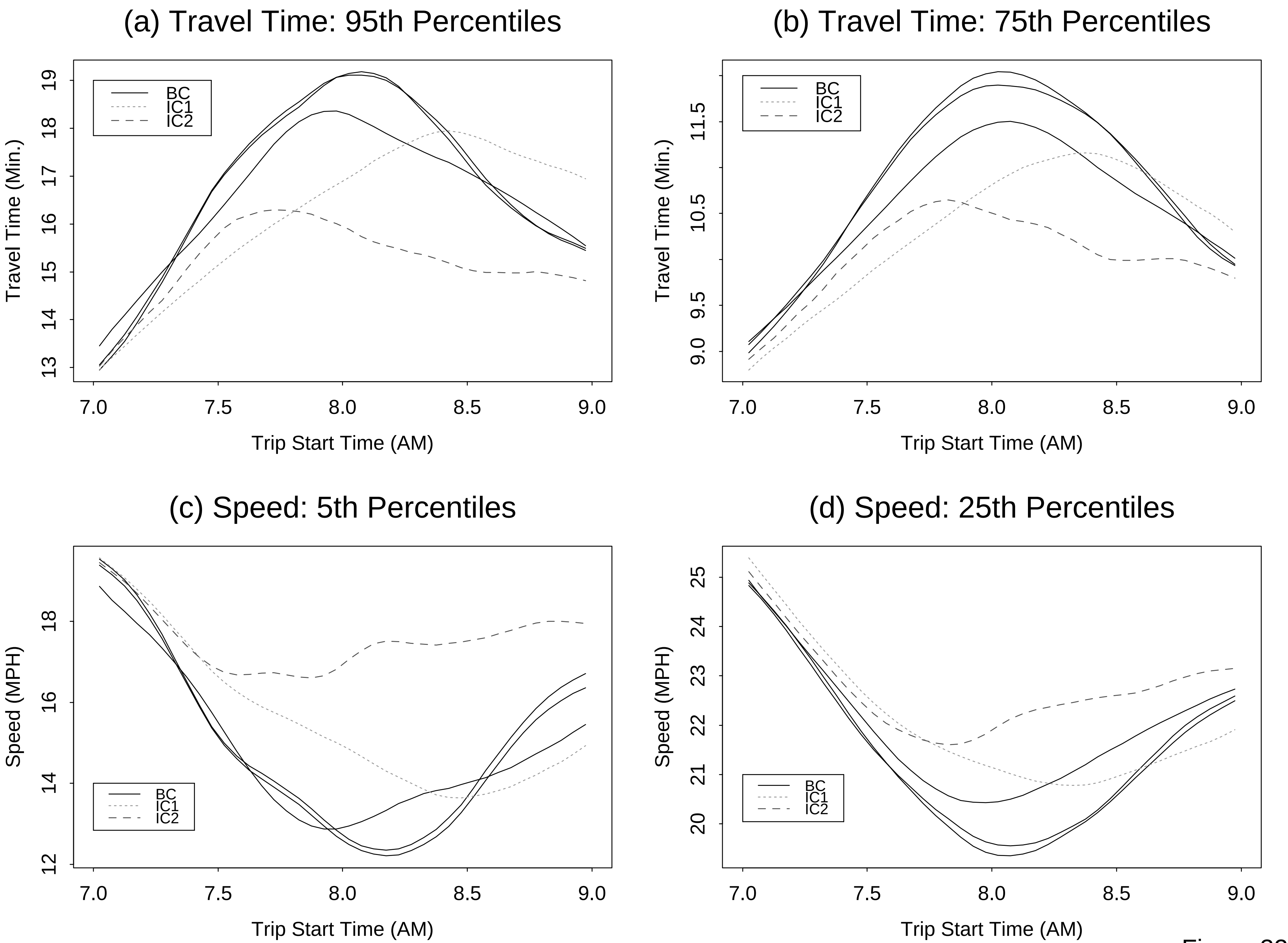


Figure 32

Reliability: All Networks

Percentiles of Differences

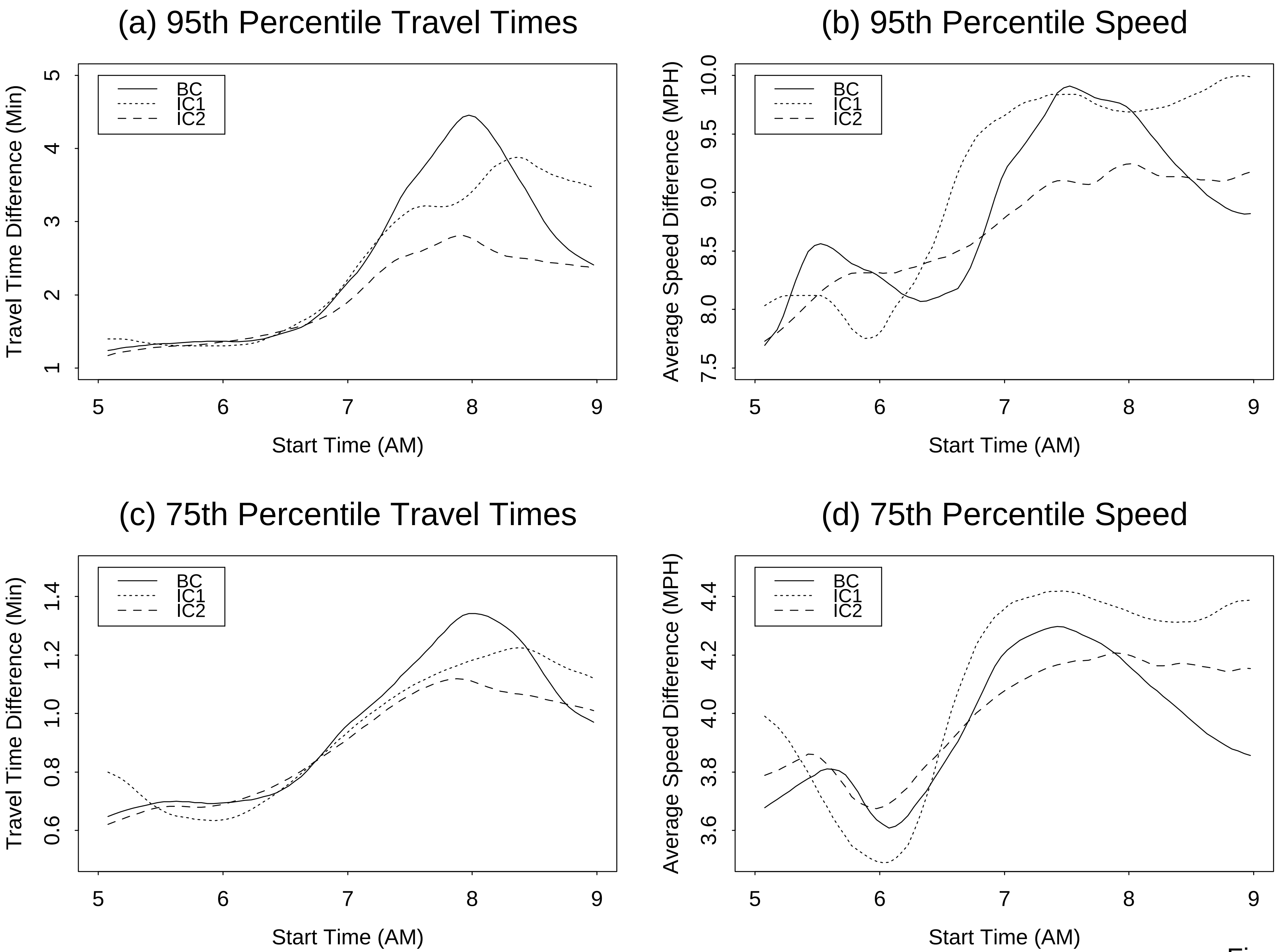


Figure 33

Median Travel Times

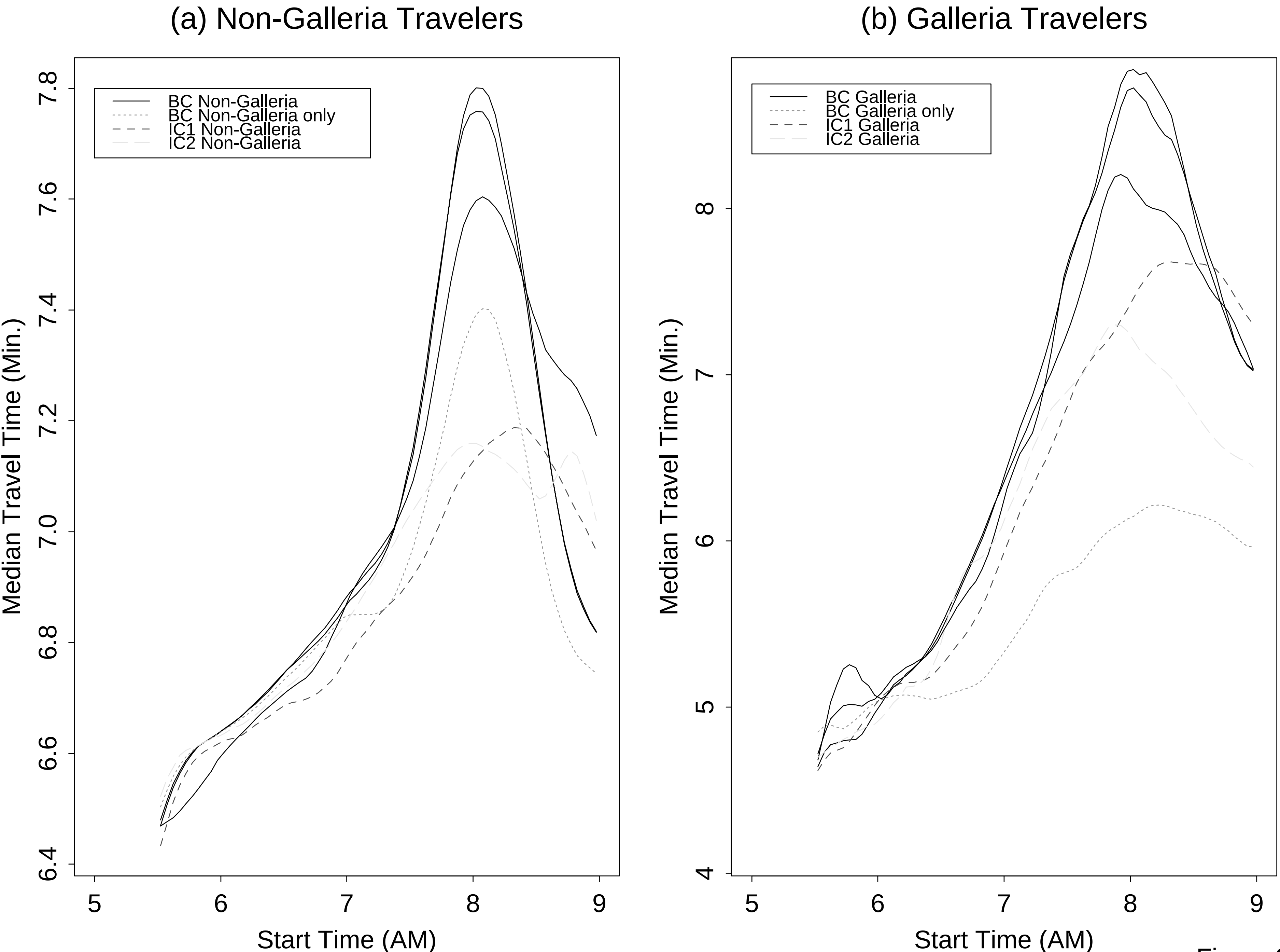


Figure 34

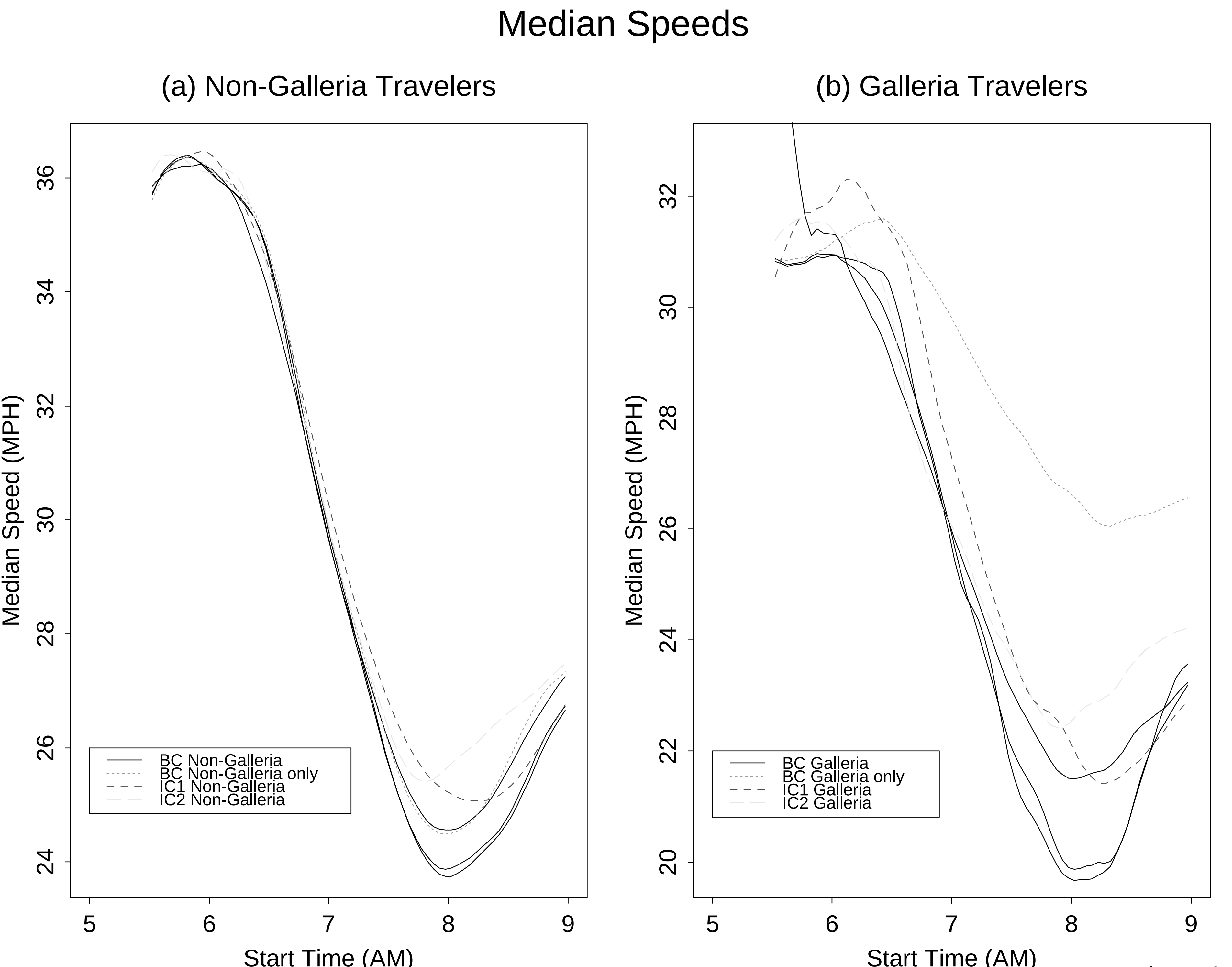

Median Speeds
(a) Non-Galleria Travelers
(b) Galleria Travelers
Median Speed (MPH)
Start Time (AM)
5
6
7
8
9
24
26
28
30
32
34
36
20
22
24
26
28
30
32
BC Non-Galleria
BC Non-Galleria only
IC1 Non-Galleria
IC2 Non-Galleria
BC Galleria
BC Galleria only
IC1 Galleria
IC2 Galleria

Figure 35

Non-Galleria Percentiles

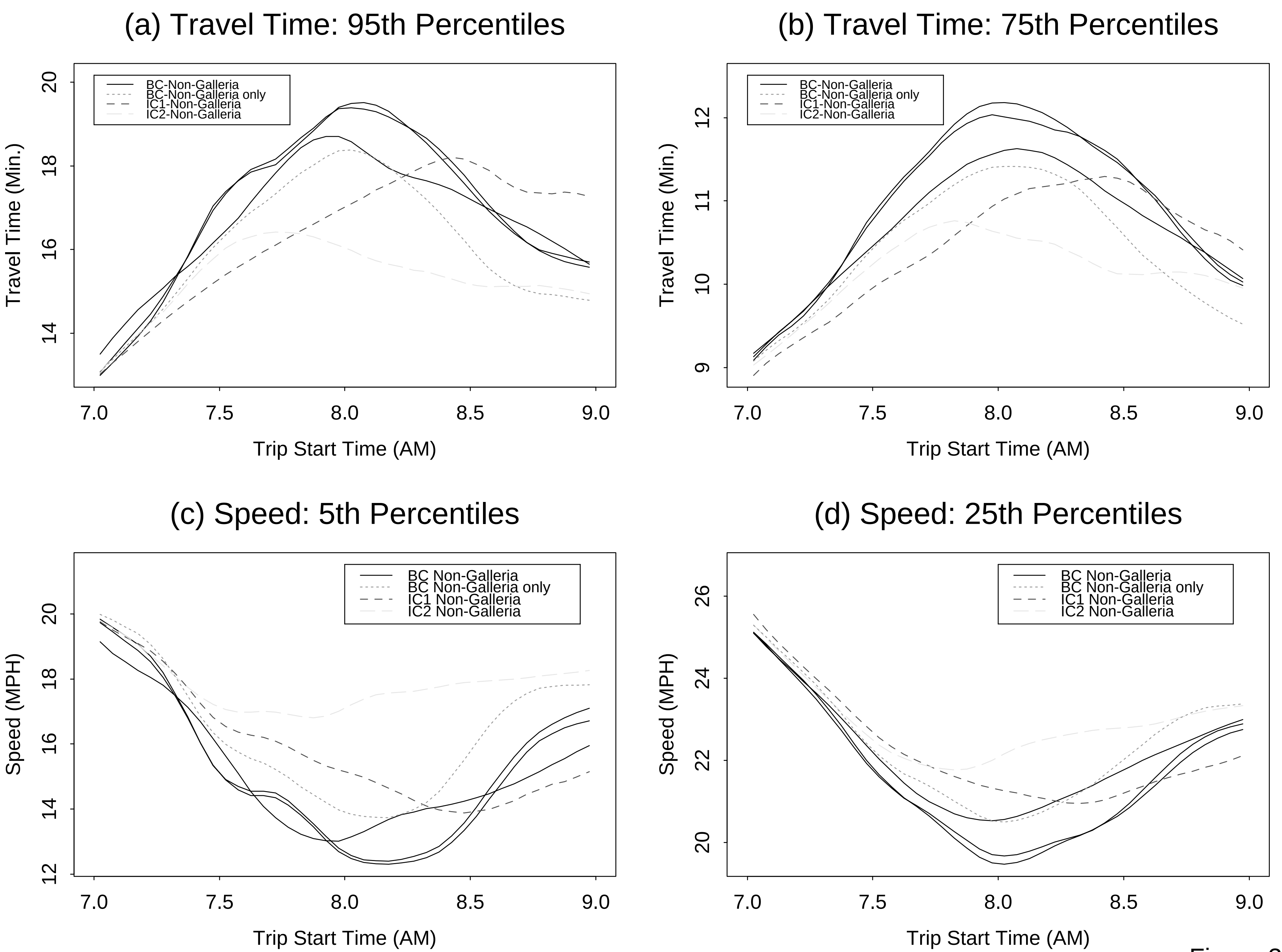
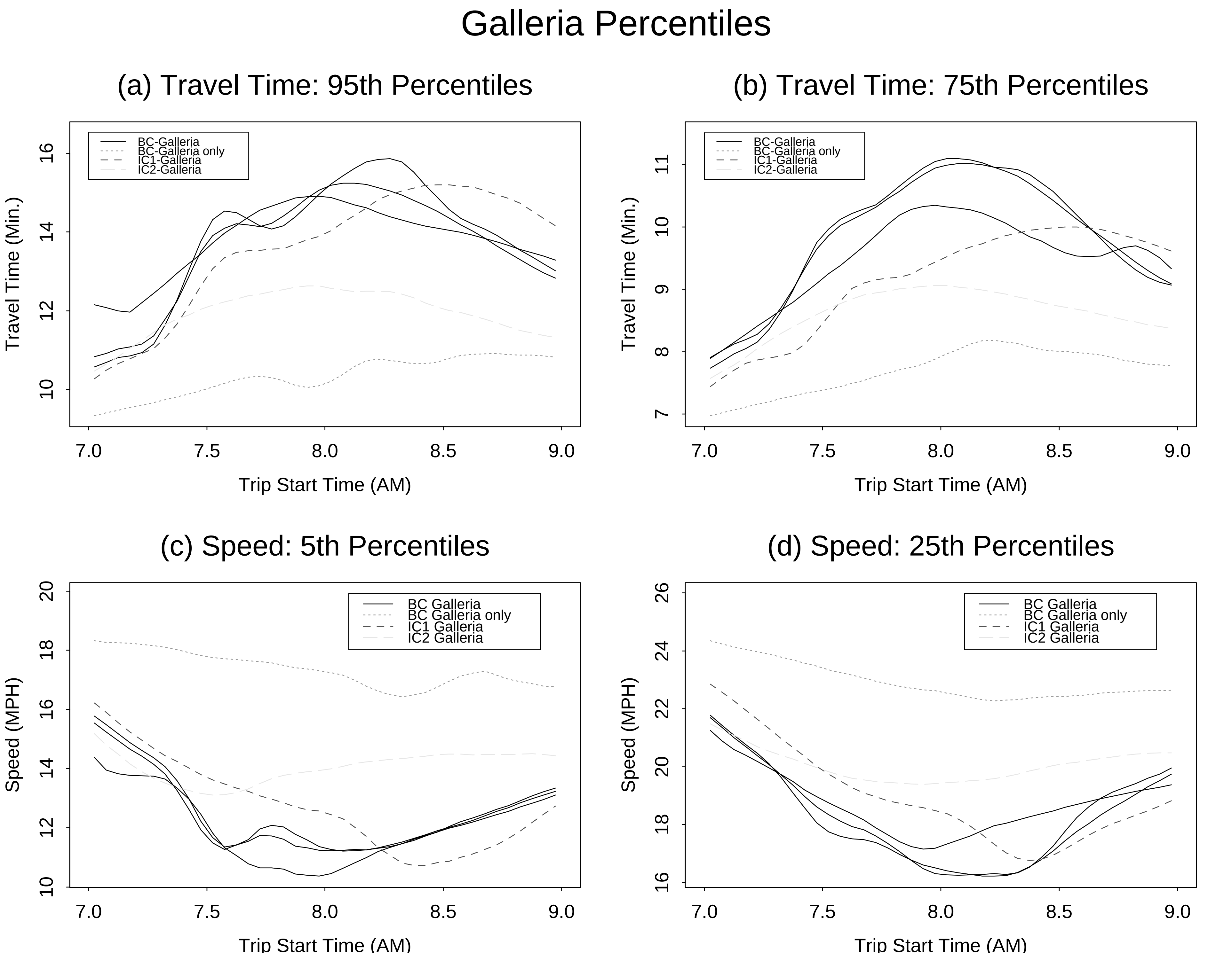


Figure 36



Galleria Percentiles
(a) Travel Time: 95th Percentiles
BC-Galleria
BC-Galleria only
IC1-Galleria
IC2-Galleria
Travel Time (Min.)
Trip Start Time (AM)
(b) Travel Time: 75th Percentiles
BC-Galleria
BC-Galleria only
IC1-Galleria
IC2-Galleria
Travel Time (Min.)
Trip Start Time (AM)
(c) Speed: 5th Percentiles
BC Galleria
BC Galleria only
IC1 Galleria
IC2 Galleria
Speed (MPH)
Trip Start Time (AM)
(d) Speed: 25th Percentiles
BC Galleria
BC Galleria only
IC1 Galleria
IC2 Galleria
Speed (MPH)
Trip Start Time (AM)

Figure 37

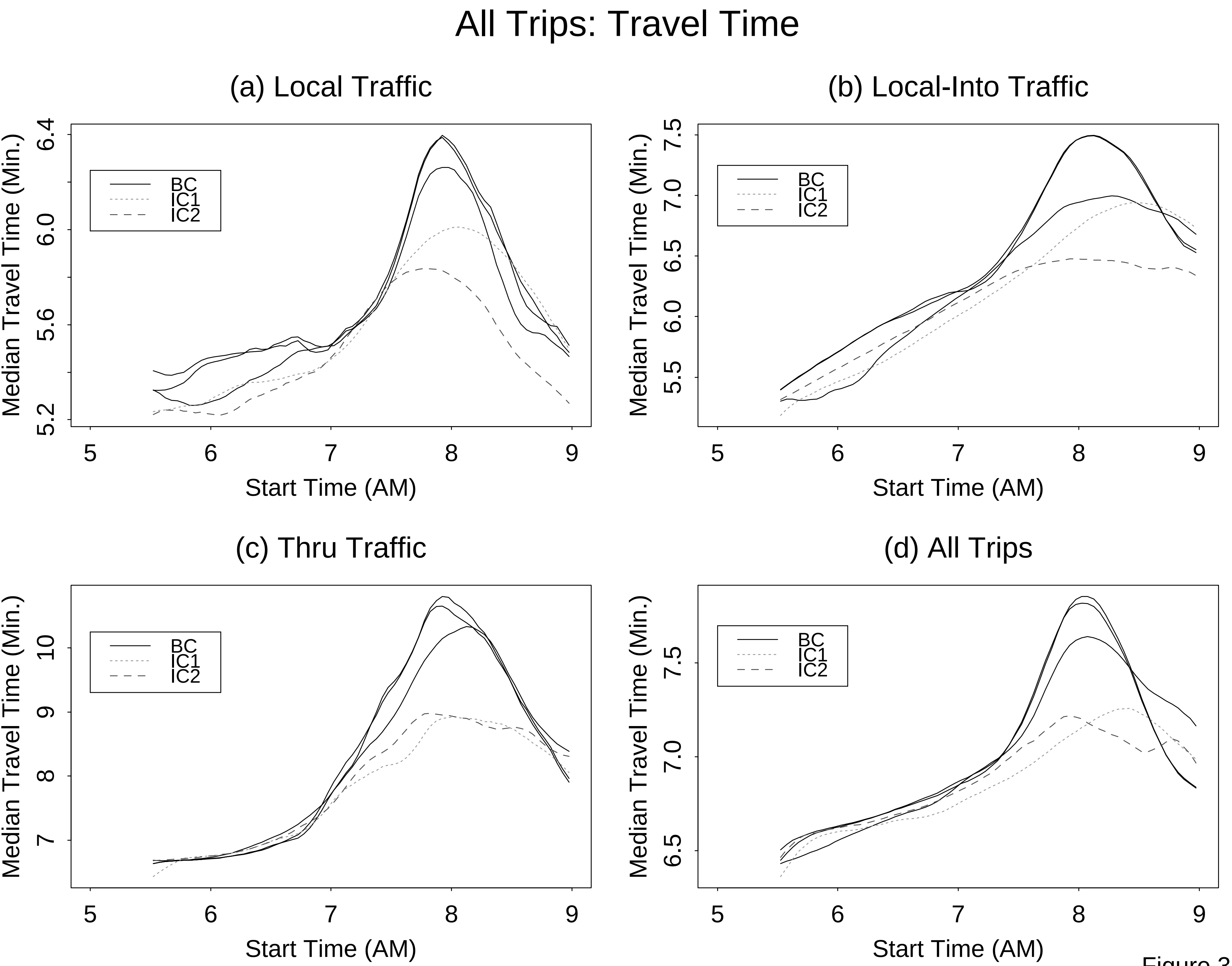

All Trips: Travel Time
(a) Local Traffic
(b) Local-Into Traffic
(c) Thru Traffic
(d) All Trips
BC
IC1
IC2
Median Travel Time (Min.)
Start Time (AM)

Figure 38

All Trips: Speed

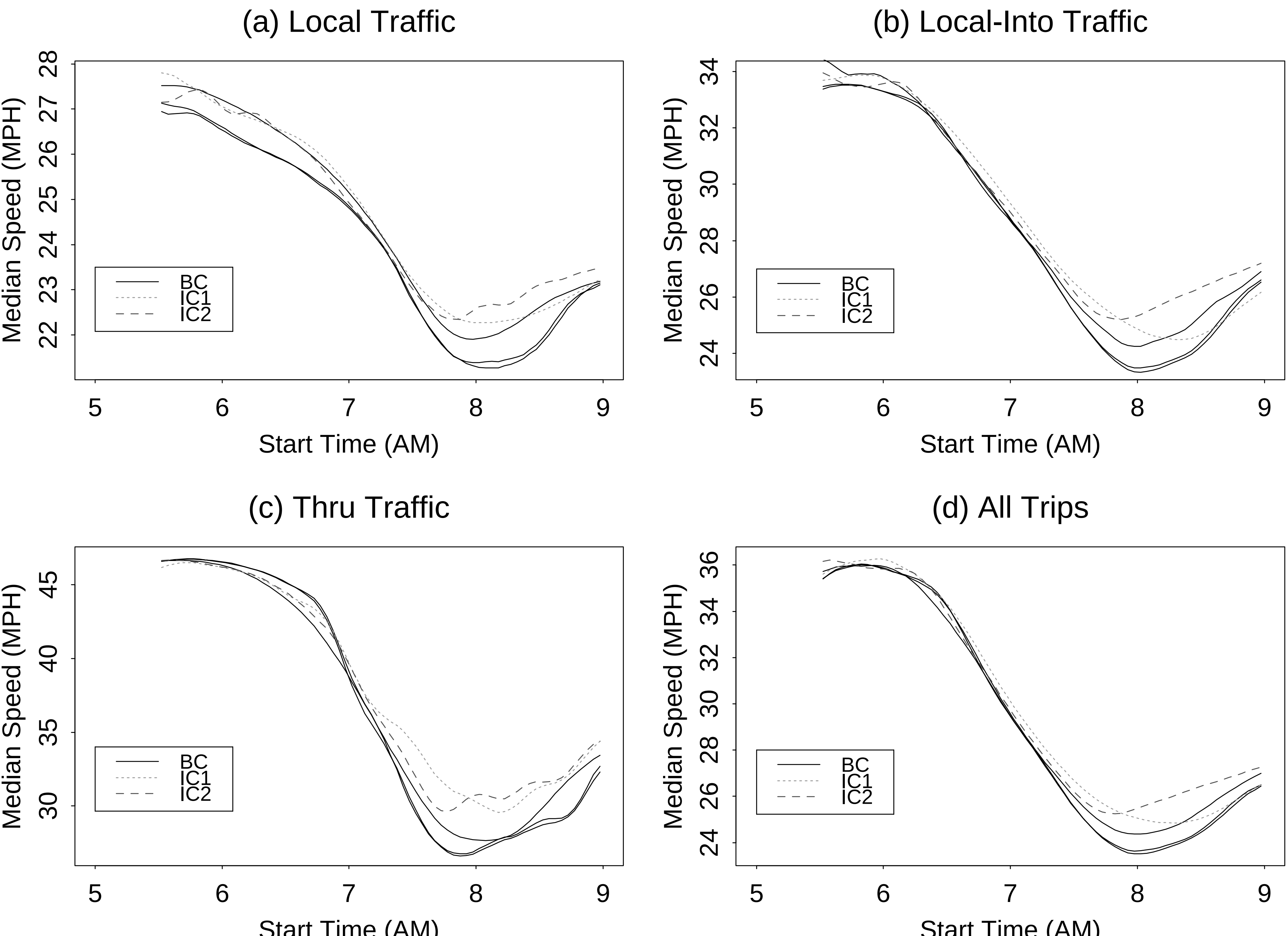


Figure 39

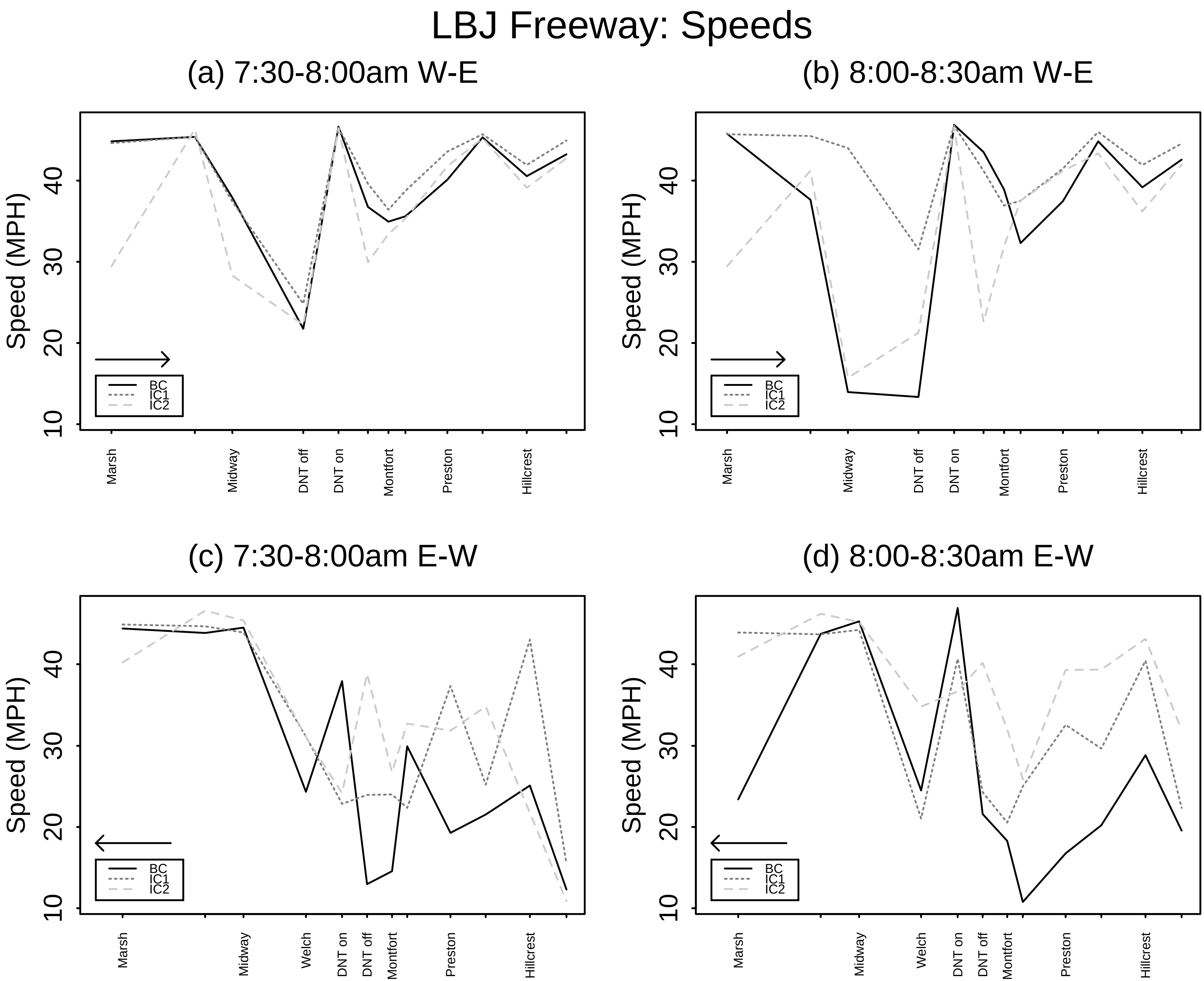

LBJ Freeway: Speeds
(a) 7:30-8:00am W-E
(b) 8:00-8:30am W-E
(c) 7:30-8:00am E-W
(d) 8:00-8:30am E-W
Speed (MPH)
10
20
30
40
BC
IC1
IC2
Marsh
Midway
Welch
DNT off
DNT on
Montfort
Preston
Hillcrest

Figure 40

LBJ Freeway: Flows

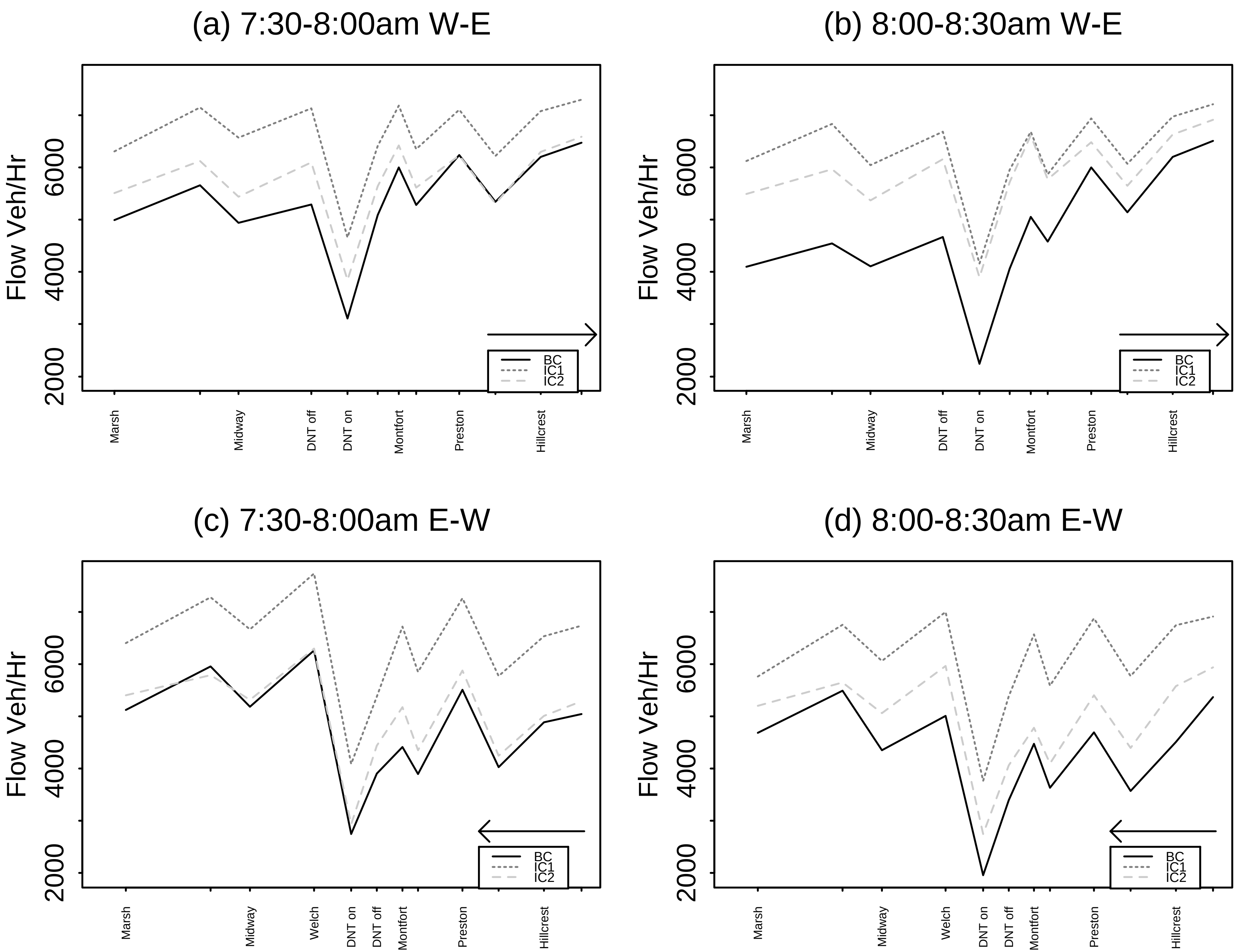


Figure 41

Alpha Road: Speeds

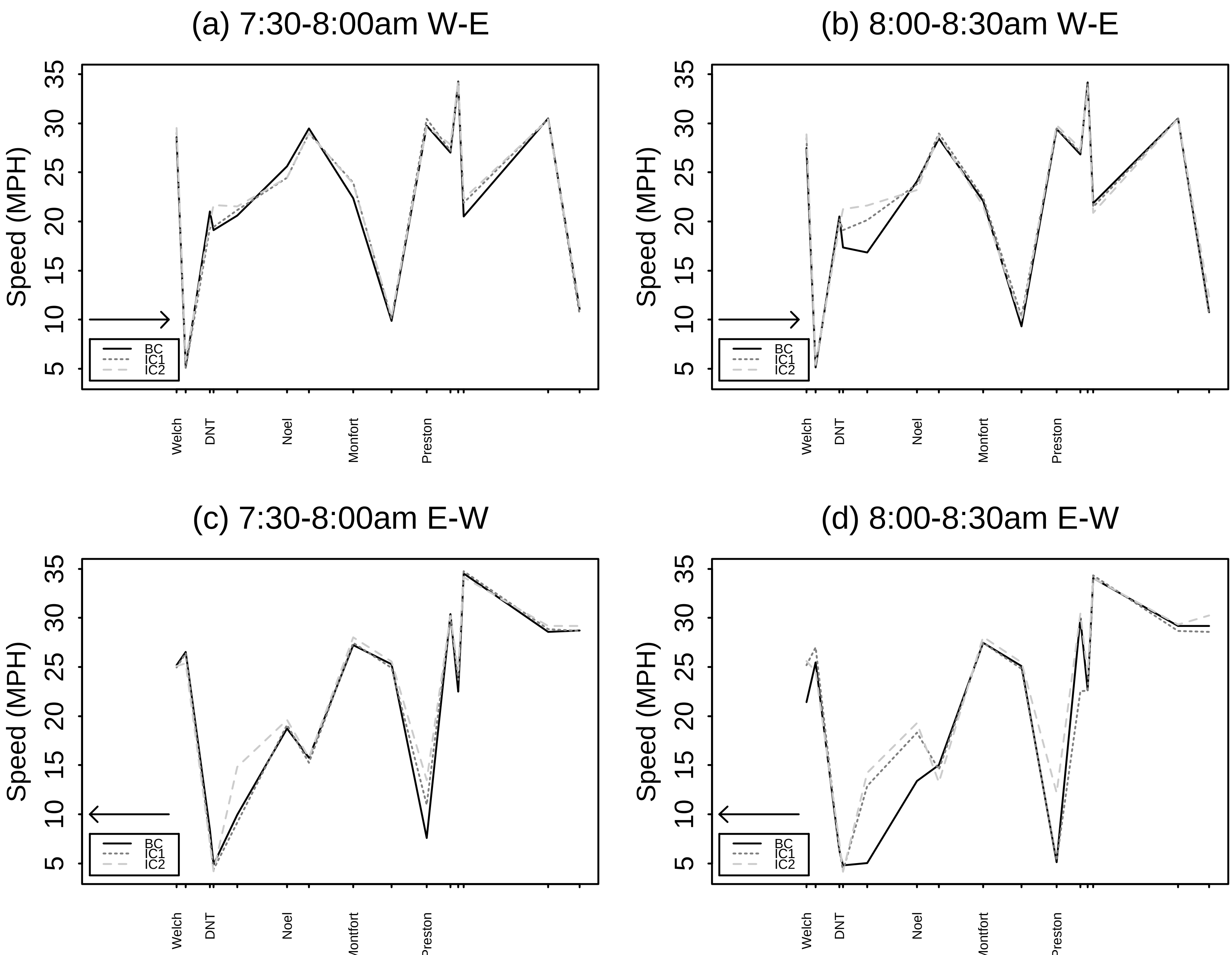


Figure 42

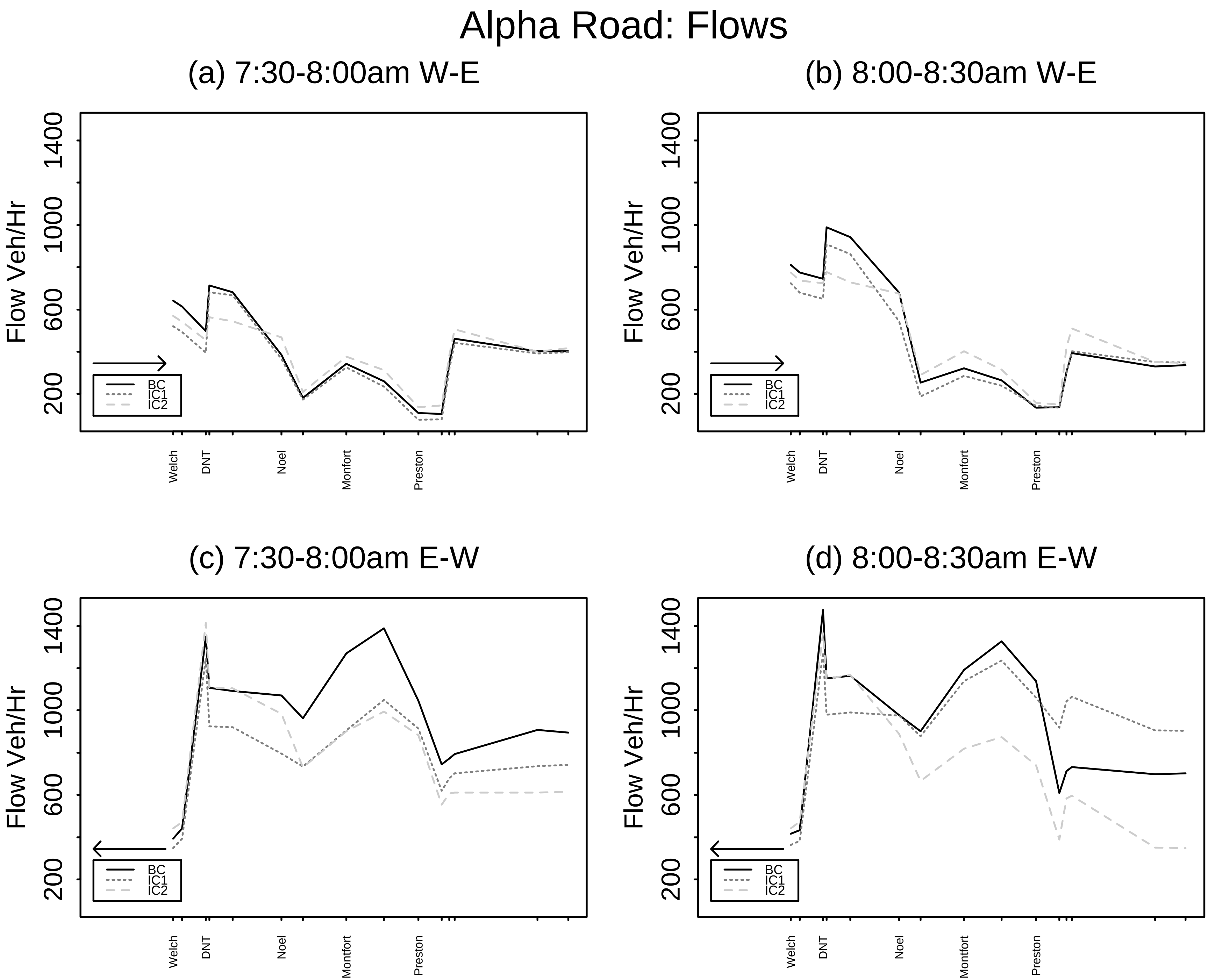

Alpha Road: Flows
(a) 7:30-8:00am W-E
(b) 8:00-8:30am W-E
(c) 7:30-8:00am E-W
(d) 8:00-8:30am E-W
Flow Veh/Hr
200
600
1000
1400
BC
IC1
IC2
Welch
DNT
Noel
Montfort
Preston

Figure 43

Valley View Mall

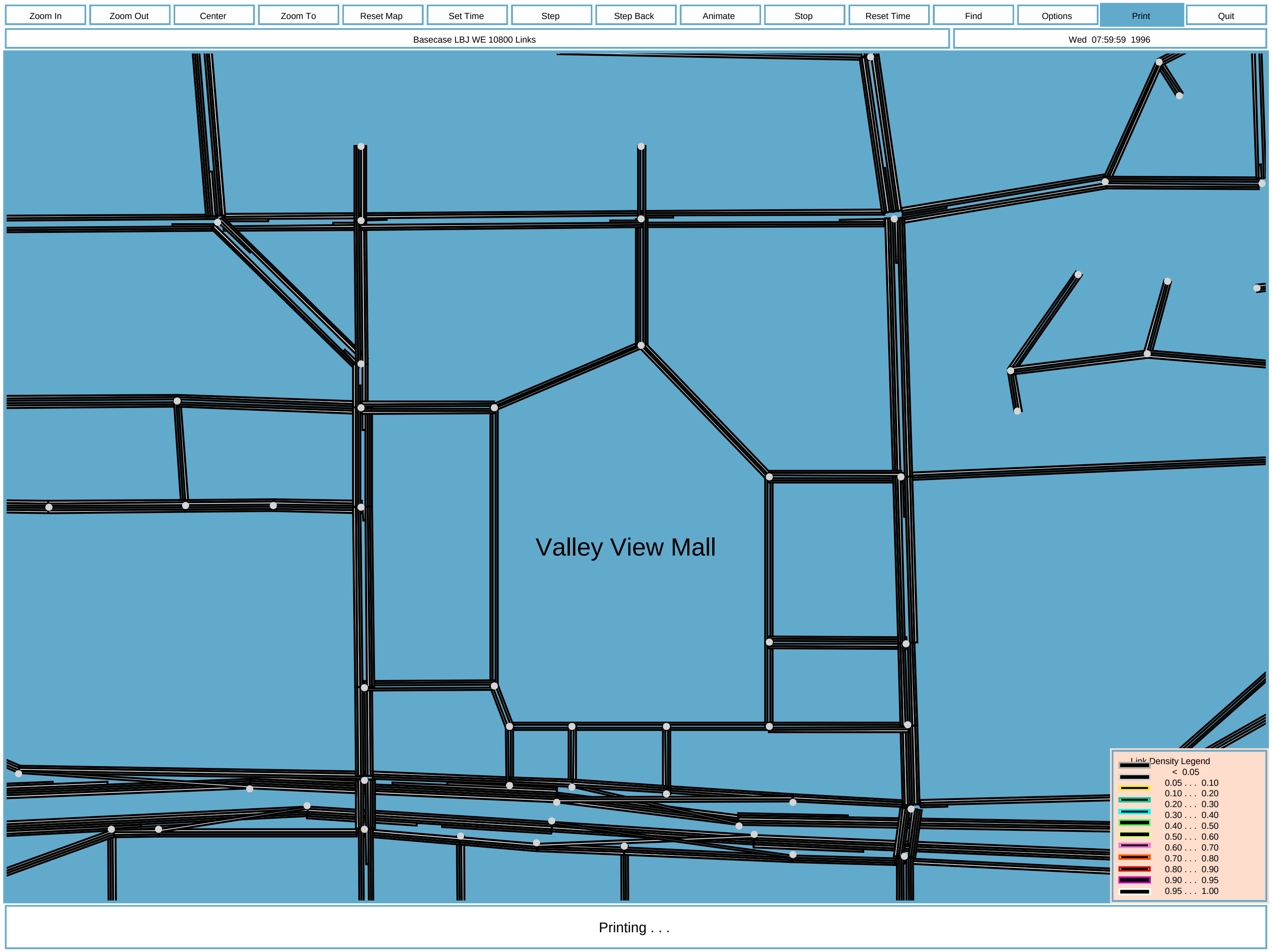


Figure 44