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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Evaluation of the OCTA Transit Probe System

**Randolph W. Hall, Nilesh Vyas, Chintan Shyani,
Vikas Sabnani, Simit Khetani**

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EVALUATION OF THE OCTA TRANSIT PROBE SYSTEM

June 30,1999

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ABSTRACT

The OCTA (Orange County Transit Authority) Transit Probe Project is a field operational test of an automatic-vehicle-location (AVL) system operating in Orange County, California. This report presents the final evaluation results for the project, concentrating on the operational period from June 1, 1998 to May 30, 1999. The report provides a detailed description of the system and the motivation for its design. It provides analyses of data reliability and accuracy, and analysis of the usefulness of transit probe data for predicting automobile travel times. Institutional issues are evaluated, based on interviews with involved personnel, direct observation of meetings and review of project documents. Customer surveys with bus riders and kiosk users are also documented.

Bus tracking systems provide many potential benefits, helping: (1) drivers stay on schedule, (2) dispatchers respond to problems, (3) schedulers determine how much time to allocate between schedule check points, and (4) general public know when buses will arrive. Capturing these benefits requires careful planning for operational procedures, data maintenance, and system interfaces and ensuring the equipment itself is reliable. Bus tracking implementations need to involve many parties within the transportation agency, and include task assignments, data transfer methods, and strategies for using information. Because of the small size of the Transit Probe project, along with a competing project within the agency, these factors received only limited attention. As a consequence, the system was not used to a significant degree in the agency.

EXECUTIVE SUMMARY

The OCTA (Orange County Transit Authority) Transit Probe Project is a field operational test of an automatic-vehicle-location (AVL) system operating in Orange County, California. A unique feature of the project was that system software was designed to estimate roadway congestion levels based on bus travel times over route segments. The system was intended to communicate congestion information to the California Department of Transportation (CALTRANS), the City of Anaheim and the City of Santa Ana, who would utilize the information in their traffic management operations. In addition, the system was designed to determine when buses are late or early in real-time, and to store data on the on-time performance of buses.

This report presents the final evaluation results for the project, concentrating on the operational period from June 1, 1998 to May 30, 1999. The report provides a detailed description of the system and the motivation for its design. It provides analyses of data reliability and accuracy, and analysis of the usefulness of transit probe data for predicting automobile travel times. Institutional issues are evaluated, based on interviews with involved personnel, direct observation of meetings and review of project documents. Customer surveys with bus riders and kiosk users are also documented.

The project itself was directed at measuring four Transit Probe objectives:

- Measurement of the reliability and completeness of data generated by the Transit Probe System.
- Assessment of the effectiveness of interfaces between the Transit Probe System and users.
- Determination of the usefulness of transit probe data for congestion management.
- Evaluation of the institutional performance of the Transit Probe Project.

Conclusions follow.

Reliability and Completeness of Data

Transit Probe experienced many reliability problems. The majority of schedule data points are either missing or undetected. In addition, the system generates numerous “duplicate” records, confounding data analysis. It appears that the remaining records are largely accurate. However, based on driver perceptions, these too may be error prone. Missing and undetected data result from inoperable or failed units, lack of complete coverage on routes, and inability to immediately update data at schedule changes. Transit Probe clearly has not met reliability expectations for an actual deployment.

Effectiveness of Interfaces

Transit Probe never created its intended interfaces to other Transportation Management Centers. Once it was apparent that Transit Probe would be a very small scale deployment, it ceased to be a priority data source. When budgets were squeezed, interfaces were therefore eliminated. Hence, it never provided a source of local street congestion data for Caltrans, and never supplemented congestion data for Anaheim and Santa Ana TMCs.

Transit Probe never accomplished its public interface objectives. Though a kiosk was installed at one location, it was not opened until the end of the project. The kiosk was well received in a test evaluation, but it could have no impact if not open to the public. No other interfaces were established for the public.

Customers in general perceived that schedule adherence had improved over the year in which transit probe units had been installed. From driver interviews, it seems that this might be attributable to placement of a clock in driver view. Because drivers generally ignore indicator lights, the improvement could not have resulted from the system's schedule adherence capabilities. The perceived improvement could also be due to other factors, such as schedule changes, or could simply be a misperception.

Usefulness for Congestion Measurement

OCTA never fully established the congestion measurement capabilities, largely because it did not have a mechanism for disseminating congestion information. Congestion segments were not completely established, and baseline speeds were never determined through field measurement. As with schedule adherence data, much of the congestion measurement data was missing, greatly limiting its value. Our analysis also found little correlation between speed estimates determined by the Transit Probe algorithm and recorded automobile speeds.

Our own analysis revealed that when automobiles experience long delays, buses traveling the same route in close proximity are also likely to experience delay. The reverse, however, is not always true. This is because buses frequently wait for extended periods when they run ahead of schedule. Any useful bus probe algorithm would need to distinguish actual congestion versus a stopping delay.

Though Transit Probe was designed to measure congestion on roadway segments, a more useful approach would be to measure congestion approaching major intersections. These are the places where delay is likely to occur. And measuring over an entire segment make it difficult to identify the exact location of the problem. Moreover, because delay randomly fluctuates in accordance to a vehicle's arrival time relative to the signal cycle, the most sensible approach is to set off a "congestion alarm" when a vehicle is delayed by more than one cycle at an intersection. A congestion alarm would indicate over-saturation, and delay well beyond normal. Congestion alarms like this are feasible with GPS based systems, but were not used in the project.

Institutional Performance

In the initial design phases of the project, OCTA did a commendable job involving partner agencies, while still moving the project forward and meeting deadlines. Participants praised OCTA, and they were generally satisfied with the institutional structure. In the second phase, after award of the system integrator contract, the project became rather conventional with a contractor and contract manager. Outside participation virtually disappeared at this point.

By way of improvement, the project would have been more effective had there been more internal involvement in design, installation and operation from communications, drivers, scheduling,

dispatch and maintenance. Given that the congestion measurement features were never used, except by the evaluators, there really was not any need to involve outside agencies. A more streamlined, internally focused project, that relied more on off-the-shelf installation and design, would have been more sensible. To OCTA's credit, this is exactly the approach being followed in a current project to upgrade its radio communication system.

Lessons Learned

Bus tracking systems provide many potential benefits, helping: (1) drivers stay on schedule, (2) dispatchers respond to problems, (3) schedulers determine how much time to allocate between schedule check points, and (4) general public know when buses will arrive. However, these benefits cannot be captured without carefully planning operational procedures, data maintenance, and system interfaces and ensuring the equipment itself is reliable. These important issues did not receive adequate consideration in the system design phase of the project, though they really should have been the primary emphasis. Design needs to involve many parties within the transportation agency, and include task assignments, data transfer methods, and strategies for using information.

The other lesson is that evaluation projects can sometimes result in artificial objectives. Congestion measurement was a driving force behind the institutional structure of the project and contracting. It greatly increased the need for customization, and likely added significantly to cost. Yet it was really a low priority for involved agencies, and there was considerable skepticism from the beginning. Without someone to champion this feature, it had little chance for success.

Overall Conclusions

Although the evaluation produced important insights as to how bus tracking should be implemented, and the likely problems to expect, the OCTA Probe failed to live up to its promise because the system was not used by drivers, dispatchers, planners, schedulers or the general public. Therefore, it could not have improved transportation conditions in Orange County.

1. INTRODUCTION

The OCTA (Orange County Transit Authority) Transit Probe Project is a field operational test of an automatic-vehicle-location (AVL) system operating in Orange County, California. A unique feature of the project was that system software was designed to estimate roadway congestion levels based on bus travel times over route segments. The system was designed to communicate congestion information to the California Department of Transportation (CALTRANS), the City of Anaheim and the City of Santa Ana, who would utilize the information in their traffic management operations. In addition, the system was designed to determine when buses are late or early in real-time, and to store data on the on-time performance of buses.

The project was created as a multi-agency partnership, led by OCTA, which had contractual authority over development and operations. The project was funded by CALTRANS and the Federal Transit Authority (FTA) in the amount of \$1.7 million. Additional in-kind contributions were made by participating agencies in the form of staff time and equipment maintenance.

This report presents the final evaluation results for the transit probe project. The report concentrates on the operational period from June 1, 1998 to May 30, 1999. The Institutional component of the evaluation covers the entire project from initial funding in 1995 to May 30, 1999. The evaluation was performed by the University of Southern California, under contract to Partners for Advanced Transit and Highways. Funding was provided by Caltrans and FTA. Mark Hickman and Baher Abdulhai participated in earlier portions of the project, but not in the final evaluation, and Nelson/Nygaard conducted surveys of OCTA customers.

1.1 OCTA Bus System

The Orange County Transit Authority (OCTA) operates 73 lines throughout Orange County, crossing into Los Angeles County in a few places. The service area covers about 800 square miles, with a fleet of 450 fixed route buses. The service area as a whole can be characterized as suburban, with pockets of urbanized land uses. Most bus lines operate with 30 minute headways, and the shortest headway is 8 minutes.

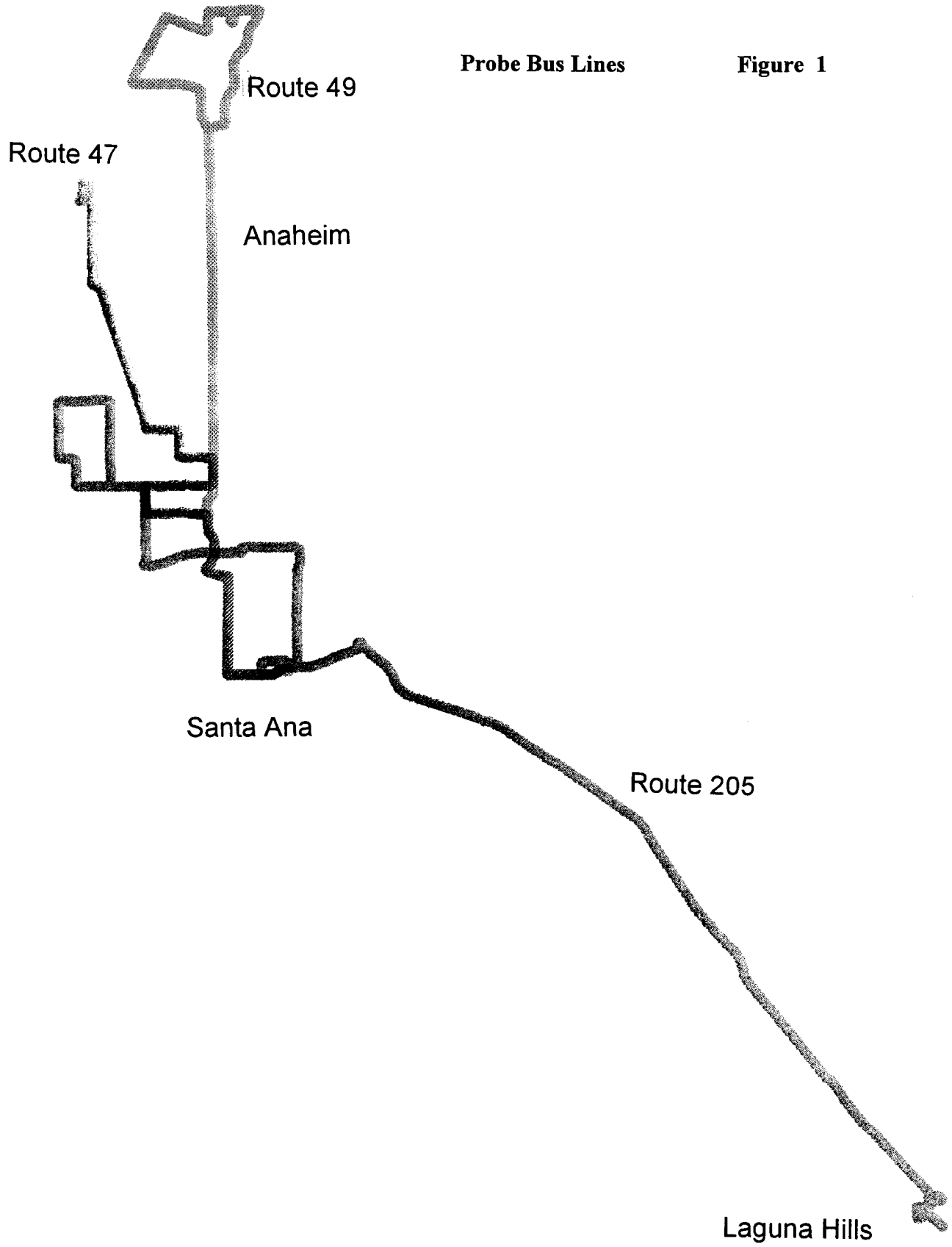
The system is configured as a grid network, with the densest service around Santa Ana (the largest city in the county with 294,000 residents in 1990), and near Irvine, Orange and Anaheim. OCTA operates bus maintenance facilities in Anaheim, Garden Grove (home of the OCTA communications center), and Irvine, and is headquartered in the City of Orange. It also operates transit terminals in Fullerton, Huntington Beach, Irvine, Laguna Hills, Newport and Santa Ana.

Due to budgetary constraints, the transit probe project was limited to 15 buses operating on three bus lines: 47, 49 and 205 (Figure 1; five buses on each). These three lines radiate from the Santa Ana Transit Terminal, located in the Downtown of Santa Ana.

47 and 49 lines The 47 and 49 lines travel north from Santa Ana on city streets, through the cities of Orange, Anaheim and Fullerton. The one-way travel time is a little more than an hour, covering a distance of 13 to 15 miles. Headways are held nearly constant at 30 minutes, seven days a week, though line 49 has some irregularity in the southbound direction, and line 49 has longer headways on weekends (40 to 50 minutes). The lines coincide for the first 20 minutes of travel, and travel on

Probe Bus Lines

Figure 1



separate streets for the remainder. Schedules are not offset to minimize waiting time over the common portion of their route (i.e., departures are not set at even 15 minute intervals).

205 line The 205 line has several variations, and includes an extension south through Irvine, and ending a Laguna Hills, and an extension north through Orange and ending at Anaheim, in the vicinity of Disneyland. The line travels 23 to 25 miles, both on city streets and on the freeway. Weekday headways vary from 15 minutes, during peak periods on the southern extension, to one hour in the early afternoon on the northern extension. Portions of the line coincide with other OCTA lines, such as the 53, 55 and 56.

Schedule Modifications Schedules and routes were modified on several occasions during the project. This primarily entailed detours in the vicinity of Interstate 5 and Disneyland, where there was extensive road construction.

1.2 Transit Probe System

The Transit Probe System is an integrated software/hardware product developed off of the “3M Info” platform. The basic system elements are on-board units, base-station software and a wireless communication system.

On-Board Units The on-board units determine bus locations through a differential-global-positioning-system (DGPS). This is accomplished by processing signals from the constellation of Department of Defense (DOD) GPS satellites, along with a correction signal transmitted from the OCTA base station. The accuracy of the DOD GPS signal is degraded for civilian purposes. The base station provides a correction by tracking the difference between its real-time GPS determined location, and its actual location (determined by averaging the GPS signal over a long period of time). Under DGPS, accuracy levels on the order of ± 3 meters are achievable in real-time applications. In OCTA, the on-board units provide a simple driver interface, which emits a light when the bus is running early or late.

Base-Station Software The base-station unit operates on a Windows platform, and provides the capability to assign vehicles and drivers to route, track the current locations of buses, and analyze historical data on schedule adherence and congestion.

Wireless Communication Both short-range and long-range communication are provided in the OCTA installation. The long-range system communicates with vehicles in the field via OCTA’s radio communication system. The system is dual purpose, providing both data and voice communication. It enables transmission of the GPS correction signal, and enables vehicles to send messages to the base station when a vehicle is running later or early. The short-range system provides for data download and upload at the start and end of the data, to create a database on schedule performance.

The OCTA Probe System includes a mixture of standardized and customized components. The base-station software and on-board GPS units are largely standard products. However the software was customized to provide the congestion analysis feature. The long-range communication system was customized to operate within OCTA’s existing radio system. The GPS base-station was also

customized to operate at OCTA's Garden Grove maintenance yard. The custom elements were developed by NET Corporation working with 3M Corporation. These were created in response to earlier design documents created by Rockwell.

1.3 Customer Interface

Customers have several means for gathering information on OCTA bus lines. The most prominent is the OCTA *Bus Book*, which is a 160 page booklet containing schedules and route maps for all OCTA lines. The *Bus Book* also contains a condensed color map of the entire system, instructions on using OCTA buses, diagrams of bus terminals, and phone numbers. The *Bus Book* is distributed at bus terminals and on buses. OCTA contracts with an independent provider to operate a telephone information line. And OCTA posts basic line information on bus stop signs.

As part of this project, a computer kiosk was installed at the Santa Ana Terminal. The kiosk, which is described more completely in Section 2.7, provides information on bus departure times from the terminal, instructions on how to get to major destinations, bus schedules and route maps, and general information on riding the bus. The kiosk began operation in May of 1999. The kiosk provides real-time bus arrival and departure time estimates for the 47, 49 and 205 lines, based on data collected from the Transit Probe system. The only other interface to the transit probe that is visible to consumers is a small box, placed by the driver. The box emits a warning light indicating whether the bus is ahead of, or behind, schedule.

■4 Study Objective And Report Outline

The purpose of this study was to evaluate the effectiveness of the Transit Probe System as a whole. Specific objectives include:

- Measurement of the reliability and completeness of data generated by the Transit Probe System
- Assessment of the effectiveness of interfaces between the Transit Probe System and users.
- Determination of the usefulness of transit probe data for congestion measurement
- Evaluation of the institutional performance of the Transit Probe project.

The remainder of the report is divided into five sections. Section 2 provides a detailed system description, along with a history for system development. Section 3 provides the methodology for evaluating data reliability along with reliability results. Next, in Section 4, congestion analysis data are evaluated to determine the feasibility of estimating automobile congestion from transit probe data. The institutional evaluation is provided in Section 5. Section 6 gives results from a customer survey. The report ends with conclusions in Section 7.

2. DESCRIPTION OF TRANSIT PROBE SYSTEM

2.1 Development History

The Transit Probe project grew out of informal contacts between the City of Anaheim, the Orange County Transit District (OCTD) and the Urban Mass Transit Administration (UMTA) around the year 1990. UMTA was impressed with Anaheim's traffic management center, and felt that similar centers could be developed for transit systems. To spur this effort on, UMTA funded OCTD and Anaheim to investigate joint opportunities for intelligent transportation system in traffic and transit. The study, conducted by JHK and Associates, recommended a bus probe project as one of several "first level priority" projects (JHK & Associates, 1993).

The probe project later crystallized in the form of a proposal to the US Department of Transportation under its Field Operational Test program. By this time, OCTD had merged with the county's sales-tax transportation agency to form the Orange County Transportation Authority. Though the proposal was rejected under the FOT program, Caltrans felt the project meshed well with its CAPTS (California Advanced Public Transit Systems) program, and funded the project from its own funds (some of which come from Federal Transit Administration, FTA, sources; FTA is the successor to UMTA). One of the innovative features of the proposal was the dual use of bus tracking system as traffic probes in addition to serving transit specific needs. Santa Ana was brought in at this time to broaden the project's base. The project commenced in late 1995 when OCTA issued a contract to Rockwell to serve as system manager.

The initial system design was developed by Rockwell's Autonetics Electronic Systems Division of Anaheim California under contract to OCTA, after being selected through a competitive bid process. Rockwell's work has included development of a system architecture, writing specifications, and preparing a scope-of-work statement for a system integrator (Rockwell, 1996).

In the fall of 1996, a request-for-proposals was issued to select the system integrator to implement the project. NET Corporation was selected as prime contractor in 1997, with support from 3M Corporation. A draft system design was created in the summer of 1997, and the final System Design Report was issued in January of 1998 (NET, 1998b). The system was operational in May of 1998, and is expected to continue to operate until the year 2000.

The Transit Probe project is one element in the Orange County Intelligent Transportation Systems (ITS) plan. The project will be a data source for the Orange County "TravelTip" project, which is intended to provide multi-modal traveler information services via an advisory telephone system and a web page. It is also a source of information for traveler kiosks located at the Santa Ana and Fullerton transit terminals. The project is only loosely related to the Southern California Priority Corridor and its "Showcase" collection of projects, which it preceded.

2.2 Evolution of System Concept

The concept for the transit probe system evolved over the last six years, as reflected in a series of milestones discussed below.

Orange County IVHS Study This 1993 plan proposed development of a “Public Transit/Smart Bus Program” in four areas: (1) automatic vehicle monitoring, (2) data collection, (3) information processing and (4) transit operations center. Separately, the plan proposed creation of the “Interagency Transportation Information Exchange (INTERTIE)” for exchanging information among agencies and the “University Traveler Information Program (UTIP)” for traveler information dissemination. Using buses as traffic probes was not mentioned at this time.

Rockwell System Manager Proposal When the project commenced in 1995, it was guided by this expansive and visionary document. Rockwell proposed 12 Transit Probe Innovations, including:

Mini kiosk	Mobile data terminals
Passenger demand sensors	Low power advisory transmitters
Driver panic button	LAN/WAN capability
Dual Communication path	Computer dial-in service
Integrated transit operator workstation	TravelTIP simulator

The Rockwell proposal also contains the innovation of using buses as traffic probes, along with communication of probe data to traffic agencies.

As a historical note, the proposal was written before web pages were well established. The concept at the time was that people could access the information from dial-in modems, rather than from the Internet. Otherwise, the proposal suggested a great range of services and technical features. The broad scope can further be seen in the deployment vision (Figure 2), which shows the probe system as one part of a broad range of services offered through intelligent transportation systems. The System Manager Proposal also defined a set of project objectives:

- To test the application of APTS [Advanced Public Transit System] technologies, specifically GPS, to transit management
- To test the application of ATMS [Advanced Traffic Management System] and ATIS [Advanced Traveler Information System] technologies to transit operations
- To measure the benefits gained in the form of efficiency, congestion reduction and mode choice awareness
- To evaluate the institutional arrangements necessary to install, operate, and manage multi-jurisdictional transit/traffic operations and traveler information systems.

These objectives reflect the experimental nature of the project, and the desire to step beyond what was currently available.

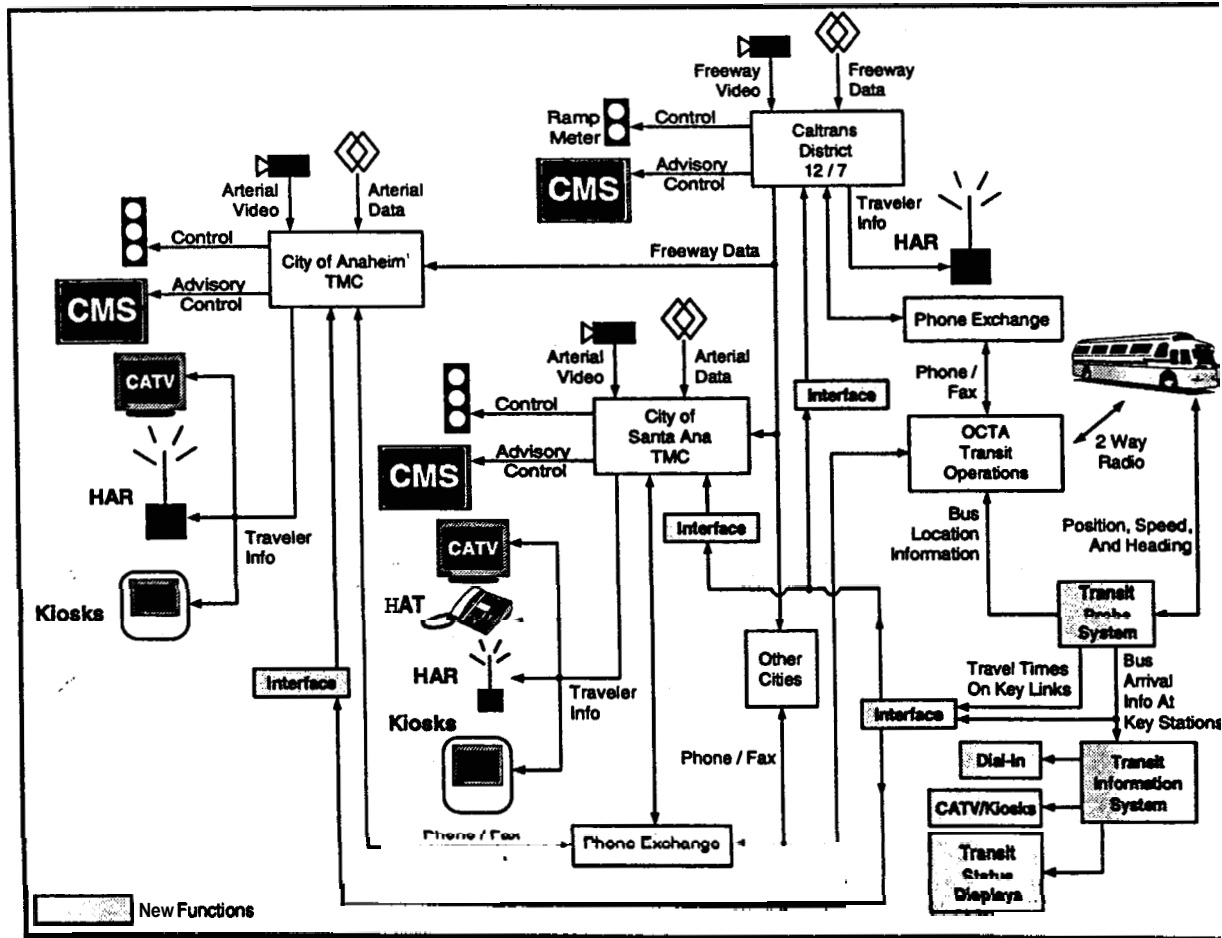


Figure 3-4. Transit Probe Development And Integration

33.5 Transit Probe Development

Development of Transit Probe begins with identifying and designing key elements of automated transit operations. Each function is developed and integrated into the system one function at a time. Once the basic functions are integrated, interim external interfaces to Transit Probe are developed. As shown in Figure 3-4, this provides the means to provide transit status via remote displays or dial-in service.

Interfaces to external agencies such as Anaheim TMC, Santa Ana TMC, and Caltrans District 12 are also provided. At this point, TravelTIP is not available so individual interfaces to these agencies are accommodated via telephone exchange and direct connectivity at minimal cost. This is done by dedicated dial-up or leased line services. When TravelTIP is deployed, these interim interfaces are removed and the information exchange

occurs via TravelTIP. Some of the interfaces, however, are maintained after TravelTIP integration, namely kiosks and cable TV.

In either case (before and after TravelTIP deployment), transit data such as transit vehicle link travel times can be used by the other agencies and correlated with normal private vehicle travel times if required. Vehicle position, speed, and heading data are used by the transit operations to effectively plan transit routes and schedule adjustments.

33.6 TravelTIP Integration

Ultimate probe deployment and transit status dissemination occurs when Transit Probe integrates with TravelTIP. Although the schedule of this project does not coincide with TravelTIP's deployment schedule (TravelTIP is to be deployed later than Transit Probe), the strawman architec-

Scope of Work This document, written **in 1996** for the system integrator request for proposals, represents the culmination of Rockwell's design efforts. Its scope is much narrower than the initial probe proposal, reflecting funding realities along with the specific purpose of the Probe Project relative to TravelTip and other projects. The document defined four subsystems: (1) in-vehicle, (2) dispatch center, (3) kiosk and (4) communication. The system was specified to provide functionalities for locating vehicles, determining schedule adherence, measuring congestion, and determining anticipated arrival times. The system was also specified **to** provide an interface to TravelTIP, for information dissemination to partner agencies and the general public, and to provide data to help planners and operators manage their fleets. The in-vehicle unit was intended to provide an interface to the bus operator, for the purpose of communicating information on emergencies, observed traffic incidents and transfer coordination requests to the dispatch center.

System Design Report The final design is a somewhat scaled back version of the Scope of Work. It built from an off-the-shelf software product (3M Info) rather than customized code. In particular the driver interface is greatly simplified; drivers cannot use it to send messages on traffic incidents, as earlier envisioned. Most of the innovations contained in the original Rockwell proposal have either been dropped, or deferred to other projects.

Follow On System During the course of Transit Probe operation, OCTA entered into an agreement with Orbital Science to upgrade its radio communication system and to install GPS based tracking on a systemwide basis. ITCS will also allow buses to directly communicate transfer information with each other, to reduce voice radio traffic and to provide higher quality information in coordinating transfers. The new system, called ITCS (Integrated Transportation Communication System), will be operational in the year 2000. It remains to be seen how ITCS will interface with TravelTip and with OCTA's future run-cutting and scheduling system. However, it is clear that ITCS will not offer congestion analysis and TravelTip will rely on traffic agencies instead of OCTA for data on roadway speeds. For an interim period, ITCS may operate in parallel with Transit Probe, which will be utilized **as** the initial OCTA interface to TravelTip.

2.3 System Architecture for Transit Probe

The final system architecture was designed to leverage pre-existing software and hardware, while satisfying unique project requirements. For instance:

- OCTA's conventional 800 MHz frequency band radio system, coupled with the county's microwave network, was utilized for data transmission to and from buses in the field.
- Software for the Transit Probe system was a modified version of the 3M Info bus tracking product.
- In-vehicle units include components from the 3M Info product, as well **as** other off-the-shelf products

Customization was needed to meet the specific installation requirements of OCTA, **as well as** to provide the functionality for congestion analysis.

Figure 3 provides the system architecture found in the Transit Probe System Design Report (NET, 1998b). The fundamental components are the vehicle unit, dispatch center and kiosk. Critical interfaces are described below

Bus/Dispatch Center: Two wireless connections are provided, one for communication with vehicles in the field and the other for short-range communication with vehicles in the maintenance yard. Long-range communication is provided through a Motorola MSF5000 base radio coupled with an Ericsson MDX 800 MHZ model PM82SN mobile radio. Long-range communication is utilized to transmit real-time status information from bus to base station, and to transmit differential corrections and limited instructions from base station to the vehicle. Short-range communication is by Proxim Model 7510 2.4 GHz spread spectrum/wireless LAN. Transceivers are mounted at both the Garden Grove and Anaheim maintenance yards. The short-range system is utilized for uploading and downloading data, such as vehicle logs.

Dispatch Center/Kiosk: A leased line phone connection is used by the kiosk to access current bus schedule information, as well as updated data on bus arrival times. Transmission is at 56 Kbps, connected through a Digital Service Unit (DSU).

Dispatch Center/TravelTip: An external interface is provided to the TravelTip traveler information system, being developed by OCTA as a multi-agency partnership. This allows the general public, as well as Caltrans District 12 and the cities of Anaheim and Santa Ana, to access bus schedule information and bus arrival time estimates. TravelTip acquires transportation information from various other systems, including Caltrans and 14 cities in Orange County. The connection is by leased line (56 Kbps). The connection will not be operational until late 1999.

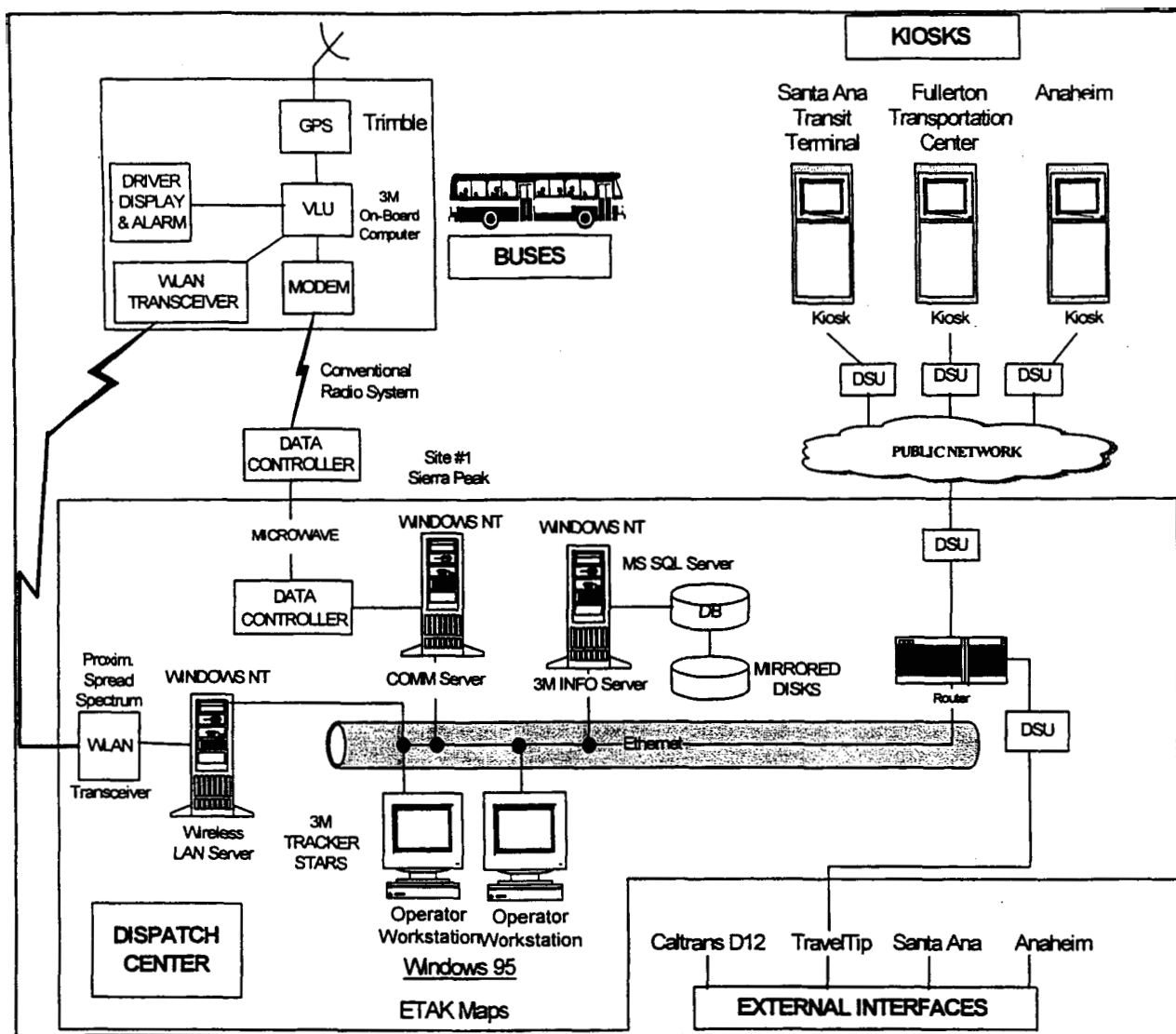
Bus/GPS: The Trimble SvecSix-CM3 six-channel differential GPS receiver is utilized, providing 2-sigma accuracy of $\pm 2-5$ meters. The receiver is used for position and time determination.

Dispatch Center/GPS: Though not shown in the figure, a GPS reference station is placed at the Garden Grove dispatch center. A Trimble model DSM reference station is used to provide corrections every 15 seconds, which are broadcast through the conventional radio.

2.4 On-Board Unit

The on-board unit consists of several inter-connected hardware components, providing capabilities for computation, driver interface, GPS signal processing and reception, and communication interface. The computation unit runs on an Intel 80386SX 33 MHz processor, supported by 2MB DRAM, 1MB flash memory and 512 kB SRAM. The SRAM is utilized for storing log files, and requires continuous power (either from the bus battery or a lithium back-up battery). The computer includes interfaces to other on-board devices, and also includes a 51708 interface, which can connect to the vehicle data network (not currently used). The computer also interfaces with a door sensor, which was specially mounted to determine when the door is open or closed. Integration is also provided with the vehicle's panic button/silent alarm (these are mounted throughout OCTA's fleet). When the panic button is pressed, position updates are provided several times per minute and the affected vehicle is highlighted on the dispatcher's screen.

Figure 3: Transit Probe System Diagram (NET, 1998b)



Transit Probe System Diagram

These subsystems work together to provide the functionality described herein. There are three routes that have been selected in order to adequately demonstrate the objectives of this project. The selected routes are as follows:

- #205 Anaheim/Laguna Hills
- #47 Fullerton/Santa Ana
- #49 Brea/Santa Ana

The criteria used to select these three routes are listed as follows:

- for bus probe congestion measurements the routes traverse roadway segments in each of the three partners agency jurisdictions namely, Santa Ana, Anaheim, and Caltrans.



The driver interface is a simple device, providing lights indicating to the driver whether the bus is on-time, early or late. A radio modem is provided for interface with the conventional radio, and a wireless LAN transceiver is provided for short-range communication. As described earlier, a Trimble GPS receiver and antenna are also mounted on the bus.

2.5 Base Station Software

3M Info software consists of four functional modules, which interact with the 3M STARS database (NET, 1998a). These modules are described below.

Scheduler This module is used for entering data that define routes, schedules, and congestion segments. Routes are defined by a set of points, corresponding to check points listed in the bus schedule and other route features. Points can be entered by point-and-click from a digital map, they can be geo-coded from street intersections or entered from their map coordinates. In all cases, a location (latitude/longitude), stop name and stop type are entered. Stop types include: curve, garage, left-turn, right-turn, station point, stop, timepoint, and transfer point. Routes are created by sequencing points from start to finish. Points can be re-used when multiple routes serve the same stop.

Schedules are created in the form of runs and blocks, which define the times when buses are scheduled to visit stops, and the grouping of these schedule points into units of work. **Scheduler** also allows entry of driver information, and entry of data for defining congestion segments. A congestion segment has a start location and end location, and parameters defining a normal speed and thresholds for determining whether speed is below normal (classified as light, medium or heavy congestion). Other parameters are described later in the section on algorithms.

Scheduler is only used periodically when schedules change, or when driver lists are updated. When the system is first installed, considerable effort is needed to create the route points and initial bus schedule.

Assigner This module is used to assign specific buses to specific blocks, and to adjust driver assignments. With this information, 3M Info can compare bus positions to the schedule of where the bus is supposed to be, thus determining whether it is on-time, early or late. **Assigner** maintains an assignment for the current week and a subsequent week. As a practical matter, because buses are frequently taken in and out of service for maintenance reasons, **Assigner** would be used at least once a day in a full deployment.

Tracker This is the real-time monitoring module. **Tracker** provides both a tabular and a map display, showing bus status as well as when the status is last updated. Other attributes include run, vehicle, driver, last stop, last call, latitude, longitude, heading and speed. The user has the option of only displaying buses that satisfy certain criteria, such as being late or overdue. A tabular display is also provided for congestion level status by segment. This shows congestion level, estimated bus speed, expected bus speed (entered by user in **Scheduler**), time, vehicle, run and driver. Through **Tracker**, users can also initialize position logging, which records bus locations at user-specified intervals over a desired time period. Users can also reset parameters for when status should be updated through **Tracker**.

Reporter The **Reporter** module is used for viewing and analyzing historical data for on-time performance and congestion. The **Route Analysis** feature provide a pie-chart showing the percentage of stops for which a bus (or set of buses) was on-time, later, early or “undetected” (system could not determine status). By clicking on the chart, individual records can be viewed in tabular form. The **Incident Report** feature provides a complete list of records, including both on-time performance and other data, such as position logging records and door open/closed records. Similar reports can be generated for congestion analysis. For more detailed analysis, users can cut-and-paste records for export to other ODBC (open-database-compliant) programs, such as Microsoft Excel.

User Interface All four modules operate in the Windows environment and have the look and feel of most Windows applications. This includes pull-down menus and a tool bar with clickable icons, as well as dialog boxes for entering information. One difference from some Windows applications is that only one window can be viewed at a time. The cut-and-past feature also operates differently. Instead of selecting any rectangular grouping of cells in tables, as in Microsoft Excel, the user must select entire lines of data.

2.6 Algorithms

The base station and on-board computers utilized algorithms to estimate congestion on route segments, to determine schedule adherence and to estimate bus arrival times at stops.

Congestion Estimation Congestion classifications are based on the estimated speed for the bus within segments of roadway, after adjusting for bus stop time (NET, 1998b). The speed is compared to a nominal free-flow speed. Depending on the ratio, congestion is classified as “none”, “light”, “moderate” or “heavy.” Screens are provided for users to enter the threshold ratios separating the classifications, and to enter the nominal speed for each segment. OCTA defined light congestion as a speed of 75-90% of normal, moderate congestion as 60-75% of normal and heavy congestion as less than 60% of normal.

The estimated speed is calculated from the equation:

$$\text{Estimated Speed} = (N_1 * SL) / (ST - SDT - N_2)$$

Where:

- SL = physical length of segment
- ST = measured time to traverse the segment
- SDT = station dwell time
- N₁, N₂ = empirical coefficients to compensate for performance differences between Autos and buses

The measured time is estimated by first determining when the bus passes in the vicinity of the points that define the start and end of the congestion segment, and second calculating their difference. The traversal times are approximated, because the **GPS** does not necessarily record the

exact same latitude/longitude as the congestion point, and because the GPS does not poll its location continuously.

The station dwell time is calculated as the sum of the time that the door is open, and the time lost due to accelerating and decelerating from free-flow speed (assuming constant acceleration and deceleration rates). Adjustments are made when a door is opened and closed multiple times at a stop. The Transit Probe system has been implemented in a way that N_1, N_2 have been set at 1 and 0, respectively, so that they have no effect on the result. The nominal free flow speeds have been estimated to approximate speed limits. Field data collection was not used to set these values, and speed limits naturally overestimate free-flow speeds, as the former does not account for normal stopping at traffic lights.

Congestion status is calculated within the on-board computer, and is transmitted back to the dispatch center whenever the bus completes a segment.

Schedule Adherence Early, on-time and late performance are estimated by comparing arrival times to scheduled arrival times. The actual arrival time is estimated by determining when the bus passes in the vicinity of the schedule check point. Once this deviation is determined, the stop is classified based on user set parameters, which specify thresholds for late and early arrivals. OCTA has set these values at five minutes for each. Schedule adherence is calculated in the on-board computer whenever a bus passes a schedule check-point. In normal operation, the result is only communicated to the dispatch center when a change in status classification occurs (e.g., if a late bus becomes later, a new message is not transmitted). This approach is intended to reduce data traffic loading on the radio system.

Estimated Arrival Times (ETA) Arrival times are forecasted for future stops for display in the kiosks. According to the System Design Document (NET, 1998, p. 46): "ETA receives schedule adherence information from the STARS database and calculates the time of arrival at the next bus stop. ... The ETA algorithm is a simple linear extrapolation of arrival time based upon the INFO System schedule adherence process." It should be noted that in normal operation schedule adherence data are only transmitted from the bus when a change in status occurs, so the precision of the estimates depends on the thresholds for late and early buses. Thus, the ETA will not change if an already late bus is further delayed.

2.7 Kiosk System

Transit Probe budgeted for three kiosks for customer interface. The first kiosk was opened to the public at the Santa Ana terminal in May of 1999 (it was available for testing earlier), around the time the evaluation was completed. The second kiosk will be opened at the Fullerton terminal in the near future. A third kiosk was planned for the Anaheim convention center, but was shelved after a suitable site could not be found.

The kiosk allows users to determine the arrival time of the next bus at a stop, to find the way to prominent destinations, to look up schedule information and route maps and to obtain general information (fares, phone numbers, etc.). The kiosk runs on an Intel Pentium Pro 166 MHz

processor, with 32 MB EDO memory. It is enclosed to enhance durability, and is placed in a covered environment. The user interface is through a touch-screen CRT display.

The system interface is quite simple, allowing users to select from a discrete set of alternatives by touching appropriately defined boxes. A hierarchical menu structure is provided in which the user first selects a language, next selects a category of information and then navigates through a set of alternatives for each category of information. The allowed set of destinations for the wayfinding function is predetermined. Thus, instead of typing in the name of the destination, the user selects a destination from a set of alternatives. The system cannot provide the wayfinding service to other destinations, but can offer maps and schedules for the entire OCTA network.

The architectural design relies on communication with the dispatch center to obtain information on schedules and arrival times. This approach simplifies data maintenance, as the key information is stored on a single computer. However, it comes with the expense of additional communication load. Also, by limiting wayfinding to pre-selected destinations, the program does not need to compute shortest paths. Instead, paths are stored and looked up as needed.

2.8 Integration With OCTA

3M Info requires exchange of information with a variety of external applications, as described below. Interfaces need to be designed to minimize the effort in transferring data into 3M Info, and to fully exploit the data generated by the system within other applications.

Scheduling Interface Transit Probe requires several critical internal interfaces to be operational. Most importantly, a method is needed for transferring schedule data from OCTA's "Trapeze" run-cutting and scheduling system. Trapeze is used to create the schedules. Trapeze could also be a source of location data (latitudes/longitudes) for bus stops. Initially, it was hoped that data could be transferred electronically from Trapeze to Transit Probe. Unfortunately, an interface could not be created, and all data have been manually entered. Because data were entered for the entire fleet, the undertaking was quite massive. OCTA utilizes an older DOS version of Trapeze, which did not easily facilitate extraction of schedule data. OCTA is planning to replace their DOS version of Trapeze with a new Windows version, which should make the task easier.

Detour Interface A second important interface is the transfer of schedule detour and modification data. This occurs when a route is temporarily altered, outside of the normal times for schedule changes. Detours are not entered into Trapeze and are instead manually generated. The Dispatch Center prints detours on maps and posts them on a wall for viewing. During the course of the project, detours were not entered into Transit Probe.

Operations Interface An interface is required to receive information on bus assignments at a minimum of every six months, and likely every day or whenever buses depart from maintenance yards. During the project, bus assignments were held fixed. This is not practical in normal operation, because garages need flexibility to reassign buses when they are taken in and out of maintenance. OCTA uses a system called BATS to automatically make its longterm bus assignments, using bus block and vehicle data as input. If a vehicle is taken out of service, the maintenance supervisor enters its number into a BATS terminal, which relays the information to

the dispatcher. The dispatcher then assigns an alternate bus from a pool of spares. After the bus is repaired, it is reassigned to its original block. Proper operation of the 3M Info system would require placement of a workstation at the dispatch window, so corrections can be made in assignments as needed.

Scheduling and Planning Interface Another important interface entails extraction of schedule adherence data for use in transit planning and schedule creation (i.e., as input to running Trapeze). Potential users could extract the data from one of the terminals at the Communications Center, and export it to ODBC compliant applications. Software was not installed in the scheduling and planning departments, making it logistically complicated to transfer data. Transit probe data were not used by OCTA for evaluating schedule adherence during the project.

Communications Center Interface In terms of real-time operation, Transit Probe could be accessed from the Communications Center, making it available to the people who operationally manage the bus fleet. The software ran on stand-alone workstations, which were in close proximity to, but not directly in front of, dispatchers. Dispatchers had separate workstations to control voice communication with operators.

Customer Information Interface OCTA customers access schedule information from a telephone information line operated by CDS NET, and from a printed *Bus Book*. They will soon be able to access schedule information from kiosks as well. The telephone information and Bus Book have been limited to static schedule information, which have been entered manually from the Trapeze system. In the future, real-time information may be integrated, relying on Transit Probe as a data source. A kiosk interface was created for the project; a telephone information interface was not created.

2.9 System Operation

The four modules of 3M Info require different levels of human intervention. Scheduler requires significant set-up effort, but only periodic human interface thereafter. Assigner is applied on a daily or weekly basis. Tracker is run continuously. And reporter is used periodically to analyze historical performance. The specific the steps requiring user intervention are described below.

Geocoding Stops To initialize routes, schedule check-points along with other points curve points must be set and connected to form routes. To support kiosks and future TravelTip applications, the entire OCTA network was manually entered, not just the **47**, **49** and **205** lines. In the project, these steps were performed by the contractor, NET.

Schedule Data To initialize routes and update schedules, schedule data must be entered. In the project, these steps were performed by NET. To support kiosks and future TravelTip applications, the entire OCTA schedule was manually entered, not just data for the **47** and **49** lines. OCTA intends to perform this task on its own in the future.

Congestion Data To initialize the system, the end-points for congestion segments must be defined, along with parameters for normal speed and thresholds. Field data collection is desirable in these steps, though it was not completed in the project. 3M entered these data.

Schedule Adjustments Detours and other schedule changes should be entered **as** they happen. Several significant detours occurred during the project due to extensive road construction in the vicinity of Disneyland in Anaheim. These were not recorded during the project, unless they were of sufficient duration to appear in the regular schedule.

Assigning Buses to Runs Each week, individual buses must be assigned to individual runs. This task was performed by the OCTA project manager during the project.

Downloading Data from Buses As buses check-in to, or check-out from, the maintenance yard, they must stay near to the LAN transceiver for sufficient time to download or upload data. Completion of this task is shown to the driver with an indicator light. If the bus does not reside for sufficient time, logs will be downloaded late, or possibly not at all if the on-board unit runs out of memory.

These steps require a considerable time commitment on the part of the transit agency, especially in the absence of methods for electronically entering schedule information.

Software Usage As part of the evaluation project, OCTA was contacted to assess their operational experience using the 3M Info software. Most of the communication personnel were trained in use of the software in late spring of **1998**. However, the software was not fully operational until sometime later. Due to this delay and other problems, the software was never actually used by OCTA within actual operation. These other problems include the small number of lines affected, and the lack of complete coverage on the lines. In addition, the simultaneous development of the ITCS system, and the award of the ITCS contract to a different company (Orbital), greatly reduced the importance of the 3M Info software. An interface was never created for Anaheim, Santa Ana, and Caltrans, so there was also no operational experience at the partner agencies.

Despite the fact that 3M Info was never used, the general perception was that the software was user friendly and relevant to their work. However, it lacked important functions, such as messaging between driver and bus. Another drawback was that the software was not integrated with other communication applications, and ran on a separate workstation. This workstation was not placed immediately in front of the dispatcher, but to the side. A dispatcher would have to move from his or her desk to the workstation to view the screen. Another drawback was that the system was not designed to assist in transfer coordination. If they needed another bus to wait for a connecting passenger, drivers still needed to use the voice radio. Likely because of these problems, procedures were never created for utilization of the probe data in bus operations. In the absence of these procedures, the software was never used.

Though OCTA did not use the system in their operations, the evaluation team had extensive operational experience with the 3M Info Software. The following is our list of possible improvement, based on our own use:

- Each program module is a distinct application, making it difficult to navigate from one to another.

- Data analysis capabilities are quite limited, providing only simple bar and pie charts. The system is not configured for sorting route analysis and incident report data by attribute, and does not provide sufficient tools for statistical analysis and graphing.
- Though data can be copied to other ODBC applications for statistical analysis, the copy feature is not as simple as other Windows applications. Entire rows of data must be selected, instead of desired cells. Furthermore, we found that it was impossible to copy more than about **400** lines of data at a time without encountering a “string” error message. This made it extremely time consuming to export data to other applications for detailed analysis.
- Tables and reports were not customizable to display all of the desired fields of data.

Bus Driver Surveys Bus drivers were surveyed in June, **1999**, to determine how useful the probe system had been for drivers. A total of **13** drivers participated, all of whom had been exposed to the device, and all of whom had noticed the device. Driver experience varied from just a few weeks driving on their line to **22** years.

Drivers, on the whole were quite dissatisfied with the device. They rated the accuracy at an average level of 2.7 on a 5 point scale, with more experienced drivers generally rating the device lower than newer drivers. Even this rating may be an exaggeration, as it was clear that drivers were most satisfied with the digital clock on the device. Most drivers look at the device every 1 to five minutes, with two stating every **6** to **30** minutes, three stating never and **just** one more frequently than once per minute. However, only two were looking at the late/early lights. The remainder were only looking at the clock.

The majority (2/3) felt that the device was useful in keeping on schedule and (1/3) felt that it had helped improve their on-time performance. However, only one person felt that the on-time/late lights were working effectively. These improvements seem to result solely from installing a clock. The only people who had not encountered problems with the system were drivers who did not use it (even though it had been present on their buses. Their comments point toward perceived unreliability:

- *In the beginning it was accurate, but not after change in schedules*
- *Was showing late when he was actually 3 minutes early*
- *Shows early or late at end of day during deadhead*
- *Schedule is inaccurate intentionally to get them early*
- *Didn't know what it was*
- *Doesn't work most of the time*
- *Followed it once and came in earlier than scheduled*
- *At checkpoint it was time to go while it was telling her to wait*
- *Shows wrong position*
- *Says late when early and vice versa (4)*
- *Believes that a false schedule is on the system*
- *It's off all the time*
- *Went haywire once*

- *Sometimes the early/late lights don't light up*

Clearly, whether or not the system generates accurate data, drivers believe it is inaccurate and therefore generally ignore the late/early lights. Furthermore, there is a definite need to improve communication with drivers on the purpose of the devices.

When asked for system improvements, drivers provided the following suggestions:

- e *Should be calibrated regularly*
- e *Deadhead should be ignored*
- e *Should be positioned so that only drivers can see it*
- e *Nice clock, otherwise worthless, get rid of it*
- e *Take it off; it's distracting*
- e *Put it on all buses, provides a great backupfor watch*
- e *Shouldn't be there if it doesn't function well*
- e *They didn't explain what it was*
- e *There should be a clock on all buses*
- e *Take them off; they distract*

There is a strong feeling among drivers that the system, as implemented, did not function reliably, and would have limited value until reliability is improved. In fact, some drivers had even been advised to ignore the devices because of reliability problems.

A few positive suggestions also came from drivers:

- *Put it on all buses, provides a great backupfor watch*
- *There should be a clock on all buses*
- *Would be better if tied into an announcement system*

One clear conclusion from the survey is that the most important way to improve schedule adherence from the perspective of drivers is simply to post an accurate clock in view. This is especially true for experienced drivers, who know the schedule well. The on-time/late indicators have greatest value for new drivers on the line. However, the lights provide no value if they are either believed to be unreliable or in reality are unreliable. Lastly, it is apparent that communication with drivers should have been improved. Placing devices on buses will have little value if drivers are not fully involved and instructed in how to respond to the information.

2.10 Installation

Installation of software and hardware were significant project issues. The Probe System is not designed for “plug-and-play” as significant system integration issues must be resolved. To make the system operational, the following **tasks** were required:

- On-board hardware was mounted on the buses, and wired for interconnection and connection to the radio and power systems.

- Wireless LAN transceivers and wireless LAN servers were installed at the Garden Grove and Anaheim maintenance facilities.
- A kiosk was installed at the Santa Ana Terminal and connected to a leased phone line.
- The differential reference station was installed and calibrated at the Garden Grove facility, and connected to the radio communication system.
- The **3M Info** server and workstations were installed at the Garden Grove Dispatch Center, and interfaced through an Ethernet LAN.
- **3M Info** software was initialized to represent the OCTA network, schedule and requirements.
- Additional modifications were required to pre-existing OCTA systems to accommodate Transit Probe hardware and functions.

Clearly, these steps are not simple, and are best performed by people who are experienced with the given systems. NET and **3M** assumed responsibility for the installation, with assistance from Macompco (data radio) and Cinergy (communication).

The evaluation team had significant difficulty with its self-installation of the **3M Info** software. Unlike out-of-the-package software, installation procedures were not self-evident. System settings were not documented and had to be manually altered to get the system running. Help documentation and error statements were insufficient for debugging problems without consulting the vendor. The vendor was quite helpful in resolving problems over the telephone, though resolutions were neither immediate nor obvious. The evaluation team was never successful in enabling position logging from its remote site, though it was possible to do so from the Dispatch Center computer.

3. RELIABILITY OF TRANSIT PROBE DATA

A detailed evaluation was completed on the reliability of Transit Probe Data, covering a one year period from June 1, 1998 to May 30, 1999. The reliability evaluation was limited to historical data that have been downloaded to the system database. There was no practical means to evaluate the reliability of real-time system data. Although source data for historical and real-time data are the same, differences can exist in reliability due to errors that occur in storing or transmitting data. For instance:

- A failure in the wide-area radio network can cause an error in real-time data that does not occur in historical data.
- A failure in on-board data storage (e.g., if memory is exhausted) can cause an error in historical data that does not occur in real-time data.
- A failure in short-range communication can cause an error in historical data that does not occur in real-time data.

For these reasons, the reliability analysis can only suggest how the real-time system performs.

3.1 Error Classification

The Transportation Probe System provides functions for “Route Analysis” and “Congestion Analysis”. The “Route Analysis” function is designed to measure adherence of buses to schedules at check-points. The “Congestion Analysis” function measures levels of congestion on route segments.

If the “Route Analysis” system is performing perfectly, the data set will contain one record for each check point in each daily schedule. This amounts to about 250 records for each weekday on each line. Because only five buses were assigned to each line, the maximum possible coverage was reduced by about 25%. In addition, each record will contain the exact time that the bus arrived at the check point. If the “Congestion Analysis” system is performing perfectly, the data set will contain one record for each time a bus passes through a congestion analysis segment in each direction. A total of eight congestion segments were entered in the system. A complete data set would contain about 30 records for each weekday. The system was not set up to operate on weekends, which were, therefore, excluded from analysis.

Unfortunately, the system did not collect a perfect data set, due to the following types of errors:

Undetected Error: In this case, a record appears for a check point or congestion segment, but the time is listed as “undetected.” Undetected errors can occur when the GPS signal is blocked due to poor satellite positioning or physical obstructions (buildings, trees, etc.). Undetected errors can also occur when a bus has been assigned to a different run than normal, when a bus has been detoured from its normal route, or when equipment has malfunctioned or is reporting incorrect positions.

Missing Error: This is a point in the schedule for which no record at all occurs in the database. Missing data can occur when a bus (or its driver) failed to download data, when a bus has not been

assigned to a run, when equipment is totally inoperable or taken out of service, or when equipment has been turned off (sometimes when bus is not on its normal run).

Duplicate Error: This occurs when a given check point or congestion segment appears more than once in the data set. In some instances, a record was duplicated more than 100 times. In all instances, duplicates had the “undetected” status. The cause of duplicate errors was not clear.

Numerical Error: This occurs when the arrival time at a stop is incorrectly recorded. This appears to be caused by approximations imbedded in the algorithm for estimating arrival time or in errors in inputted values for stop latitude/longitude coordinates.

Because numerical errors can only be determined from field data collection, most of our analyses was limited to the first three types of errors, for which error rates were calculated as follows:

$$\text{Undetected } Y_o = \text{Undetected/Non-duplicate Errors} \div \text{Total Points in Schedule}$$

$$\text{Missing } Y_o = \text{Missing Errors} \div \text{Total Points in Schedule}$$

$$\text{Duplicate \%} = \text{Duplicate Errors} \div \text{Total Points in Schedule}$$

$$\text{Total \%} = \text{Undetected \%} + \text{Missing } Y_o + \text{Duplicate \%}$$

It should be noted that because of duplicates, the total % can exceed 100%. Furthermore, the detected Y_o can be calculated as follows:

$$\text{Detected } Y_o = 100\% - \text{Undetected } Y_o - \text{Missing \%}$$

The detected % is the number of points in the % of points in the schedule for which a numerical value appears in the database. Because the numerical value can also be in error, it provides an upper bound on the % of data points that are correctly detected.

3.2 Error Analyses

Error rates were tracked over the lifetime of the project in the following ways:

- Daily error rates, summed over all stops, runs and lines
- Error rate by stop, summed over all days and lines that use the stop

C language code was written to classify records by error type. Unfortunately, the process could not be fully automated, as records had to be retrieved manually for each line and each month, then cut **and** pasted into a separate database. Data retrieval times were quite large, sometimes taking hours from our remote site. Average time was about **45** minutes for each line in each direction for one month. This time is due in part to modem transfer time.

In addition to tracking undetected, missing and duplicate errors, field measurements were used to assess numerical accuracy. Floating car measurements were used to assess the accuracy of

congestion estimates. These are reported on in Section 4. Field measurements were also made by stationing an observer and recording the time that a bus opened its door, closed its door, and pulled away. These were compared to recorded arrival times.

3.3 Error Results

Overall performance is summarized in Table 1. Over four sample months, we found that 23% of the points in the schedule were successfully recorded on line 47, 33% on line 49 and 24% on line 205. Over half of the data points were missing (in part because there was not complete line coverage; in part because buses were not always assigned). 10 to 17% were shown as undetected, roughly half the number of points that were successfully detected. In addition to these errors, we found numerous instances of duplicate records. This was most problematic on line 205 in the month of April, when in excess of 120,000 duplicate records were generated. Typically, each line generated about 100 to 200 duplicate records each month.

Performance varied from stop to stop, as indicated in Figure 4. The Santa Ana Transit Terminal performed the worst, with very few good data points. This might be the result of its location at the bottom floor of a high-rise building, where it is impossible to read a GPS signal. Stops located in the area of roadway construction also performed worse. It appears that detours around the Haster and Katella stop in particular resulted in worse data. Figures 5 – 8 plot errors by day, combining all days. As shown, on a number of days the entire data set was missing. This would occur if bus assignments had not been made, or if buses are operating on the wrong routes.

Table 2 compares observed bus arrival and departure times to time that were recorded in the transit probe system. Observations were taken at 17* and Bristol, which was selected because two lines serve the stop, making data collection more efficient. We found the errors to be small or inconsequential for the stop analyzed.

Figure 9 presents analysis for congestion segments. Unlike schedule adherence, error rates did not differ substantially from location to location. This may indicate that the particular end points of the segments were not affected by detours, and did not have problems with blocked GPS signals. The number of undetected points tended to be smaller than for scheduled adherence, but the amount of missing data was still substantial (again due, in part, to incomplete coverage of buses on the lines).

3.4 Sources of Errors

The 3M Info software produces a diagnostic report that documents the occurrence of errors by type. This report is automatically generated through a self-diagnostic process. Data were analyzed for the months of August, November, February and May, resulting in the distribution shown in Figure 10. The most frequent errors were serial port receive errors, followed by LAN card not responding, LAN card failed initialization and GPS receiver broken. Figure 11 shows how errors vary from computer to computer (identified by their vehicle number). The computer with the most errors had

Table 1. Missing Data Analysis (Total by Route, sum of all days)

Month: July-98

Route Id	% Good Points	% Undetected	% Missing	# of Duplicates
47	19.15551839	12.44147157	68.40301003	151
49	26.40871215	12.1772131	61.41407475	250
205	15.00443656	5.909494232	79.08606921	181

Month: October-98

Route Id	% Good Points	% Undetected	% Missing	# of Duplicates
47	31.92307692	8.626373626	59.45054945	194
49	35.64651667	3.96674799	60.38673534	192
205	26.77179963	21.11317254	52.11502783	639

Month: January-99

Route Id	% Good Points	% Undetected	% Missing	# of Duplicates
47	16.51923077	12.42307692	71.05769231	0
49	38.28499142	9.975603144	51.73940544	25
205	29.56268222	25.24781341	45.18950437	184

Month: April-99

Route Id	% Good Points	% Undetected	% Missing	# of Duplicates
47	25.69055944	23.51398601	50.79545455	103
49	31.60255304	14.76625841	53.63118855	106
205	*	*	*	120000*

Analysis with all four months

Route Id	% Good Points	% Undetected	% Missing	# of Duplicates
47	23.32209638	14.25122703	62.42667658	448
49	32.98569332	10.22145566	56.79285102	573
205	23.77963947	17.4234934	58.79686714	1004

*Due to extreme number of duplicates, data could not be analyzed accurately

Figure 4. Analysis: By Station Points (Total of 4 months)

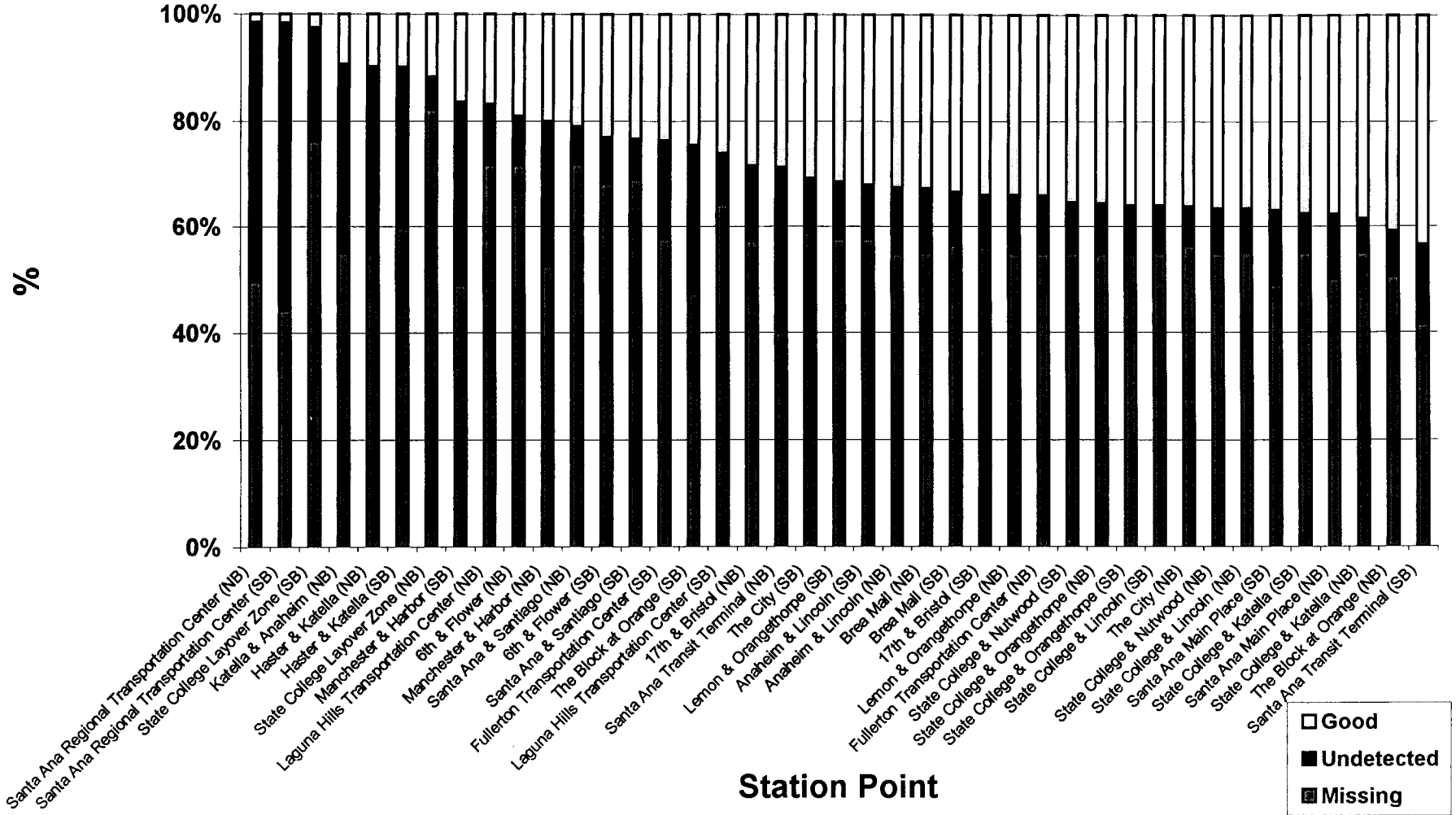


Figure 5. July 98 Analysis

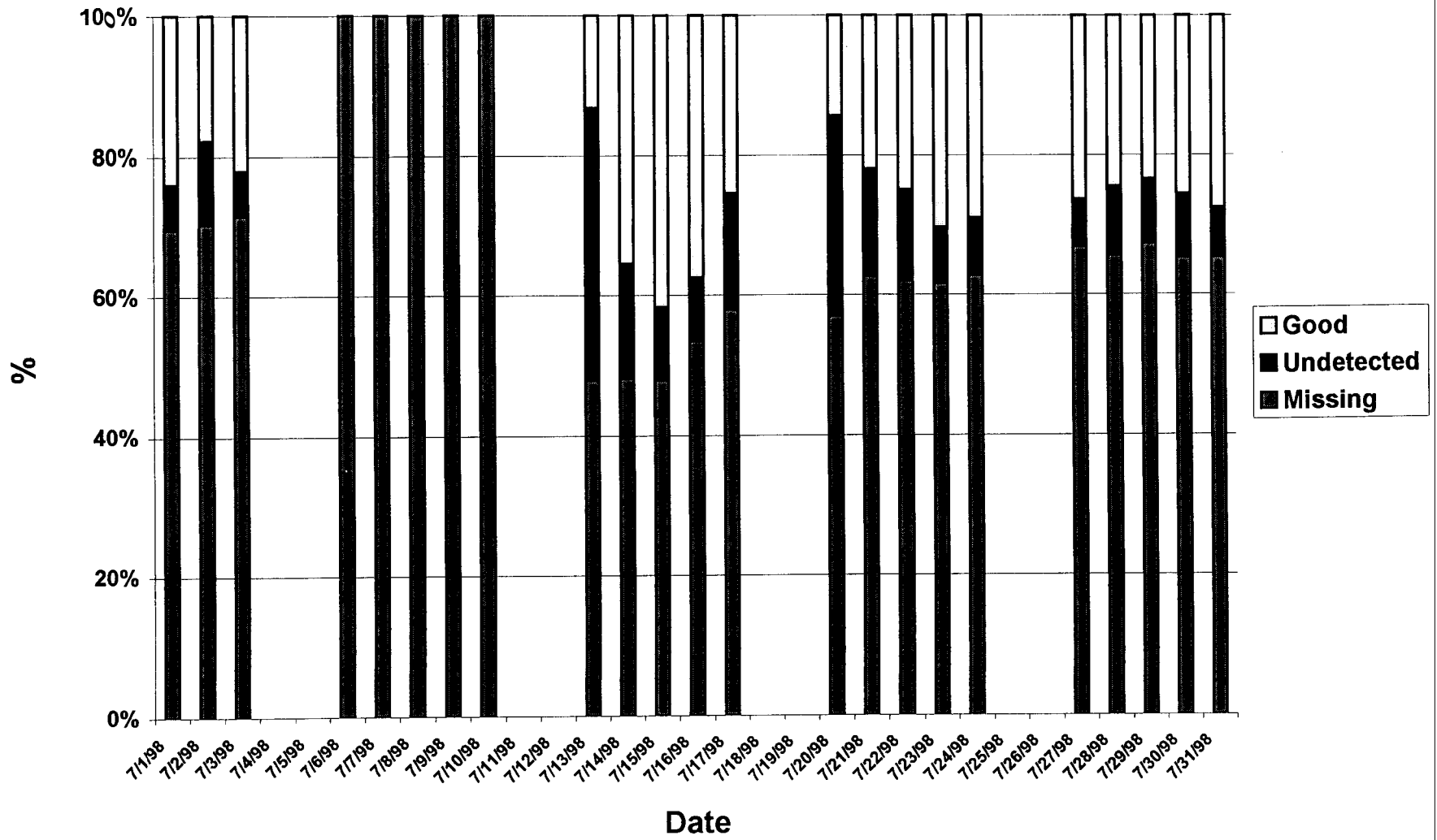


Figure 6. October 98 Analysis

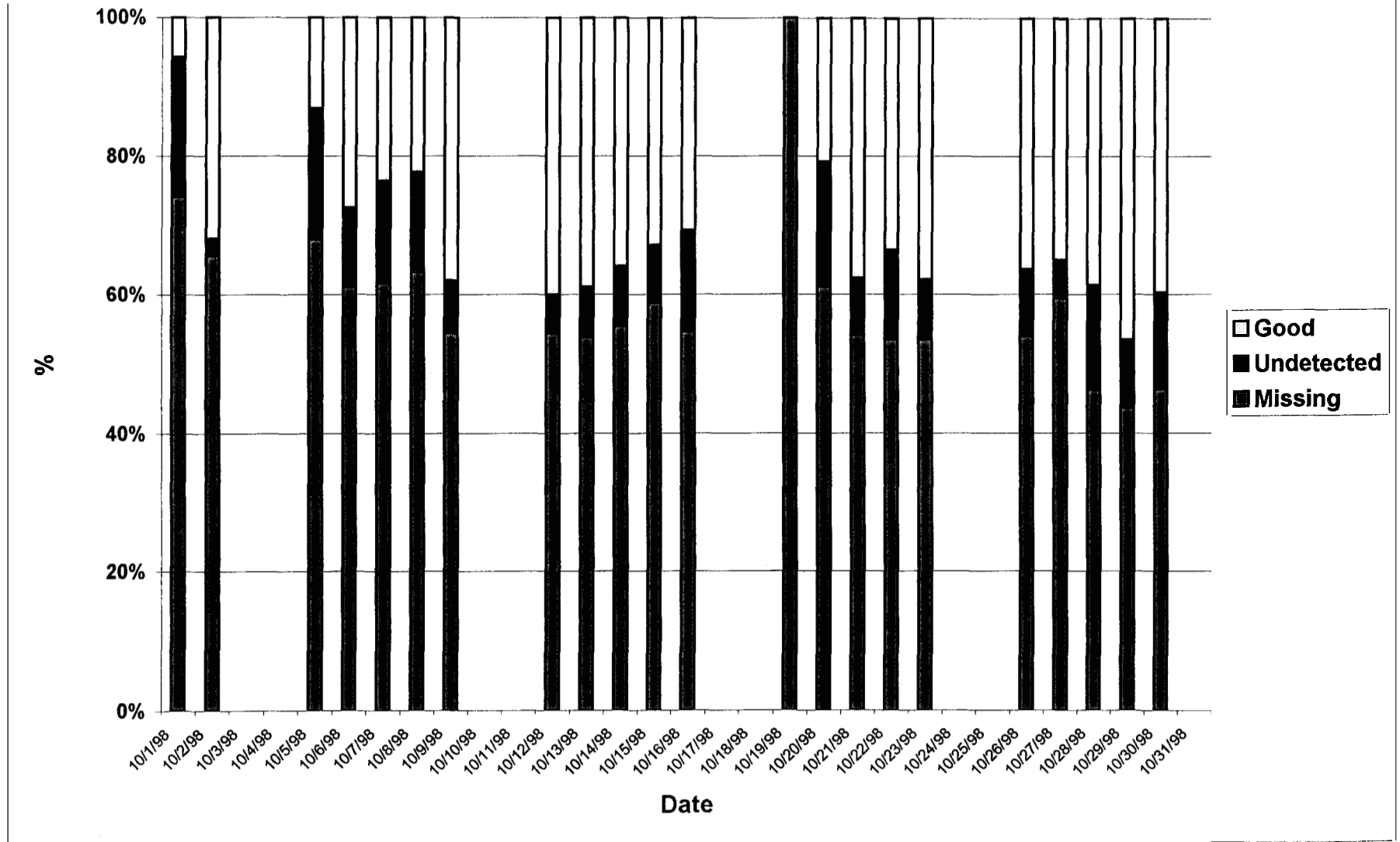


Figure 7. January 99 Analysis

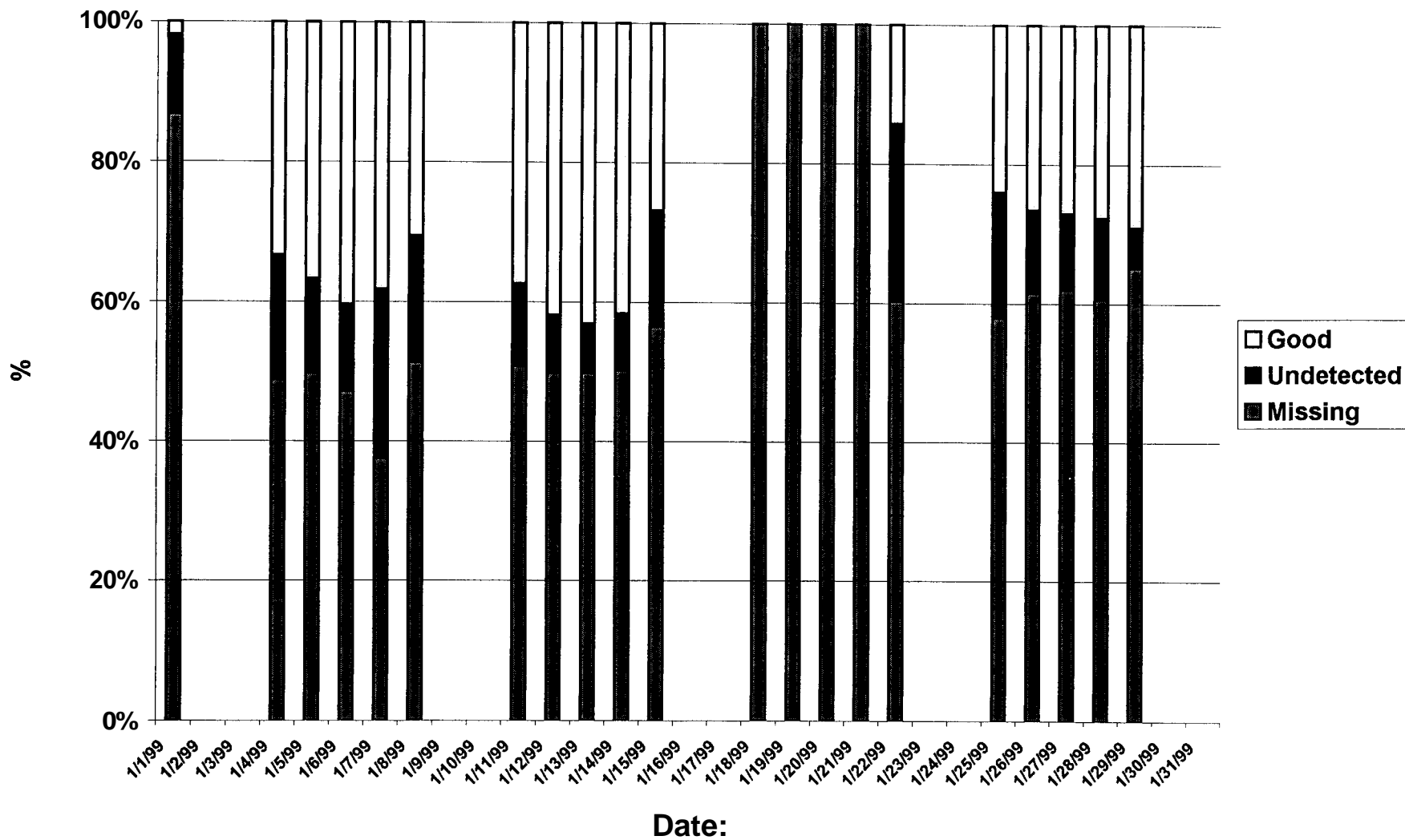


Figure 8. April-99 Analysis

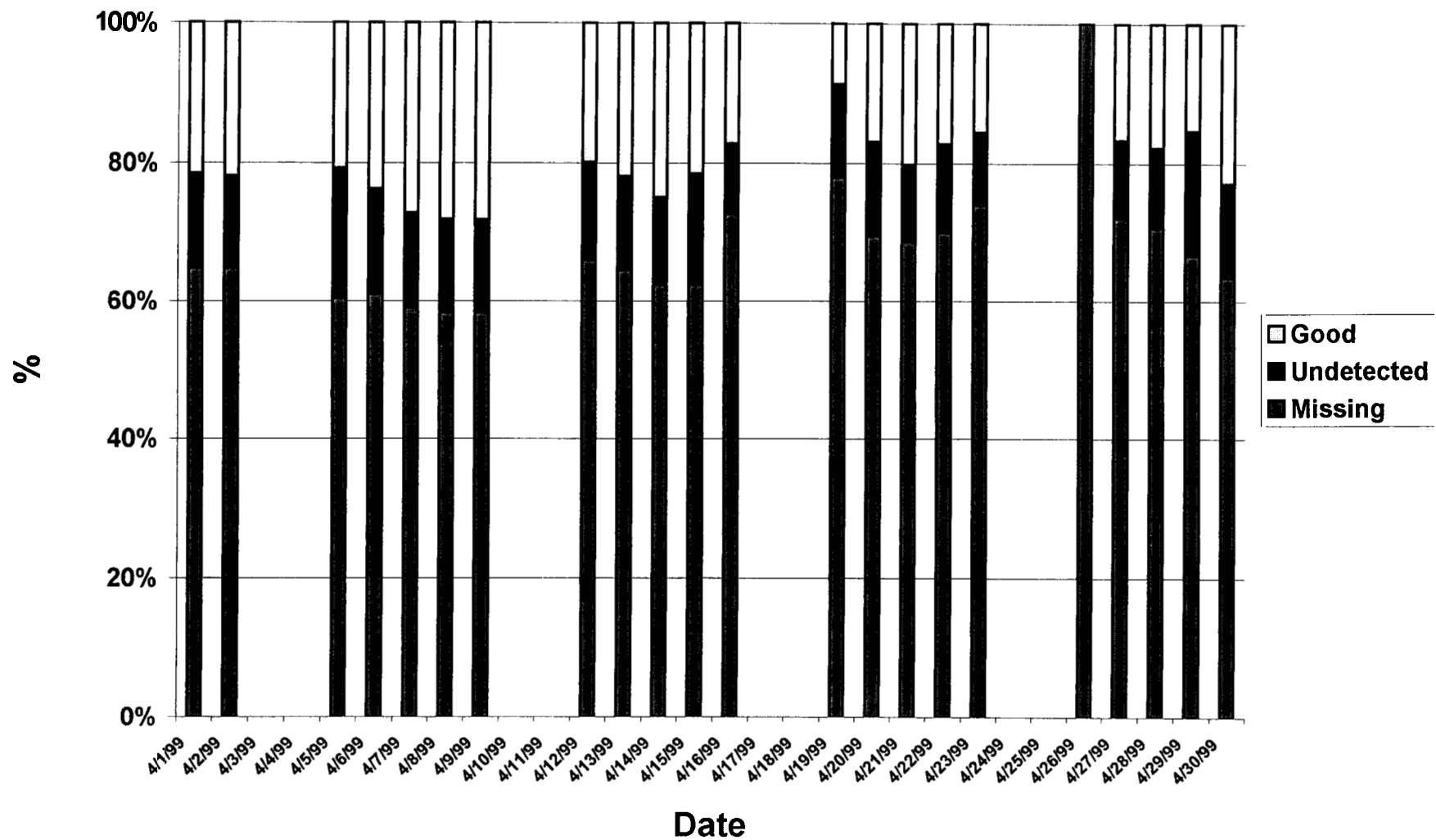


Table 2.
Comparison of Bus Arrival/Departure Time Versus Data in Transit Probe
17th and Bristol, Line 47 and 49

#	Bus #	Line	Direction	Recorded Arrival	Recorded Departure	Time in system	Observed - System Time (sec)
1	5310	49	SB	12.37.46	12.38.27	12.38.33	0
3	5303	47	NB	12.52.07	12.52.46	12.52.55	9
10	5301	47	SB	2.03.18	2.04.16	2.04.23	7
11	5305	47	SB	2.27.27	2.30.47	2.30.52	5
13	5301	47	NB	2.49.20	2.49.41	2.49.47	6
15	5305	47	NB	3.09.23	3.10.13	3.10.20	7
17	5303	47	SB	3.29.07	3.29.36	3.31.04	28
18	5310	49	SB	3.37.30	3.37.47	3.37.51	4
22	5303	47	NB	4.09.15	4.09.38	4.09.44	6
26	5306	49	NB	4.41.01	4.43.35	4.43.39	4
28	5301	47	SB	5.09.02	5.09.35	5.09.38	3
29	5305	47	SB	5.27.28	5.29.10	5.29.12	2
32	5305	47	NB	6.16.02	6.17.16	6.17.20	4
33	5303	47	SB	6.33.43	6.33.50	6.33.53	3
34	5310	49	SB	6.35.34	6.37.04	6.37.07	3
35	5304	47	SB	12.28.03	12.28.55	12.29.02	7
35	5306	49A	SB	1.06.43	1.07.08	4.06.52	-16
35	5304	47	NB	1.14.10	1.19.08	1.19.14	6
35	5309	49	SB	1.36.36	1.37.09	1.36.35	-1
35	5306	49	NB	1.41.23	1.41.58	1.42.07	9
35	5309	49A	NB	2.09.18	2.10.33	2.09.18	0
35	5303	47	SB	3.31.28	3.34.28	3.34.34	6
35	5304	47	SB	3.49.22	3.49.26	3.49.33	7
35	5306	49	SB	4.08.50	4.08.48	4.07.47	-3
35	5303	47	NB	4.11.20	4.11.48	4.11.50	2
35	5304	47	NB	4.29.19	4.29.34	4.29.46	12
35	5306	49	NB	4.39.23	4.41.11	4.41.16	5
35	5309	49	NB	5.09.35	5.12.33	5.09.29	-6
35	5303	47	SB	6.33.24	6.33.33	6.33.30	3

* Based on door open time rather than departure time

Figure 9. Data Analysis: Congestion Report

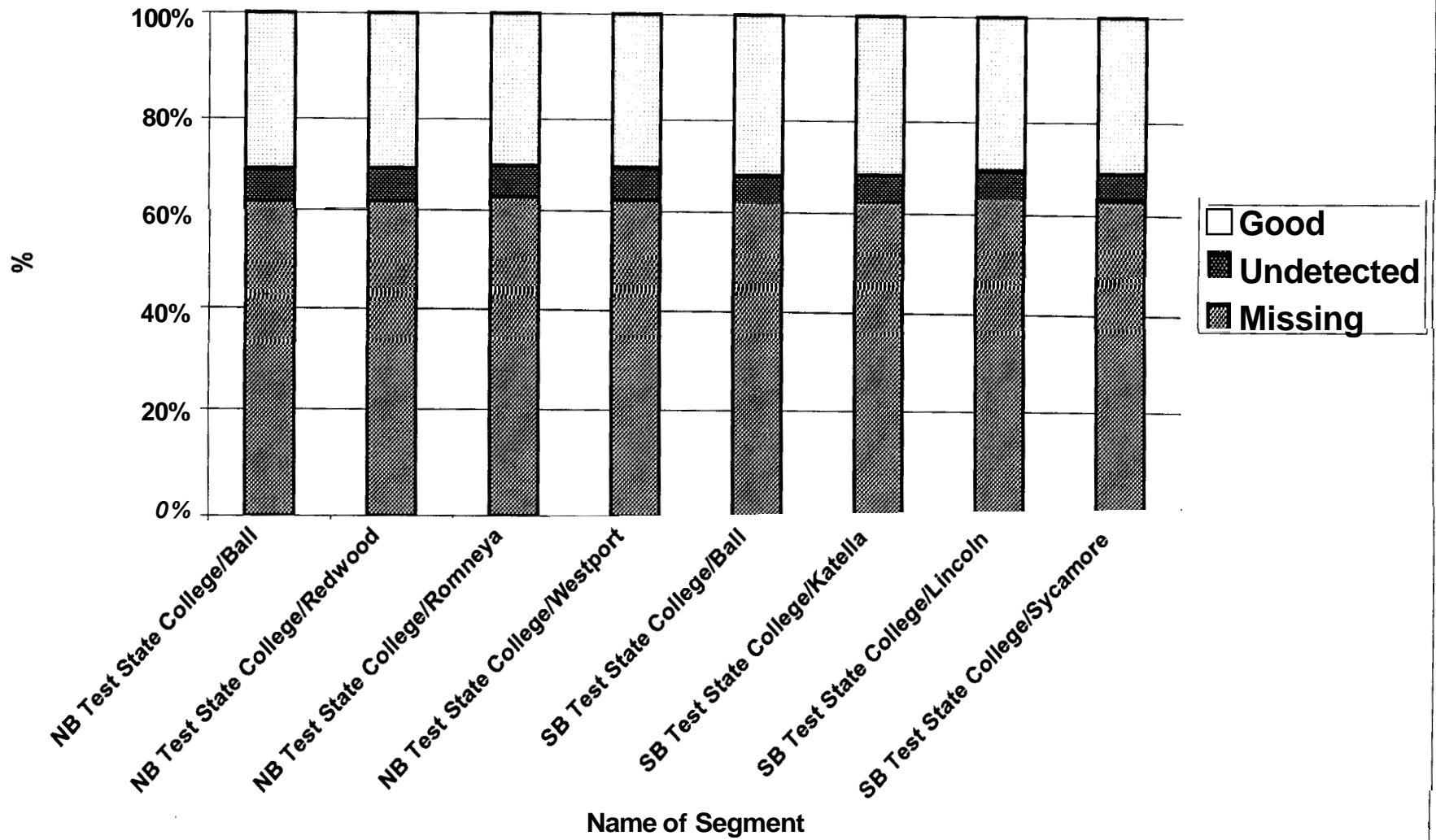


Figure 10. Percentage of Errors by Type

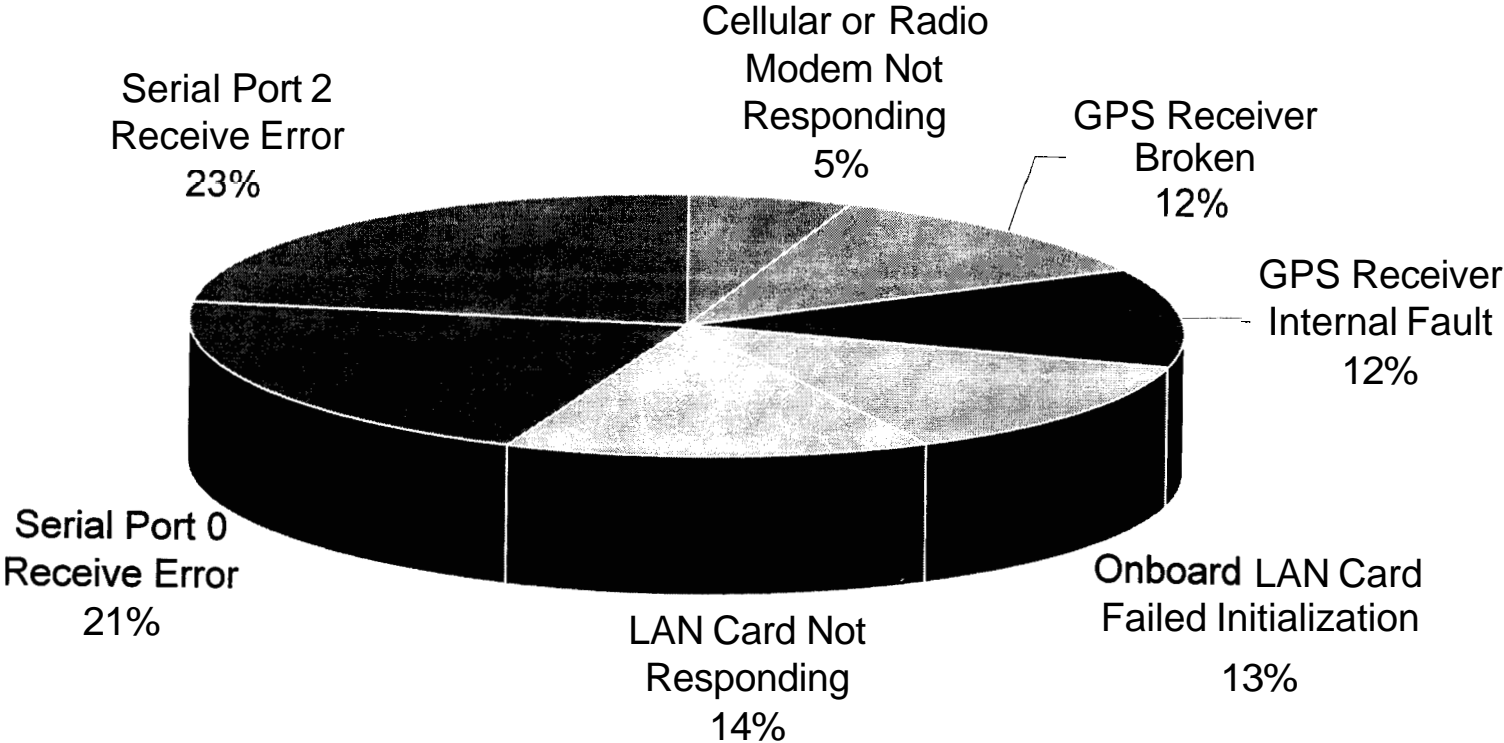
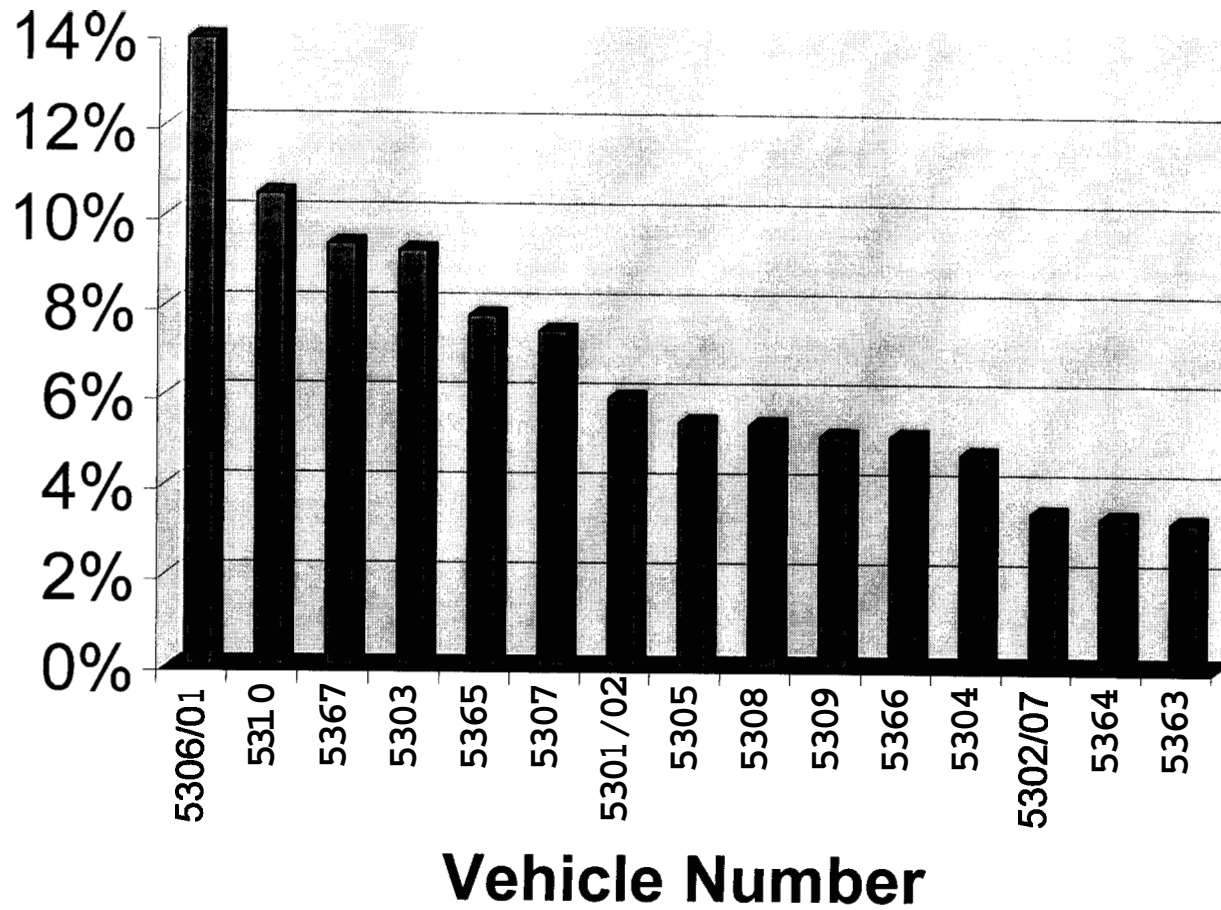


Figure 11. % of Errors by Vehicle Unit



roughly four times as many as the computer with the fewest errors. Lastly, Figures 12-15 plot cumulative errors for four separate months. Errors occur at a rate of about 600 per month (roughly two per weekday per computer), with little change in rate within months and between months.

Because some failures generate multiple records, it is impossible to tell exactly how many distinct failures occurred. The diagnostic report also does not identify the root cause for failures. Some of the errors could have been external to the bus (e.g., LAN transceiver), which would not be mentioned in the diagnostic report. During the course of the project, some units were returned to the manufacturer for repair. In addition, bus vibrations caused some cables to be disconnected. Cables were easily reconnected by OCTA maintenance staff.

Potential Causes of Inaccurate Schedule Adherence Data

Though we did not find significant errors in our field measured data, there are indications of occasional problems, at least as perceived by the drivers. There are three potential causes of inaccurate schedule adherence readings: (1) inaccurate entry of latitude/longitude for schedule check points, (2) inaccurate GPS readings, and (3) inaccurate schedule entry. In addition, some loss of precision can occur due to polling frequency, because the vehicle does not immediately determine when it has left the vicinity of the stop.

Check Point Locations Route points were entered into 3M Info through a geo-coding process without field data collection. If, for some reason, a check point is incorrectly entered, then there is potential for generating incorrect values for bus lateness and earliness.

The evaluation team verified the entered data through use of GPS based data collection. An automobile, mounted with a GPS receiver, was parked at each check point bus stop to determine a latitude and longitude. In a few instances, where it was impossible to park at a stop, data were collected at another location, usually within 100 feet of the stop. GPS readings were averaged over 3 to 5 minutes, with a 5 second polling interval. These data were then loaded into ArcView GIS, and compared against latitudes and longitudes from 3MInfo. We found an average deviation of approximately 400 feet based on this method. The largest deviation was on the order of 600 feet. These deviations are consistent with the errors that might be introduced when a stop is geo-coded from a street intersection rather than from the actual stop location relative to the intersection. Deviations do not appear to be large enough to create substantial errors in time measurement.

GPS Data Accuracy Appendix A provides trajectory plots obtained from 3MInfo and, for comparison, from automobiles. Each point represents a single GPS record. More points are shown for automobile than bus because the polling frequency was higher. Streets are also shown, extracted from the Tiger map database. It should be noted that Tiger maps do not show all links in the network. For instance, on-ramps and off-ramps are not shown, and the maps do not separately plot opposite directions of freeways. Roadway curvature is also approximate. Finally, recent roadway improvements (such as construction on the 1-5) may not appear in the database. With these caveats, the following observations can be made:

- Some of the bus data exhibit a slight shift in longitude relative to the Tiger map. A longitudinal shift is not seen in the automobile data.

Figure 12. Diagnostic Errors, Aug 98

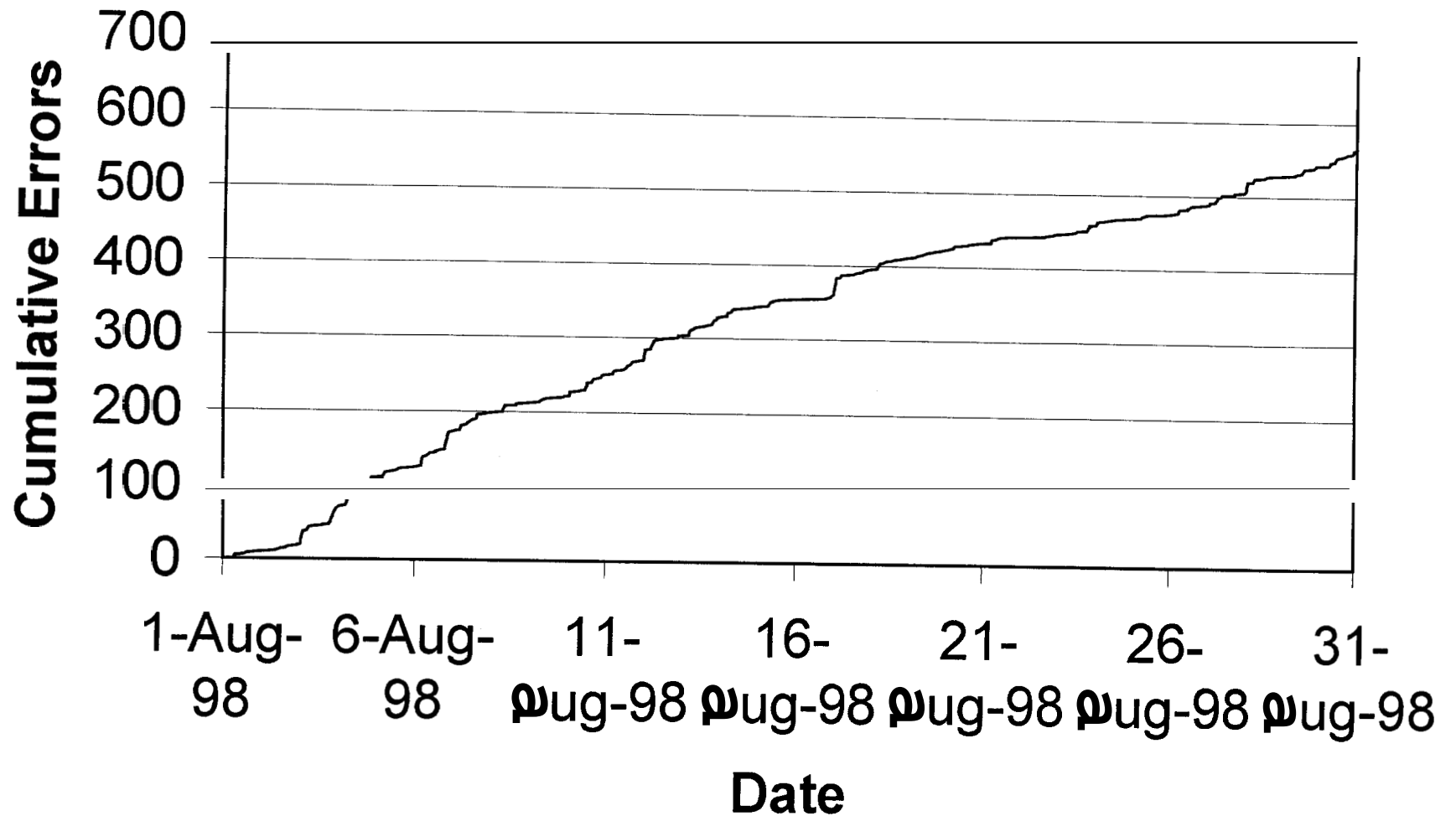


Figure 13. Diagnostic Errors, Nov 98

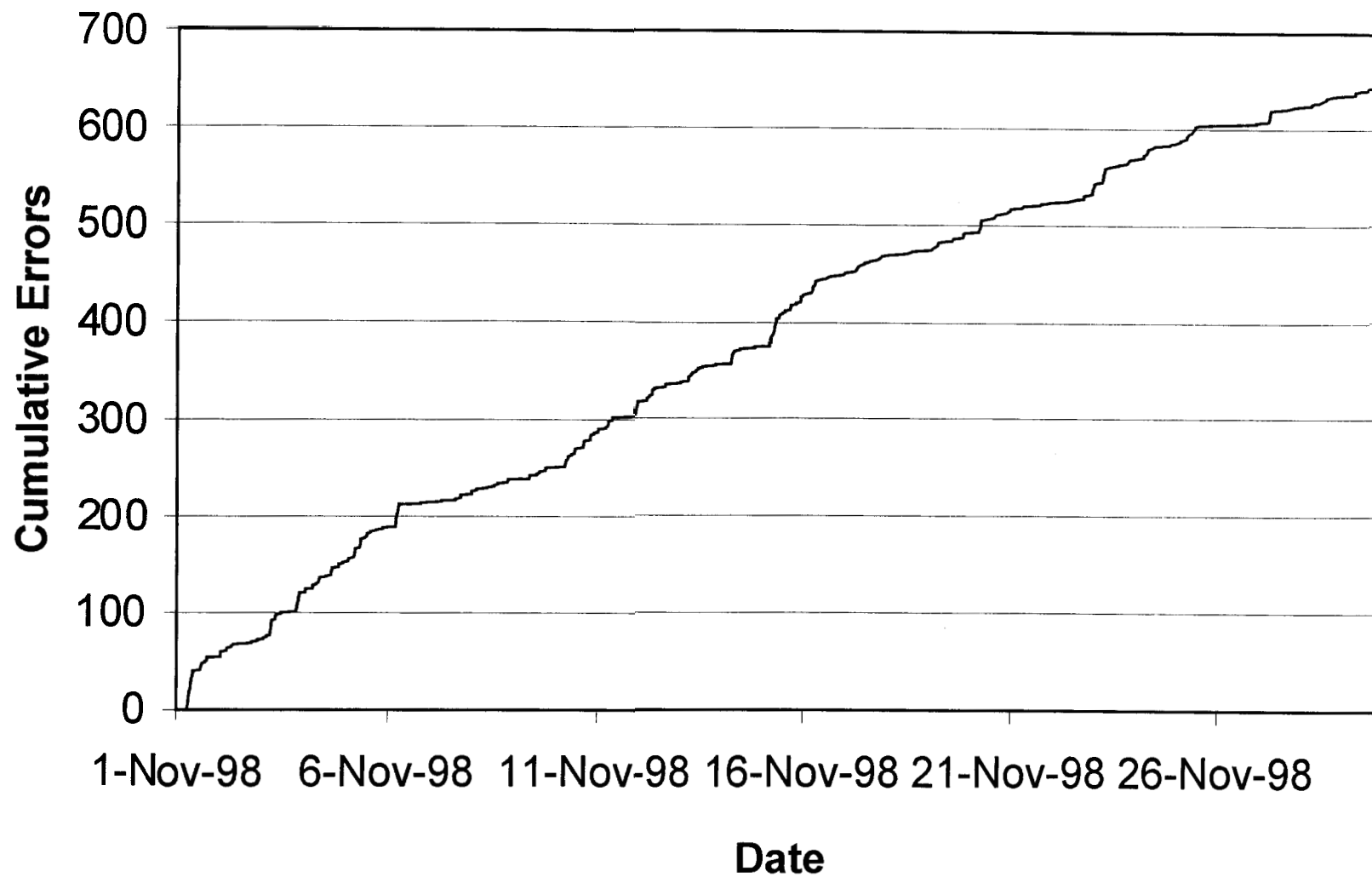


Figure 14. Diagnostic Errors, Feb 99

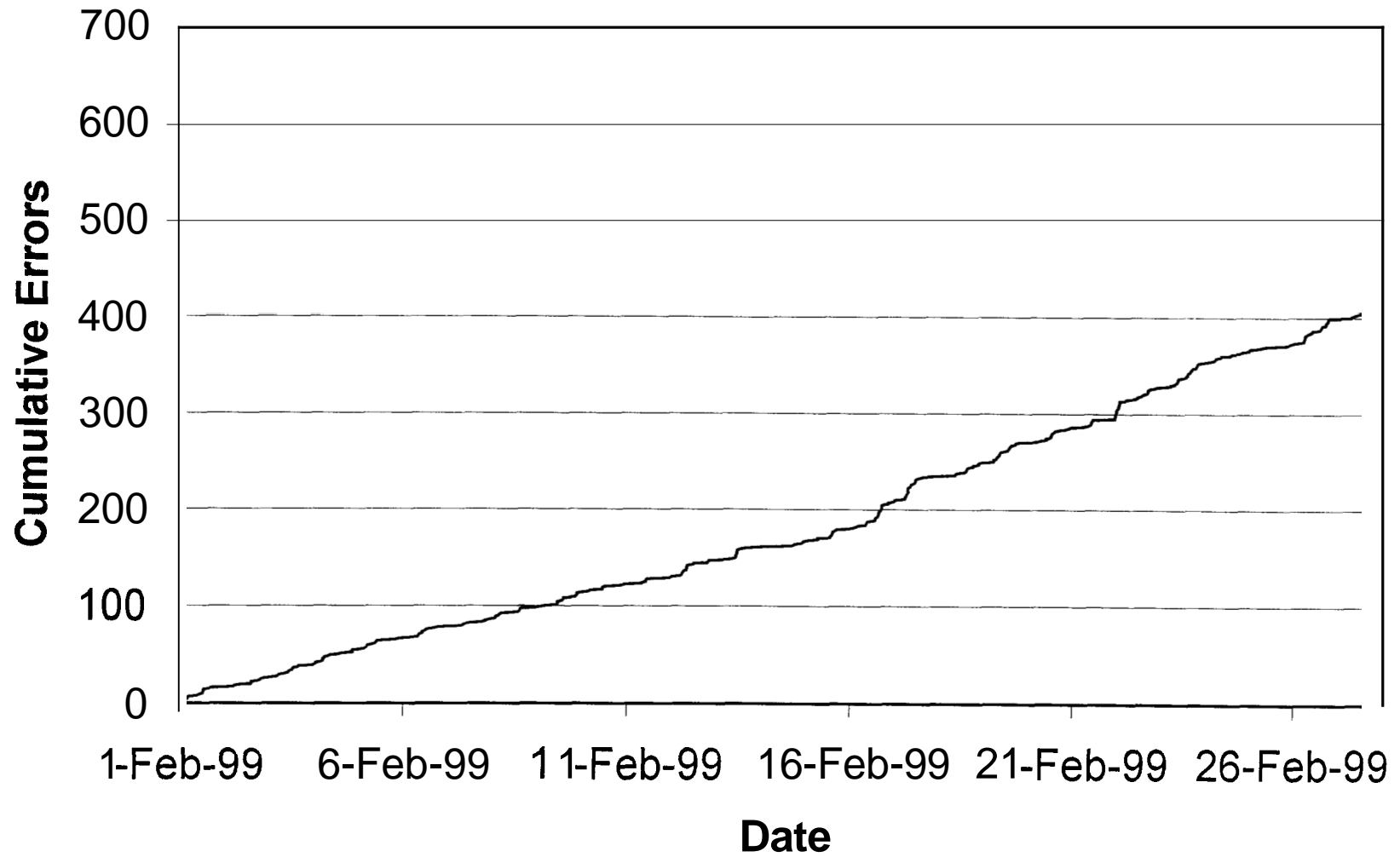
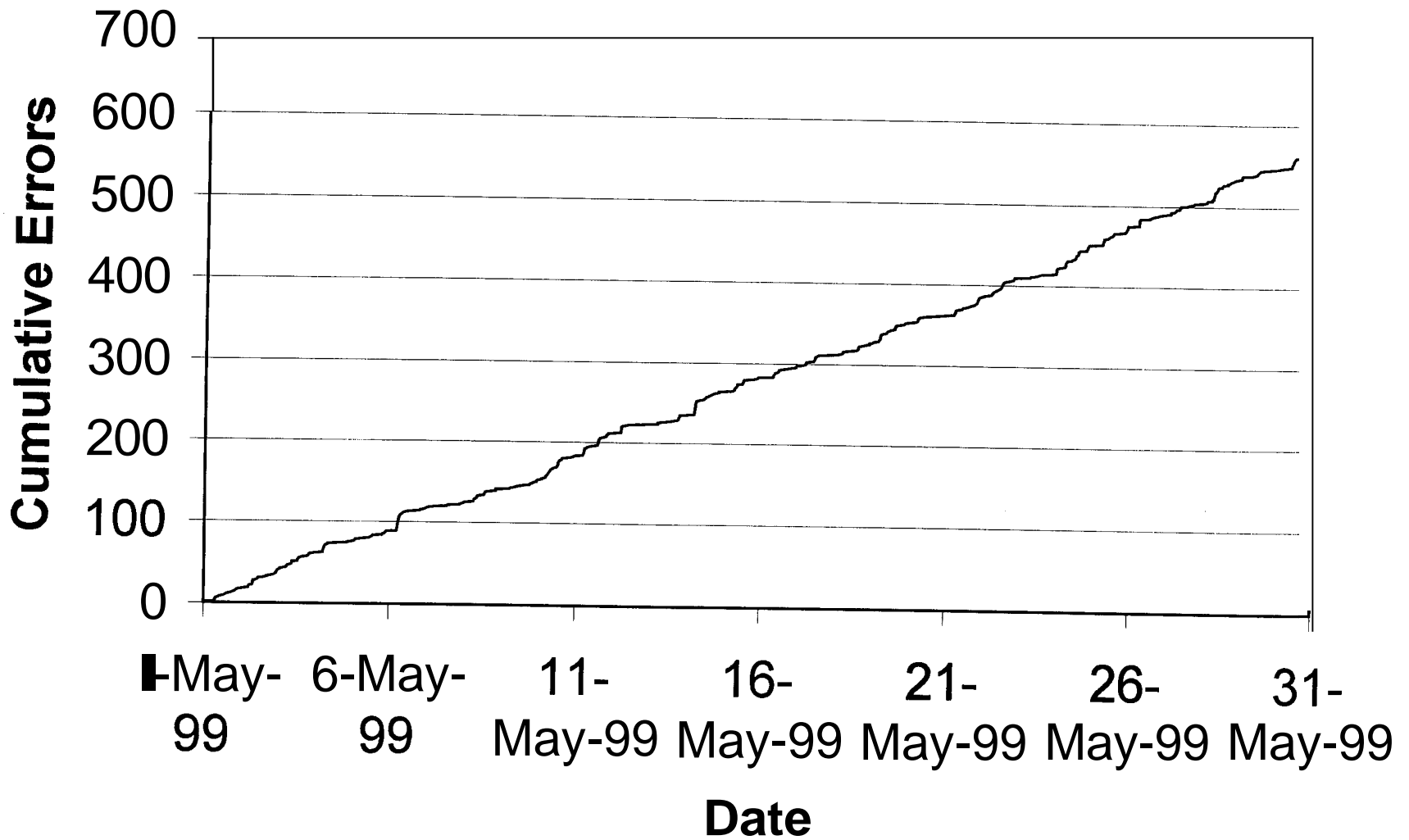


Figure 15. Diagnostic Errors, May 99



- 3MInfo produces occasional outlier points, located far away from their actual route. Outliers also occur in the automobile data, though with less dispersion than the bus data.
- Despite the presence of differential correction, the bus data does not appear to show significantly higher precision than the automobile data, for which differential correction was not used.

Overall, though 3MInfo does seem to be reasonably accurate in most instances, outlier readings are likely to have caused some errors in measurement of schedule adherence.

Schedule Entry

We have not verified the entered schedule data for this study.

4. EVALUATION OF CONGESTION ANALYSIS FEATURE

The unique feature of the Transit Probe System was its capability to estimate congestion along roadway segments. This is accomplished with a relatively simple algorithm, combined with specialized screens to facilitate user interface. Otherwise, the congestion analysis feature relies on the usual data collected by the on-board GPS unit.

Congestion analysis data were evaluated through comparison to a series of floating car measurements. The analysis entailed a comparison of automobile trajectories to bus trajectories, and a comparison of automobile trajectories to transit congestion estimates. Most of the data were collected in the spring of 1999.

4.1 Data Collection Method

Automobile data were collected by the floating car method, traveling at the rate of traffic in the middle lane. The method entailed tracking a specific bus as it traveled its route from start to finish. However, because floating cars naturally travel faster than public transit buses, a modified approach was required. Through initial data collection, we determined that a 75 minute bus route on lines 47 and 49 could be covered by a floating car in about 45 minutes. The floating car was instructed to leave the start of the route 15 minutes after the bus. With this method, the car passed the bus somewhere around the middle of its route, and arrived at the end of the route 15 minutes before the bus. Hence, the difference between when the car and the bus passed any point in the route was usually no more than 15 minutes. Each day of data collection covered 4 to 6 (one-way) bus runs. For the 205 line, which operates by freeway, the car departed just 5 minutes after the bus, as travel time differences were smaller. Most data were recorded between noon and 6:00 p.m.; all data were recorded on weekdays.

The car was equipped with a Trimble Placer GPS 400 receiver that was configured to sample automobile location and speed at 5 second intervals. These were recorded on a laptop computer for later analysis. To maximize the probability of collecting good bus data, we logged into 3M **Info** prior to each data collection wave to view the status of each bus. We limited our collection to buses showing an active real-time status. Later on in the experiment we also restricted data collection to buses that had downloaded historical data on the prior day. Despite these precautions, some of our data collection efforts were wasted due to missing bus data. Prior to going to the field for data collection, position logging was enabled, so that bus locations would be tracked at 30 second intervals.

4.2 Data Analysis

Tracking data were first converted to trajectory plots showing vehicle location versus time. This was accomplished by first creating a reference data set for each bus line. The reference data set contained the latitude/longitude positions for a series of points along the line (spaced roughly 5 seconds apart), along with the distance from the points to the starting position of the line. Each tracking data set was then matched to the reference data set to estimate the vehicle's position along the line versus time. Then, for each `run`, the bus trajectory was plotted against the automobile trajectory. In total, we were able to obtain six successful trajectory plots for the 47 line, six plots

for the 49 line and 13 plots for the 205 line. Many more runs than this were completed by automobile. Unfortunately, much of the data had to be discarded, because bus comparison data were not available. Appendix A provides all 25 trajectory plots.

4.3 Trajectory Analysis Results

The trajectory analysis was used to compare bus travel times to automobile travel times over segments, to determine whether one could be used to predict the other. Because freeway and city street bus segments behave quite differently, they are analyzed separately.

City Street Segments The entire 47 and 49 lines, and portions of the 205 line, operate on city streets. As indicated by slopes on trajectory plots, cars and buses travel at different speeds on city streets, and experience different delays. The general trajectory pattern includes segments when the vehicle is stopped or moving slowly and segments when the vehicle is moving at the regular speed of traffic. Delays are dictated by the former, which typically precede intersections.

In total, there are huge differences between bus and car speeds and delays. However, correlations clearly exist during major incidents. We classify major incidents as those in which cars travel at greatly reduced speed (less than 4 mph) over a duration of 4 minutes or greater. These are documented below:

<u>Line</u>	<u>Plot</u>	<u>Mile</u>		<u>Delay Period Length (seconds)</u>	
		<u>Location</u>	<u>Time</u>	<u>Car</u>	<u>Bus</u>
47	1	2.4	66500	250	250
49	4	2.5	63000	650	500
49	5	1.7	62000	300	400
49	3	3.0	62300	300	250
205	2	3.5	59500	350	350
205	3	24.5	56000	250	250
205	14	.7	46300	250	300

In all of the major car incidents, major delays were also experienced by the bus. This is logical, as car delays typically occur when an intersection is over-saturated, and when this occurs cars and buses experience similar travel times. Therefore, our data indicate that car probes could be useful for predicting delays on transit lines.

Unfortunately, it is more difficult to use bus probe data to predict major car delay incidents than the reverse. The following major bus incidents did not result in major car incidents

Line	Plot	Location	Time	Car	Bus
47	1	1.5	65700	0	250
47	2	3.0	60200	0	400
47	4	3.5	49500	0	500
47	5	3.5	44700	0	400
47	7	1.7	47500	0	500
47	8	10.8	62800	0	350
49	1	10.2	59000	0	300
205	2	4.5	59500	60	300
205	6	4.8	59000	0	300
205	11	4.8	59000	0	300
205	11	5.7	59500	0	300

In this second set of incidents buses remain stationary for extended periods at schedule check points. In many cases, these incidents appear to be preceded by periods in which buses travel at faster than normal speeds. Once the schedule check point is reached, the bus remains there until schedule departure time, and then leaves. To be effective at identifying major incidents, probes clearly need to distinguish these stationary points from actual traffic delays. Alternatives follow:

- The most exact mechanism would be manual entry by the driver when a check point is reached and departed. However, this is potentially unreliable, as the driver may forget to make correct entries.
- An alternative is to disregard delays around check points. Unfortunately, many of these points coincide with major intersections, where delays are most likely to occur. Therefore, the most valuable data could be lost.
- A third method might be to identify check point delays from tracking door open and close times. This too has reliability problems, as buses frequently leave their door close when waiting at a check point.
- A fourth method would be to disregard major delays when the vehicle speed is 0 for extended periods. In most major incidents, vehicles move in a stop and start pattern, remaining stopped for no more than about 2 minutes (the length of a signal cycle). However, very large incidents could result in longer stopped periods. These could be overlooked in this method.

Clearly, buses are imperfect as traffic probes. The information is less valuable for cars than car information is for buses.

In actual operation, bus probe data suffered additional drawbacks, due to: (1) relatively large bus headways, (2) lack of complete coverage, and (3) reliability problems. Though our experiments ensured that buses and cars were in close vicinity to each other, in actual operation an hour or more could easily elapse between the arrival of buses with operable probe equipment.

Freeway Segments Only the 205 line operates on freeways. The freeway segments are easily distinguished by the steep slope of the trajectory plot. Cars had a somewhat steeper acceleration profile than buses, but once they were on the freeway speeds were identical or very similar. Only one notable incident occurred in the sample, in plot 7. The automobile traveled in congested traffic for approximately seven minutes, whereas the bus traveled in congested traffic for approximately

three minutes. This can be attributed to queue build-up behind an accident. The accident occurred immediately before the bus. Because the car was trailing the bus, it experienced more delay.

Because there was only one incident, it is impossible to draw firm conclusions as to the usefulness of buses as probes. However, it can be said that buses and cars travel at similar speeds in highway traffic, and that when a bus is delayed, a car is also likely to be delayed. Therefore, tracking bus speeds and travel times could provide a useful measure for predicting automobile delays.

4.4 Congestion Analysis Results

We compared recorded automobile speeds against bus speed estimated by the Transit Probe system. Again, we were frustrated by missing or undetected probe data. In addition, because only a limited number of congestion segments had been defined, little data were available for comparison. Results follow:

<u>Segment</u>	<u>Probe Speed Estimate</u>	<u>Recorded Speed</u>
47 Test Segment 1	18.5 mph	9.3 mph
205 Segment 8	13.0 mph	12.5 mph
47 Segment 1	22.3 mph	13.1 mph
47 Segment 1	16.2 mph	12.9 mph
205 Segment 8	21.1 mph	9.8 mph
205 Segment 8	15.8 mph	13.3 mph

In all cases, the recorded automobile speed was less than the bus probe estimate. However, given the small sample size, general conclusions cannot be drawn regarding the applicability of the probe algorithm. This is especially true because small changes in arrival time to a segment can significantly alter average speed. This is due to natural cyclic variations in traffic signals. Given that segments are short (on the order of 5 minutes), a single red light could explain a large difference in speeds, even with no change in congestion.

5. INSTITUTIONAL EVALUATION

The institutional evaluation was designed to document the project history, and to identify ways in which overall project organization helped, or hindered, project success. A first wave of the institutional evaluation was completed in **1996-97**, and was documented in a working paper (Hall, **1997**). This initial wave was based on interviews with key project members, observations at project meetings, and review of project documents. A second wave of interviews was completed in May and June of **1999**. These interviews, along with further observations and document review, are the basis for this evaluation.

5.1 Summary of Initial Wave

An initial wave of interviews was completed between August and November of **1996**, roughly the time when the initial design work was completed by Rockwell, and before a System Integrator was selected. Participants had all been active in the project, and included OCTA personnel, and points of contact at Caltrans and the Cities of Anaheim and Santa Ana. These representatives had all been invited to participate in design review meetings and to provide input to the design review process.

The report concluded that project participants were generally satisfied with project organization and management. **OCTA** was commended for its efficiency and its efforts towards consensus building. They were also praised for keeping partners informed of progress. Some participants, however, felt that Rockwell had been too schedule driven, and had not put enough effort into soliciting the specific needs of each partner. Nevertheless, the report noted that OCTA and Rockwell had taken great strides to distribute all documents in draft form for review. There ~~was~~ some frustration that participants did not take up the invitation to provide input, and instead waited until many of the decisions had been locked in before raising concerns.

The critical issues facing the project were identified **as**:

- Formatting data to be useful for partners
- System integration, information exchange and interface standards
- Validity of methods for congestion management and schedule tracking
- Participation of system operators in project meetings (i.e., participation from the people who will directly interact with the system)
- Adequacy of budgets, staffing and training

The budget, staffing and training issue was cited for both OCTA and partner agencies.

Participants were also asked to state project objectives, for which they agreed on the following:

- Develop a new means for analyzing roadway congestion, especially on arterials
- Develop new means for managing transit fleets
- Improve information for transit users
- Develop cooperative multi-modal relationships between transit and traffic agencies

Multi-modal cooperation was the most prominent objective in interviews. Other objectives were viewed as means toward this end. In fact, all of the participating traffic agencies were skeptical about using buses as traffic probes (falling under the first objective). Agencies were more optimistic about generating useful information for transit users, which was a shared objective among all participants.

The report concluded by stating:

“The major question marks for the project center on whether the tracking data can be effectively integrated into existing traffic and transit systems, and whether deployment efforts can be funded. While largely a technical issue, the success will depend in part on whether contracts are written with sufficient precision to ensure that the system fulfills project objectives, and that the design effort is well integrated with system deployment.”

5.2 Later Institutional Issues

The second interview wave was executed in May and June of 1999, immediately prior to completion of the entire evaluation project. Based on these interviews, and our own observations, the institutional character of the project changed markedly after the system integrator was selected. Though external partners were still involved, the project relied less on general meetings, and more on the OCTA project manager to get the system started and to ensure that the system integrator met contractual commitments. The project assumed a rather traditional relationship of contractor/contract manager, between one agency and one company.

During this phase, it became clear that some of the initial institutional issues would not be immediately resolved. First, delays in execution of the TravelTip project eliminated the critical interface between OCTA and the partner agencies. Without this interface, TransitProbe could not disseminate congestion data, making it impossible to execute the first project objective, and also diminishing the significance of the fourth project objective. And without an interface, the issue of formatting data in a way that is useful became moot. The validity of congestion analysis methods also became moot from the perspective of partners, though it did remain an important issue within the context of the evaluation. Other institutional issues are summarized below.

Participation Attention was diverted from the Transit Probe because of simultaneous work on TravelTip. Project meetings among partner agencies continued on a monthly basis, and were even expanded to include additional cities, but the focus was almost entirely on TravelTip. And as TravelTip evolved, the design switched to roadway sensors (both arterial and highway) as the sole source of speed data, and bus probes were eliminated as a source of traffic data. Therefore, while inter-agency cooperation continued, it continued under the auspices of another project.

Involvement of Partner Agencies The City of Anaheim, City of Santa Ana and Caltrans District 12 all participated in the project, especially in the early phases of the project. Their participation included design review and proposal selection. Their involvement diminished considerably after the System Integrator was selected. In part, this was a reaction to the general down-scoping of the project. Once the fleet was reduced to 15 buses, on just three lines, it became clear that the system lacked a “critical mass” for providing valuable data, either to the individual TMCs, or the general

public. It was also apparent that funding was not available to integrate probe data into existing Transportation Management Center Workstations. Lastly, the TravelTip project was selected as an alternative interface. Because TravelTip itself has not been deployed, it was clear that Transit Probe would not be providing data to the partners. Though it would have been possible to remotely install 3MInfo software at any of the TMCs, the partners did not view the data to be sufficiently important to expend additional funds.

The original Transit Probe partners continued to meet through the project under the auspices of TravelTip. However, Transit Probe was discussed only rarely. Instead, Transit Probe entered a project delivery mode, relying on the project manager to oversee satisfaction of contractual requirements. In this sense, the multi-agency institutional structure ceased to exist after contract award, giving Transit Probe a conventional contractor/contractee structure.

Competing Priorities Simultaneous to installation of Transit Probe, OCTA entered into a competitive procurement for a complete upgrade of its radio communication system (ITCS), including installation of tracking equipment, drivers displays and communication hardware throughout the fleet. When OCTA selected a different contractor than 3M for this work (Orbital), it was clear that 3MInfo would only be a temporary system, to be replaced within 2 years of installation. At this point, maintaining and operating 3MInfo became a much lower priority. It was hard to convince OCTA personnel to invest large amounts of effort to keep a system running for just 2 years, when that system would soon be obsolete. Transit Probe was also lower in priority because it was viewed as a demonstration project rather than a deployment.

Integration across Systems and Organizations Integration across systems proved to be a huge problem, making it extremely difficult to maintain the data to keep 3MInfo accurate. The contractor was unable to develop a direct interface with Trapeze software, forcing all schedule entry to be manual. Furthermore, with periodic schedule changes and many detours (due to highway construction in the vicinity of the lines), OCTA did not have the internal resources to keep the data current. They were forced to rely on negotiating a maintenance agreement with the System Integrator, adding cost and causing some delays in entering data at schedule changes. On the positive side, the system was successfully integrated with OCTA's radio communication system, and an interface was created between the 3M Info system and public information kiosks. An external interface to TravelTip remains under development.

Another problem was keeping bus assignments current. Probe hardware was occasionally swapped between buses or taken out of service. Buses were also periodically taken out of service for regular maintenance. Unfortunately, procedures were never created to make these daily updates, potentially causing inaccuracies and lost data.

Lastly, it was apparent that no one in OCTA used the schedule adherence data from 3M Info in scheduling and route planning. In part, this might be due to not placing a work station in appropriate departments. More importantly, though, the project was perceived to be too small in scope to provide much useful information.

The initial design steps would have been more effective had the effort concentrated more on designing these external interfaces. Instead, the focus was more on internal operation. In the end,

this was less important, because of the existence of off-the-shelf hardware and software for performing many of the system internal functions.

Staffing, Training and Participation Closely coupled with system integration were staffing, training and participation. Dispatchers at the communications center were trained on the system several weeks before installation. It took more than a month after this time to make the system fully operational, creating too big a lag from training to actual use. In the end, dispatchers made little use of the system. Likewise, during the course of the project, on-time performance data was not used within OCTA's planning function or in schedule creation. The lack of interest by both parties can be attributed to a variety of reasons, including system performance problems, limited coverage, and plans to replace the Transit Probe system with another tracking system in the future. In the end, the evaluation team was the primary user of Transit Probe data, and no procedures were established to utilize the data in actual operation and planning.

Internal staffing was not available for data entry, so OCTA had to rely on the system integrator and temporary employees. At one schedule change, this created an extended period when the system was not operational due to the absence of schedule data and bus assignments. Staffing also was not available to enter data on bus detours as they occurred. Bus drivers also needed training (they did not know the circumstances under which they should use the system).

Procedures were needed for utilizing the data in actual operation. To make the system effective, procedures need to be established for: (1) entering schedule data at schedule changes, (2) entering detour data, (3) entering bus assignments, (4) operational responses when buses are shown to be late or early, (5) operational responses when the operator sets a silent alarm, and (6) analysis of historical data to improve schedule adherence.

Lastly, implementing a system like Transit Probe requires a coordinated effort across many departments in the organization. Each department needs to assume responsibility for its own element, instead of relying on a single project manager to do everything.

Budgeting The funding available for Transit Probe was insufficient for adequate deployment. Funding limits were aggravated by special project features, such as congestion measurement, requiring custom development. As a consequence, only 15 buses were equipped, and these had reduced functionality on the on-board unit (eliminating driver communication), and lack of a direct interface to traffic agencies. In addition, little money was available for a customer interface.

Contractual Performance Though not emphasized in interviews, contractual performance issues, as cited in the initial Institutional Report conclusions, were very prominent in the latter phase of the project. The focus here was largely on satisfying system reliability standards in the face of problems. It could also be said that because the actual tracking system centered on an off-the-shelf project, much of the initial Rockwell could have been redirected. It may well have been possible to go through a single acquisition step, rather than attempting a major design. This appears to be the approach adopted by OCTA under ITCS.

5.3 Institutional Conclusions

Although OCTA did a commendable job of involving outside agencies in the design of Transit Probe, the project suffered because it did not have the financial means to create a fully deployed system. A fleet size of 15 clearly was not sufficient to attain a critical mass for producing useful data. Because of the project's small size, it is not fully representative of how an actual system would be deployed. Furthermore, because interfaces were not created to external systems, there was no mechanism of presenting the information to potential users. As a consequence, efforts at involving outside agencies went for naught.

The project points to the need of establishing clear and achievable objectives, and complete system-level design prior to committing to system installation. System-level design should not be limited to the bus tracking system, but instead focus on the critical external interfaces, and the procedures for utilizing data in regular operation and planning. Design should begin from benchmarking off-the-shelf hardware and software products, and proceed to establish the mechanism for integrating these products into the bus operations. Less effort should be directed at specifying the system itself.

6. CUSTOMER SURVEY

Surveys were administered in spring of 1999 to identify customer perceptions of service on buses equipped with transit probe equipment, and customer perceptions of the **kiosk** placed at the Santa Ana Transit Terminal. This section provides the survey design, analysis methods and results.

6.1 Survey Design

Two surveys were conducted **as** a part **of** the project: one directed at riders on buses that have tracking equipment, and the other directed at kiosk users. For the rider survey, lines **47** and **49** were selected, because at the time it was unclear whether tracking equipment on line 205 would continue to be operable. Both surveys were administered in the week of March 29 to April 2, 1999 by the firm of Nelson/Nygaard. A team of seven surveyors (four females, three males), and one supervisor did the work.

Rider Survey

The rider questionnaire was distributed on-board buses in paper form. As passengers boarded the bus and sat down, the surveyor asked each teenager or adult if they would be willing to fill out a brief survey about their bus trip. An incentive of a free ride coupon was offered to everyone who completed a survey. A bilingual form was used, with English on one side and Spanish on the other. These are the most common languages in the areas served by lines **47** and **49**. 1700 questionnaires were distributed, of which 1199 were returned (**70%** response rate). The questionnaire was designed to be completed in about five minutes, making it feasible for most riders to finish the survey during the course of their ride.

The focus of the questionnaire (Appendix **A**) was on the perceived on-time performance of the buses, and included questions concerning:

- Waiting time at bus stop for specific trip
- Whether bus was early, late or on-time
- Usual on-time performance
- On-time performance compared to a year ago

Additional data were collected on the particular trip, including:

- Source of bus route information
- Place where bus was boarded, and where bus will be exited from
- Access mode to stop
- Whether a bus transfer is needed at trip end (and which line)
- Type of trip destination

Questions were also added to measure factors that directly influence waiting time, including:

- Whether person knew bus schedule before arriving at bus stop
- Whether person needs to arrive at destination by a set time

- Whether person considered walking all the way to the destination

The last factor is important in assessing whether the person only rode the bus because it was present, and would have walked if it was not (thus reducing waiting time), or whether people consider alternatives when they have waited a long time.

Lastly, basic demographic questions were asked regarding:

- Age group
- Gender
- Primary language
- Number of times person has used bus route

Through control numbers recorded on the questionnaires, it was also possible to identify the bus run number, date, time and line.

Each question resulted in 50 to **130** invalid responses (missing or two or more responses when one was needed). Invalid responses were excluded from all calculations.

Kiosk Survey

The kiosk survey was administered at the Santa Ana Bus Terminal. Passersby were offered a **\$5** coupon (for fastfood restaurant chain) for participation in a short survey. Each participant was instructed to follow a set routine in which they would use the kiosk for three functions: looking up the departure time for a bus, viewing a bus route map, and determining how to get to an unfamiliar destination. Participants were given minimal instruction, relying on the self-explanatory powers of the kiosk. After completing the routine, the interviewer asked a set of questions, filling in a questionnaire for the participant. All interviewers were Spanish/English bilingual.

The questionnaire included a set of questions asking for comparisons between the kiosk and traditional methods for obtaining traveler information, including the OCTA telephone information line and the OCTA *Bus Book* (containing maps and schedules). As open-ended questions, participants were also asked what they liked about the kiosk and what they would like to have changed. They were also asked whether they would use specific kiosk features in the future, along with how often they will use the kiosk. Lastly, a set of background questions was asked, including past experience using OCTA and the Santa Ana Bus Terminal, along with age group, gender and primary language.

In addition to the questionnaire, surveyors recorded problems that participants encountered when using the kiosk (based on observations).

Prior Probe Survey

As part of its design efforts, Rockwell (1996) surveyed 115 people at major OCTA transit stops regarding their use of OCTA buses and preferences for traveler information. In the survey, riders were asked to rate the importance of various service improvements. “Knowing when the next bus

will arrive” was rated highest, followed by “knowing which bus to take” and “knowing when and where you need to transfer.” These were rated much higher than knowing alternative routes and avoiding crowded buses. They rated a live person on the telephone as a more convenient source of information than television (#2), radio (#3), computerized information screen (#4), telephone with recorded message (#5) and computer at home, work or school (last). And major transit centers, shopping centers and bus stops were cited **as** the most convenient places to obtain information. At the time the surveys were administered, no new information source had been created **as** part of the project. Therefore, the thrust of the on-board survey was more on schedule adherence than on quality of information.

6.2 Data Analysis Methods

For the on-board survey, responses were tabulated and cross-tabulated against several causal factors, including:

- Source of bus route information
- Whether person knew the bus schedule before the bus arrived
- Whether person needed to arrive by a specific time
- Number of times person has used the bus line

In addition, the following values were estimated from responses:

- Average waiting time
- Average earliness
- Difference between predicted arrival time at destination and time person needs to arrive at destination (probability distribution)

Lastly, several regression models were also created. First, based on **GPS** tracking data, correlations were determined between bus lateness as perceived by riders and measured bus lateness. Second, correlations were determined between perceived waiting time and bus lateness (both perceived and measured). Last, a multivariate regression model was created to model waiting time **as** a function of: (1) whether or not bus schedule was known before arrival at stop, (2) access mode to stop, (3) whether person considered walking all the way to destination, (4) whether person needs to arrive at destination by a certain time, (5) how many times bus route has been used, and (6) bus headway for specific trip.

$$W = k + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + a_7X_7 + a_8X_8$$

Where:

- W = reported waiting time for bus
- X₁ = 1 if bus scheduled known before arriving, 0 otherwise
- X₂ = 1 if transfer is access mode, 0 otherwise
- X₃ = 1 if walking is access mode, 0 otherwise
- X₄ = 1 if person considered walking to destination, 0 otherwise
- X₅ = 1 if person needs to arrive by a set time, 0 otherwise

X_6 = 1 if 1st time bus route has been used, 0 otherwise
 X_7 = 1 if 2nd to 10th time bus route has been used, 0 otherwise
 X_8 = 1 if bus headway is < 30 minutes, 0 otherwise
 $k, a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8$ are statistically estimated parameters

Waiting time categories (e.g., 6-10 minutes) were converted to single values in the middle of their range (e.g., 8 minutes) in the analysis.

Logit (discrete choice) models were also created to analyze propensity to **know** the schedule in advance and to select a particular information source, as a function of various trip characteristics, such as language, age, need to arrive by a specific time and need to transfer. Linear utility models were utilized.

For the kiosk survey, participants gave scaled responses on comparison questions. The following provides an example:

“How easy is it to find out when your bus departs compared to phoning the OCTA information line?”

1	2	3	4	5
Kiosk Easiest				Info Line Easiest

For each question, tabulations were produced, along with average ratings. We also calculated an overall total kiosk rating among five comparison questions, and developed a regression model where this total was modeled as a function of rider characteristics: (1) how long participant has used OCTA buses, (2) age, (3) gender, and (4) primary language. The model had the following form:

$$R = k + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4$$

Where:

R = average rating among five questions
 X_1 = 1 if OCTA has been used less than 1 year, 0 otherwise
 X_2 = 1 if 35 years or older, 0 otherwise
 X_3 = 1 if female, 0 otherwise
 X_4 = 1 if English speaking, 0 otherwise
 k, a_1, a_2, a_3, a_4 are statistically estimated parameters

6.3 Findings

We separately provide findings for the rider survey and kiosk survey, summarized from Nelson\Nygaard (1999b).

Rider Survey

Rider Characteristics Survey participants were predominantly Spanish speaking, with heavy concentration in the 18-34 year age group. The survey was fairly evenly balanced between male and female. Most participants had experience riding the bus lines on which they were surveyed: **66%** had ridden more than 10 times. These characteristics are similar to those in a recent on-board survey for all **OCTA** bus lines (Nelson/Nygaard, 1999a) below:

	Current Survey	General OCTA
Under 18	9	9
18 - 34	54	56
35 - 64	34	32
65+	3	3
Male	52	49
Female	48	51
English	36	NA
Spanish	63	NA
Other	1	NA
1st Time Ever	8	NA
2-10 Times	22	NA
> 10 Times	70	NA

Trip Characteristics Trips had a variety of destinations; travel to home and travel to work were most common. About 2/3 reached their bus stop on foot, and another 25% transferred from another bus. Another 42% stated they will transfer to another bus route after leaving their current bus. Similar results were found in the earlier general survey of OCTA riders. It is odd that more people would transfer from a bus than transferred to a bus. A possible explanation is that more people *intend* to transfer than actually do transfer (possibly because they decide it is simpler to walk the rest of the way; transfers to the bus are a revealed preference, whereas transfers from a bus are a stated preference). In fact, 12% considered walking the entire way to their destination instead of riding the bus. 57% of surveys were completed on the 47 line, and 43% were completed on the 49. 14% of trips had both origin and destination in the segment where lines 47 and 49 overlap, affording them a shorter headway than other riders.

	Current Survey	General OCTA
To work	35	35
To home	30	39
To Medical	9	3
To School	8	10
To Recreation/Social	6	3
To Shopping	6	4
Other	6	6
Walked	66	64
Transferred	26	29
Got a Ride	5	4

Other	3	3
Considered Walking Whole Way	12	NA
Will Transfer	42	38

Time of Travel Characteristics The most common source of traveler information was the OCTA *Bus Book*, followed by schedules (which are also contained in the *Bus Book*), and asking someone for directions. A relatively small percentage (5%) phoned OCTA for directions. Most (69%) knew the bus schedule before arriving at their stop. The median waiting time at the stop was about 5 minutes, though 6% waited **21-30** minutes and another **2%** waited more than 30 minutes for their bus. The average wait was about 8 minutes overall, 7 minutes for those who knew the schedule and 11 minutes for those who did not know the schedule. Participants reported that the bus was on time (defined as less than **2** minutes late for survey purposes) 58% of the time; another 16% did not know whether their bus was early or late. They reported the bus was early more often than it was late. And when the bus was late, it was usually no more than **5** minutes late. A lateness of more than 10 minutes was reported in only a few instances (less than **2%** of sample). People who knew the schedule were more inclined to believe the bus was late than those who did not know the schedule.

About half (**52%**) of the participants needed to arrive at their destination by a particular time. This percentage was significantly larger for people who knew the schedule (59%) than people who did not know the schedule (**37%**; significant difference at the 1% level).

	Whole Sample	Knew Schedule
<i>Bus Book</i>	42	43
Bus Schedule	33	38
Asked for Directions	8	5
Called OCTA	6	6
None	32	30
Knew Schedule	69	--
No wait	14	14
< 5 minute wait	33	38
6 – 10 minute wait	30	31
11 – 20 minute wait	16	13
21 – 30 minute wait	6	4
> 30 minute wait	2	1
Average	8 min	7 min
Early	16	16
< 2 minutes late	58	67
2-5 minutes late	5	6
6- 10 minutes late	3	3
11-20 minutes late	1	2
> 20 minutes late	.4	.3
Don't Know	16	6
Set arrival time	52	59

Prior Experience On-time performance had improved on the route over the last year according to 31% of the sample. 8% felt it had gotten worse, 32% felt it was the same and another 30% didn't know whether it had changed. Among experienced riders (763 participants who had used route more than 10 times), 33% felt service improved, 7% felt it had gotten worse, 36% felt it was the same and 23% did not know. Most riders (91%) had not noticed any lights indicating to the driver when the bus was late or early. In fact, the 9% who had noticed lights might have noticed something other than the Transit Probe device, as experienced riders were less likely to notice the lights than new riders. Lastly, the majority of participants felt that the bus usually arrives within 5 minutes of scheduled time. Experienced riders were more likely to know usual bus arrival times; however, among those who did know usual arrival times, perceptions were little different from inexperienced riders.

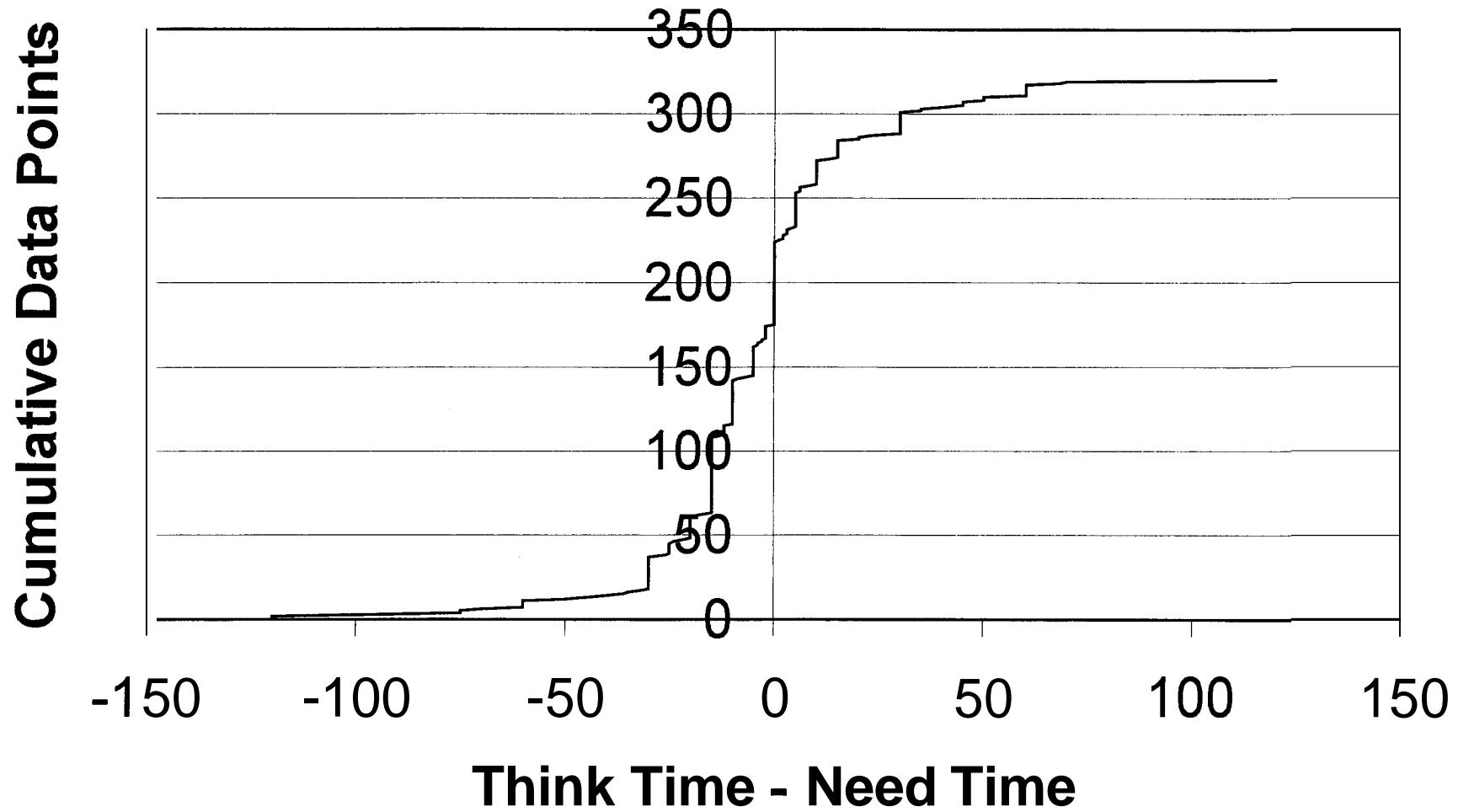
	Whole Sample	Experienced Riders
On time more	31	33
On time less	8	7
On time same	32	36
Don't know	30	23
Seen lights	10	8
Within 2 minutes	42	44
3-5 minutes	28	30
6+ minutes	8	8
Don't know	23	17

Expected Arrival Times Figure 16 provides a probability distribution for the difference between expected arrival time and when a person needs to arrive at their destination, for those who need to arrive by a specific time. 55% of the people expect to arrive at their destination early (negative values), with an average of 20 minutes early. Another 39% expected to arrive later than they need to, with a 21 minutes average. The remaining 16% expect to arrive exactly on time.

Cross-Tabulations A series of cross-tabulations were created to measure associations between various factors. The following summarizes our observations:

- There appears to be little association between average waiting time and source of information, though travelers who called OCTA reported somewhat longer waits on average than other groups (9.4 minutes versus 7.9 minutes overall). The difference is not statistically significant.
- First time users are less likely to need to arrive at their destination by a specific time than regular users (33% versus 56% for those who have ridden more than 10 times). The difference is significant at the 1% level. This may be because non-regular riders have different trip purposes, or because new riders cannot rely on the bus when they have to arrive by a particular time.

Figure 16. Arrival Time Deviation



- People traveling to work, school and medical appointments are more likely to need to arrive by a specific time (**80%**, **67%** and **63%** respectively, versus **52%** overall). Persons traveling to home are least likely to need to arrive by a specific time.
- Regular riders are more likely to know the bus schedule than first time riders (**77%** of those who have ridden more than **10** times versus **43%** of first-time riders). The difference is significant at the 1% level.
- Knowledge of the bus schedule increases with age: **83%** for **65+**, **72%** for **35-64**, **68%** for **18-34** and **59%** for under **18**. Knowledge of the schedule is not associated with gender or language to a significant degree.
- People who need to arrive by a specific time are more likely to know the schedule than those who don't (**78%** versus **59%**). The difference is significant at the 1% level.
- Information acquisition varies somewhat across demographic groups.
 - 1st time riders, English speakers, under **18**, people needing to transfer and those who need to arrive by a specific time were the most likely groups to use the OCTA information line.
 - 1st time riders, older riders (**65+**), Spanish speakers, those who do not need to arrive by a specific time and those who do not know the schedule were the most likely groups to ask for directions.
 - Under **18**, experienced riders, non-Spanish speakers, riders who do not need to transfer, and persons who do not need to arrive by a specific time were most likely to indicate no information source.

Regression Analyses Regression models were developed for lateness and waiting time, accounting for both measured lateness and reported lateness. Because the **GPS** system does not function on all buses and at all times, and because not all people reported a bus lateness, measured and perceived lateness could only be compared for **174** riders. Measured lateness was based on the next scheduled check point after the location where the traveler boarded the bus. These are spaced about five minutes apart, and should be reasonably close to the lateness at the stop where the person boarded.

To our surprise, we found almost no correlation ($R^2 < .01$) between perceived bus lateness and measured bus lateness, whether or not the model was restricted to persons who stated that they know the schedule. We also found no correlation between reported waiting time and measured lateness. These results seem to be attributable, in part, to the fact that buses were rarely more than a few minutes early or late. It seems that schedule deviations on this order are not accurately perceived by travelers. Of the **174** riders, five reported a bus lateness of **6-10** minutes, two reported **11-20** minutes and one reported **21-30** minutes. In fact, none of the measured lateness values for these eight riders exceeded **4** minutes. It may be that some riders are simply mistaken when they

report the bus is late, possibly because they read the schedule incorrectly or forgot when the bus was actually scheduled to arrive.

A more significant correlation was found between reported waiting time and reported lateness, as shown below:

Factor	Know Schedule		Don't Know Schedule	
	Coefficient	t statistic	Coefficient	t statistic
Constant	6.2	24.4	8.1	14.5
Perceived Lateness	.496	5.59	.892	6.3
R ²	.041		.148	

Clearly, perceived lateness alone is not a good predictor of waiting time. It is interesting, however, that perceived lateness is an important factor in predicting waiting time for people who did not even know the schedule before arriving at the bus stop. It may be that when a person waits a long time, they believe the bus is late, whether or not they have actual knowledge of lateness. The fact that waiting time is not correlated with measured lateness, but it is correlated with reported lateness, may simply indicate that people's perceptions exhibit stronger correlations, but perceptions and measured reality do not.

In the last linear regression, reported waiting time was modeled as a function of a set of trip and rider characteristics. The following model was highly significant (F=10.58):

	Coefficient	t statistic
Constant	10.56	12.0
Know Schedule	-3.57	-7.2
Transfer Access	-.518	-.595
Walking Access	-1.18	-1.48
Considered Walking	2.40	3.48
Arrive by Set Time	1.10	2.47
1 st Time Rider	.831	1.02
2- 10 th time rider	-.258	-.473
Short Bus Headway	-1.52	-1.98

Based on the regression, knowledge of the schedule reduces reported waiting time by 3.57 minutes, and traveling over a segment with short headway reduces waiting time by 1.52 minutes. People who need to arrive by a set time report longer waits (likely because they have a large safety margin) and those who considered walking the entire way to the destination also reported longer waits. It may be that people consider walking when they have waited a long time (hence long waits cause people to consider walking). Conversely, there is likely a reasonably large number of people who actually do walk when they have waited along time. These potential riders do not appear in the sample because they never board a bus.

First time riders wait longer than experienced riders, though the result is not highly significant. There seems to be no significant relationship between waiting time and whether someone has ridden 2-10 times. These results should be tempered by the fact that people may not really know

exactly how long they have waited. However, reported waits are likely to be more accurate than reported lateness, as the former can be estimated with no knowledge of the bus schedule.

Discrete Choice Analyses A binary/linear utility logit model was used to predict whether individuals know the schedule in advance as a function of three factors: (1) age group, (2) whether the person needs to arrive by a set time, and (3) whether the person is traveling for the first time. All three factors showed some association, as indicated below:

Factor	Coefficient	Significance Level
Constant	.166	.467
Age 18-34	.293	.032
Age 35-64	.542	.026
Age 65+	1.22	.026
Arrive Set Time	.845	.000
Traveling First Time	-1.21	.000

As indicated, older riders and riders who need to arrive by a set time are more likely to know the schedule, whereas riders using the route for the first time are less likely to know the schedule. These factors are both a reflection of the need to know the schedule, and familiarity with the bus route.

Finally, logit models were fit to predict whether a rider consults various information sources (no information, asked someone, called phone line or used *Bus Book*). The numerical results in the table below can be summarized as follows:

- Spanish speakers are more inclined to ask someone for directions or use the *Bus Book* than non-Spanish speakers; Spanish speakers are less inclined to use no information or the phone line.
- Young riders (under 18) are more likely to use no information, and less likely to use the *Bus Book*, than older riders.
- Transferring riders are more likely to use the phone line or *Bus Book*, and less likely to have no information, than non-transferring riders
- Riders who must arrive by a set time are more likely to use the *Bus Book* or phone line than those who do not, and less likely to use no information.
- First time riders are more likely to ask someone for directions or use the phone line, and less likely to use the bus book or no information at all.

	No Information		Asked Someone		Phone Line		Bus Book	
	Coef	Sig Lev	Coef	Sig Lev	Coef	Sig Lev	Coef	Sig Lev
Constant	.691	.267	-3.46	.582	-3.29	.580	-.840	.266
Spanish	-.594	.154	.824	.312	-.730	.299	.599	.147
Age 18-34	-.703	.258	.497	.550	.025	.561	.620	.257
Age 35-64	-.780	.271	.068	.583	.064	.574	.736	.268
Age 65+	-.445	.499	-.080	1.19	-.832	1.16	.648	.495
Transfer	-.367	.156	-.099	.271	.363	.292	.327	.143
Set Time	-.675	.151	-.294	.266	.915	.320	.539	.143
First Time	-.295	.284	1.60	.318	1.26	.392	-.679	.253

On-board Survey Conclusions Results from the multi-variate regression and logit models are consistent with tabulation and cross-tabulations. Clearly a variety of demographic and trip characteristics influence information acquisition, as well as wait time and knowledge of the schedule. Clear differences exist between age groups, language groups and trip types (especially whether someone needs to arrive by a set time). Young riders access information less often than older riders, Spanish riders are less likely to use the phone line, and people who need to arrive by a set time are more likely to need some type of information.

Unfortunately, people’s perceptions of waiting time and lateness are not entirely accurate. For instance, the average reported waiting time for a person who does not know the schedule is less than it ought to be (about 15 minutes) for someone who arrive totally at random. And there is essentially no correlation between perceived lateness and measured lateness. *So* while the survey is useful in identifying general relationships, it appears that precise and accurate results can only be obtained through objective observation.

Over the period in which tracking equipment has operated, riders tended to believe that schedule adherence has improved. However, based on the actual performance of the 3M System, and drivers’ propensity to ignore its display, there is no reason to believe that this improvement was caused by the tracking system. It may be due to other factors, such as schedule corrections.

Kiosk Results

Demographic characteristics for the kiosk survey were similar to the rider survey. Spanish was the primary language for **64%** of participants and **55%** were male. **6%** were under **18**, **47%** were between **18-34**, **46%** were between **35** and **64**, and the remaining **2%** were **65** or older. Most (**80%**) had used OCTA buses for **1** year or more, and a large majority (**73%**) used OCTA buses five or more times per week (just **4%** were using OCTA for the first time). The majority were also regular users of the Santa Ana Terminal. **68%** used it more than **10** times per month, and another **14%** used it **5** to **10** times per month.

Participants were generally quite satisfied with the **kiosk**. They were especially satisfied with the capability to determine when a bus departs relative to using the OCTA telephone information line. The following summarizes results, where a value of “1” indicates Kiosk is easiest to use and a value of “5” indicates that the alternative is easiest.

	Average	%1	%5
Relative to Information Line To find Bus Departure Time	1.5	80%	7%
Relative to Information Line To find way to destination	1.6	74%	8%
Relative to OCTA <i>Bus Book</i> To find way to destination	1.8	69%	9%

Relative to OCTA <i>Bus Book</i> To find Bus Departure Time	1.9	66%	13%
Relative to OCTA <i>Bus Book</i> To view map	2.0	60%	13%

The lowest rated feature was clearly the maps, which do not provide the same level of assistance as routing and departure time. Other than being displayed on a computer screen, they are similar in function to the maps found in the OCTA *Bus Book*. Though broad conclusions cannot be drawn from a small sample, riders in the survey seemed to prefer the *Bus Book* as a source of information over the OCTA telephone information line. Whereas in the earlier Rockwell survey telephone information was preferred to computer information screens, actual exposure to a kiosk computer information screen leads people to prefer it.

The total rating among these five questions was modeled as a function of rider characteristics, resulting in the following specification. A total of 5 would be the best possible score for the kiosk, whereas a score of 25 would be the worst possible.

<u>Factor</u>	<u>Coefficient</u>	<u>t statistic</u>
Constant	10.8	8.9
Used OCTA < 1 year	-3.3	-3.05
Age > 35 years	1.44	1.52
Female	.022	.0234
English Speaking	-.542	-.540

The only highly significant factor is whether someone has used OCTA < 1 year or not, with new riders favoring the kiosk over old riders. Young riders are also more favorable toward the kiosk, though the relationship is not highly significant. Gender and language are not significant factors.

Virtually all of the participants indicated that they would use the kiosk again: 94% for bus departure time, 93% for finding way to destination and 90% for looking at a map. Participants also indicated that they will use the kiosk frequently in the future, with 23% indicating 1-4 times per month and 74% indicating 5 or more times per month (3% stating never).

Participants liked several features of the kiosk, including

“It is very fast”	36%
“It is easier to find information than alternative sources”	15%
“It is simple to use”	13%
Other	21%

Most participants had no suggestions for improving the kiosk. The most frequently cited suggestions follow:

“Place more kiosks at terminal”	16%
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“Give instructions on how to use it”	11%
“Protect it better against vandalism”	5%
“More languages”	4%
“Provide print-outs”	3%
“Make it bigger”	2%
“Add maps”	2%

Based on our own observations of users, the kiosk was easy to use, and people could find what they needed without instruction. It only took a minute or two for people to find their information, and computer response time was very good. Of all the features, the maps were the most difficult for people to use. Though apparently helpful, it took more time for people to obtain the information they needed from maps. Overall, people were enthusiastic about the kiosk. Those with negative comments were most concerned about security, lighting, and lack of signage or written instructions. It does seem that it is most useful for new riders, or riders using a line for the first time.

7. CONCLUSIONS

The project was directed at measuring four Transit Probe objectives, which are discussed below:

Reliability and Completeness of Data

Transit Probe experienced many reliability problems. As shown in Table 1, the majority of schedule data points are either missing or undetected. In addition, the system generates numerous “duplicate” records, confounding data analysis. It appears that the remaining records are largely accurate. However, based on driver perceptions, these too may be error prone. Missing and undetected data result from inoperable or failed units, lack of complete coverage on routes, and inability to immediately update data at schedule changes. Transit Probe clearly has not met reliability expectations for an actual deployment.

Effectiveness of Interfaces

Transit Probe never created its intended interfaces to other Transportation Management Centers. Once it was apparent that Transit Probe would be a very small scale deployment, it ceased to be a priority data source. When budgets were squeezed, interfaces were therefore eliminated. Hence, it never provided a source of local street congestion data for Caltrans, and never supplemented congestion data for Anaheim and Santa Ana TMCs.

Transit Probe never accomplished its public interface objectives. Though a kiosk was installed at one location, it was not opened until the end of the project. The kiosk was well received in a test evaluation, but it could have not impact if not open to the public. No other interfaces were established for the public.

Customers in general perceived that schedule adherence had improved over the year in which transit probe units had been installed. From driver interviews, it seems that this might be attributable to placement of the 3M Info clock in driver view. Because drivers generally ignore indicator lights, the improvement could not have resulted from the system’s schedule adherence capabilities. The perceived improvement could also be due to other factors, such as schedule changes, or could simply be a misperception.

Usefulness for Congestion Measurement

OCTA never fully established the congestion measurement capabilities, largely because it did not have a mechanism for disseminating congestion information. Congestion segments were not completely established, and baseline speeds were never determined through field measurement. As with schedule adherence data, much of the congestion measurement data was missing, greatly limiting its value. Our analysis also found little correlation between speed estimates determined by the Transit Probe algorithm and recorded automobile speeds.

Our own analysis revealed that when automobiles experience long delays, buses traveling the same route in close proximity are also likely to experience delay. The reverse, however, is not always true. This is because buses frequently wait for extended periods when they run ahead of schedule.

Any useful bus probe algorithm would need to distinguish actual congestion versus a stopping delay.

Though Transit Probe was designed to measure congestion on roadway segments, a more useful approach would be to measure congestion approaching major intersections. These are the places where delay is likely to occur. And measuring over an entire segment make it difficult to identify the exact location of the problem. Moreover, because delay randomly fluctuates in accordance to a vehicle's arrival time relative to the signal cycle, the most sensible approach is to set off a "congestion alarm" when a vehicle is delayed by more than one cycle at an intersection. A congestion alarm would indicate over-saturation, and delay well beyond normal. Congestion alarms like this are feasible with GPS based systems, but were not used in the project.

Institutional Performance

In the initial design phases of the project, OCTA did a commendable job involving partner agencies, while still moving the project forward and meeting deadlines. Participants praised OCTA, and they were generally satisfied with the institutional structure. In the second phase, after award of the system integrator contract, the project became rather conventional with a contractor and contract manager. Outside participation virtually disappeared at this point.

By way of improvement, the project would have been more effective had there been more internal involvement in design, installation and operation from communications, drivers, scheduling, dispatch and maintenance. Given that the congestion measurement features were never used, except by the evaluators, there really was not any need to involve outside agencies. A more streamlined, internally focused project, that relied more on off-the-shelf installation and design, would have been more sensible. To OCTA's credit, this is exactly the approach being followed in its ITCS project.

Lessons Learned

Bus tracking systems provide many potential benefits, helping: (1) drivers stay on schedule, (2) dispatchers respond to problems, (3) schedulers determine how much time to allocate between schedule check points, and (4) general public know when buses will arrive. However, these benefits cannot be captured without carefully planning operational procedures, data maintenance, and system interfaces and ensuring the equipment itself it reliable. These important issues did not receive adequate consideration in the system design phase of the project, though they really should have been the primary emphasis. Design needs to involve many parties within the transportation agency, and include task assignments, data transfer methods, and strategies for using information.

The other lesson is that evaluation projects can sometimes result in artificial objectives. Congestion measurement was a driving force behind the institutional structure of the project and contracting. It greatly increased the need for customization, and likely added significantly to cost. Yet it was really a low priority for involved agencies, and there was considerable skepticism from the beginning. Without someone to champion this feature, it had little chance for success.

Overall Conclusions

Although the evaluation produced important insights as to how bus tracking should be implemented, and the likely problems to expect, the **OCTA Probe** failed to live up to its promise. Unfortunately, the system was not used by drivers, dispatchers, planners, schedulers or the general public during the course of the evaluation.

8. REFERENCES

- Hall, R.W. (1997). "Orange County Transit Probe Evaluation: Phase I Institutional Findings," California PATH Working Paper 97-12.
- JHK and Associates (1993). "Orange County Intelligent Vehicle/Highway Systems Study," for Orange County Transportation Authority.
- Nelson\Nygaard Consulting Associates (1999a). "1998 On-Board Survey Final Report, Volume 1: *Summary*" San Francisco, California.
- Nelson\Nygaard Consulting Associates (1999b). "1999 On-Board GPS Survey; Lines 47 and 49 Frequencies," San Francisco, California.
- NET (National Engineering Technology Corporation) (1998a). "Transit Probe System Integrator Deployment, Software Design Document," Project 96-304 for Orange County Transportation Authority.
- NET (National Engineering Technology Corporation) (1998b). "Transit Probe System Integrator Deployment, System Design Report," Project 96-304 for Orange County Transportation Authority.
- Rockwell (1996a). "Transit Probe System Scope of Work", Agreement No. C-96-304, for Orange County Transportation Authority.
- Rockwell (1996b). "Transit Probe, Task 6 – Rider Survey *Summary* Report," for Orange County Transportation Authority.
- Rockwell, IBI Group and Cinergy Innovations (1995). "Transit Probe Analysis and Design," proposal to Orange County Transportation Authority.

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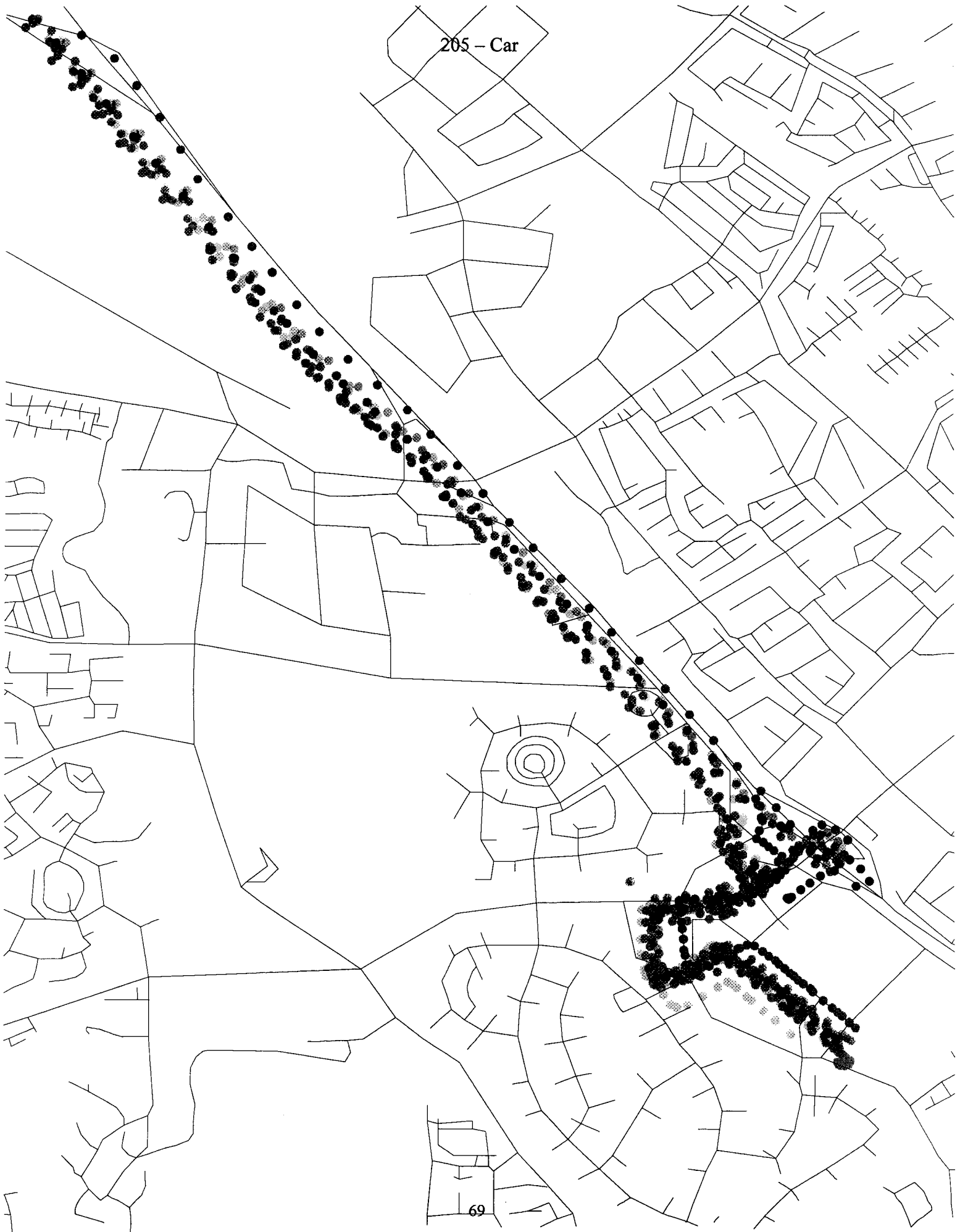
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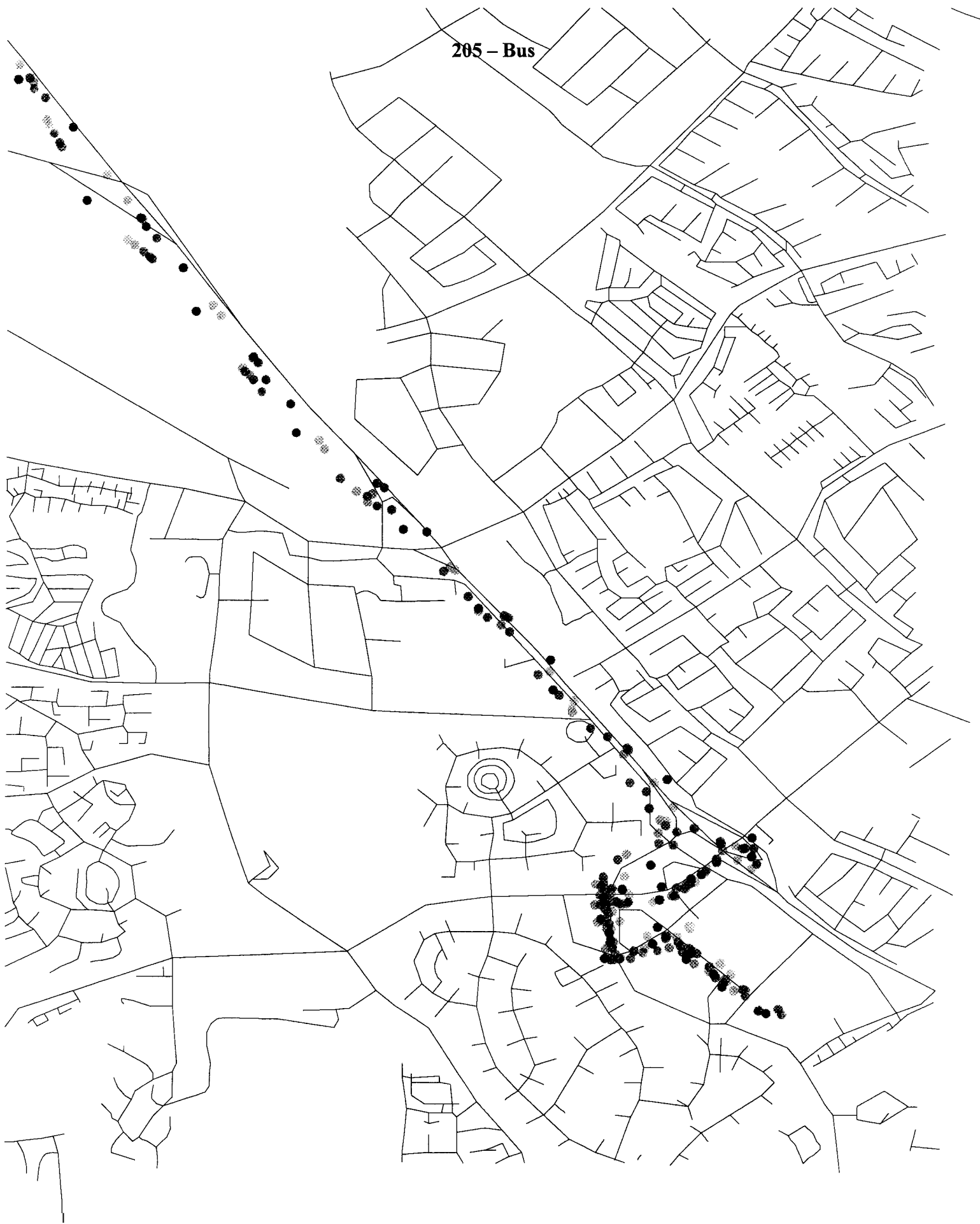
APPENDIX A. SAMPLE GPS PLOTS

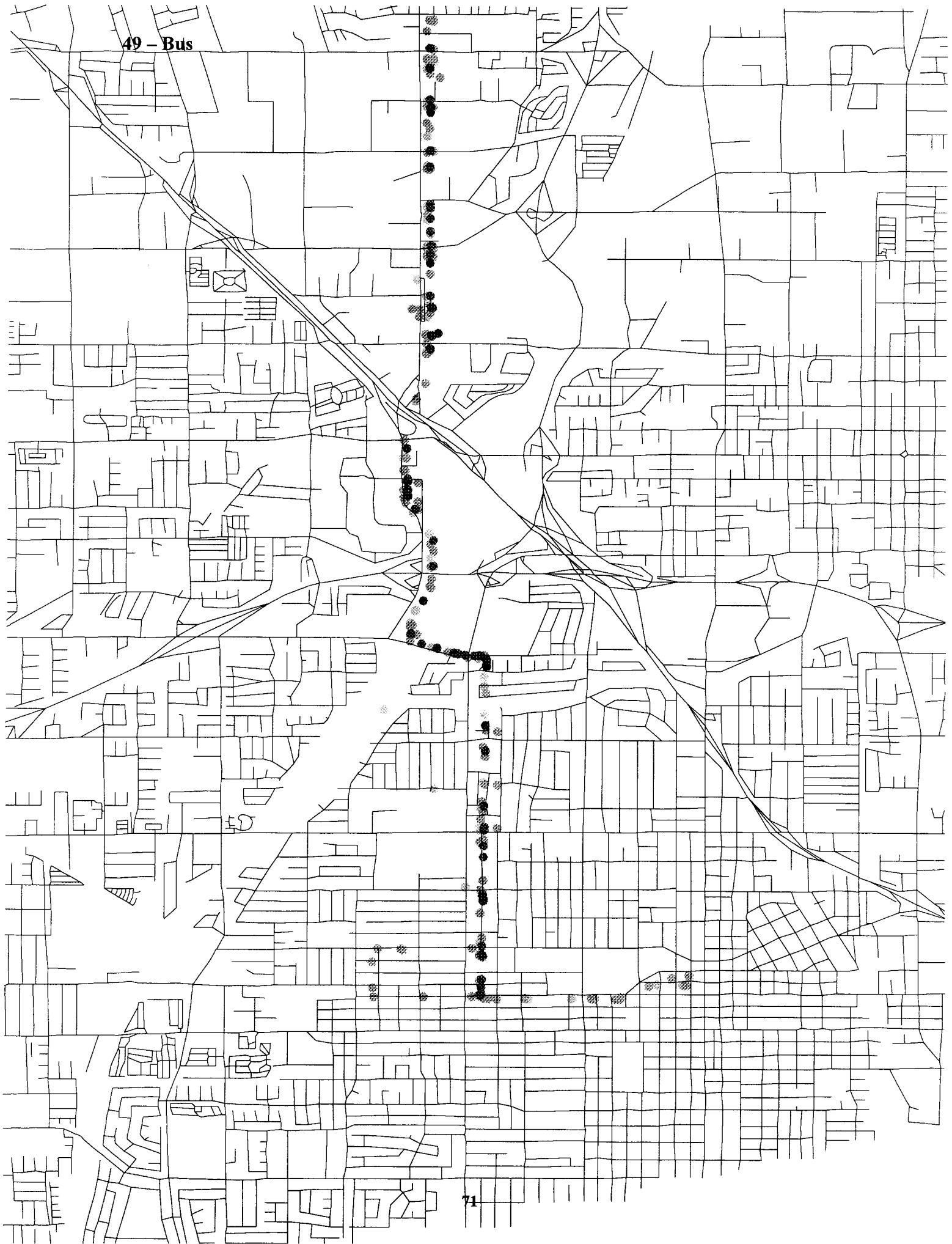
205 - Car

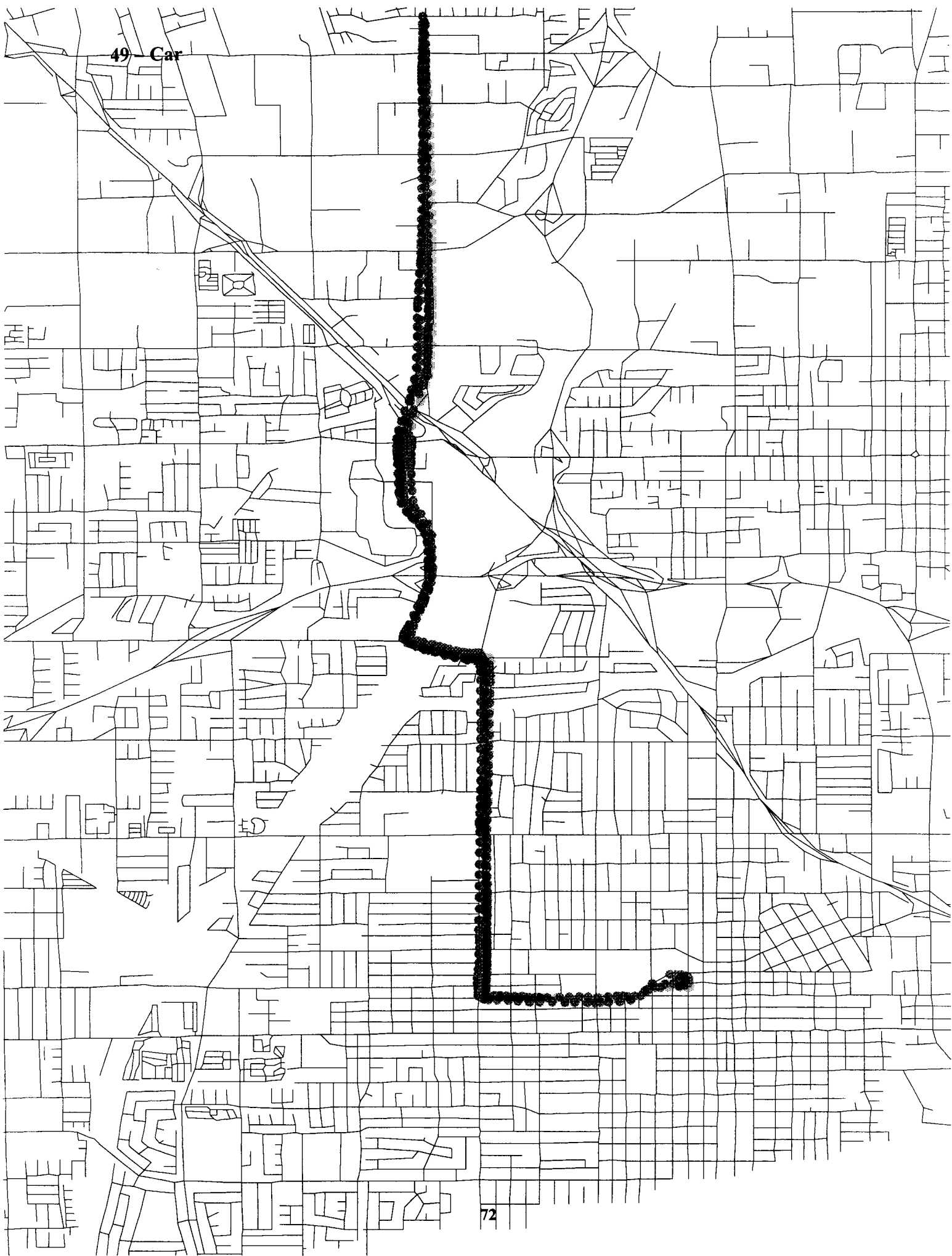


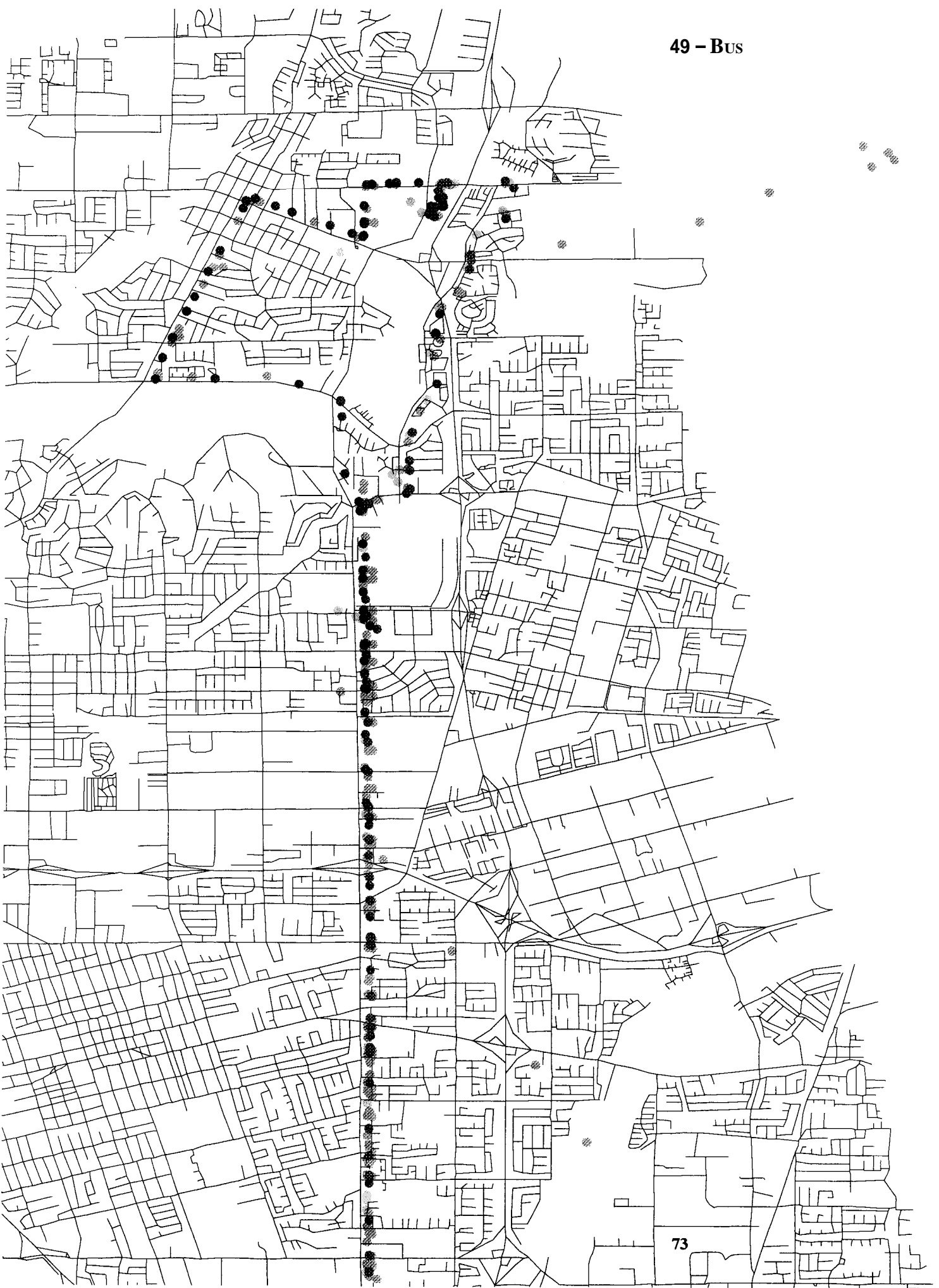
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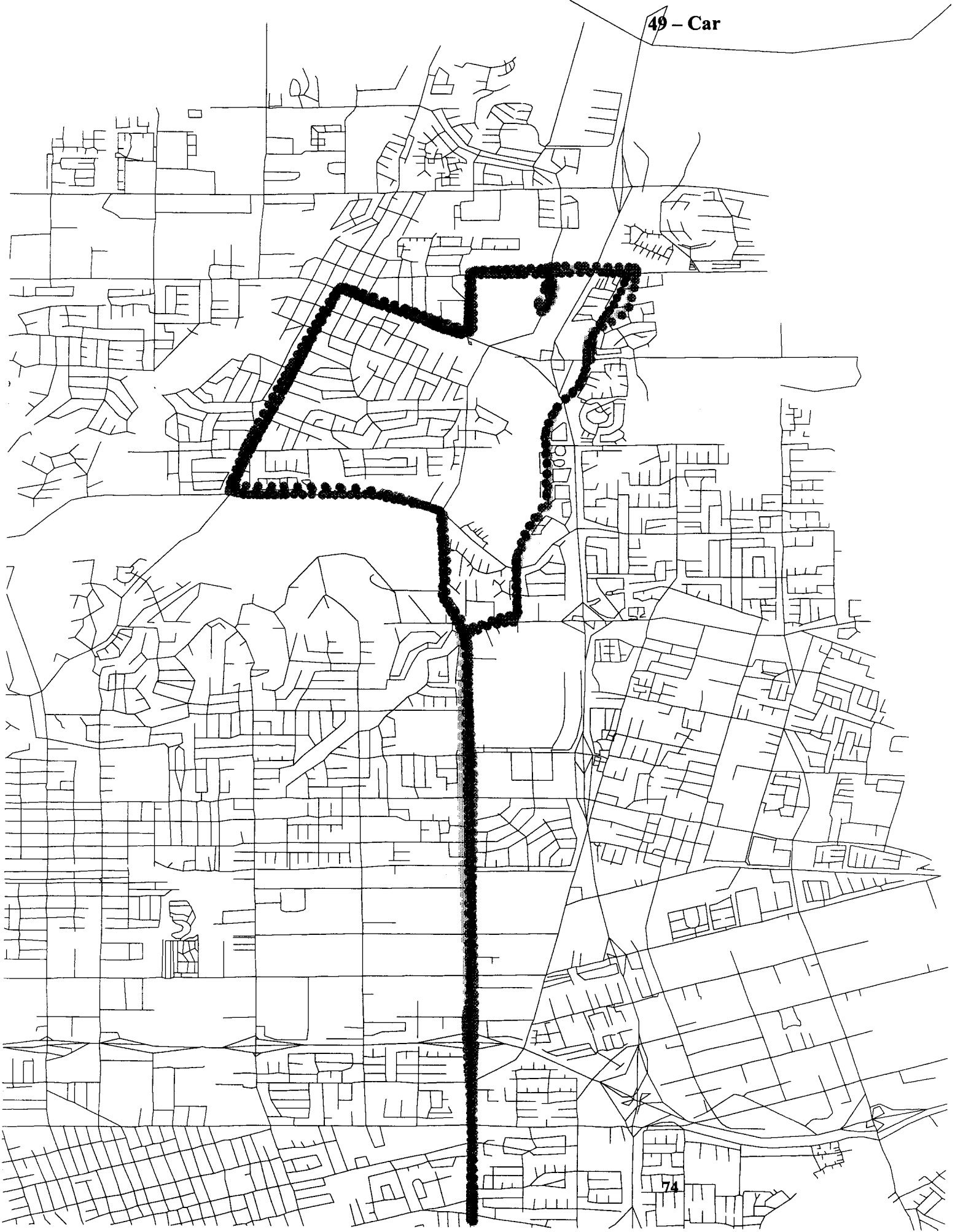
205 - Bus

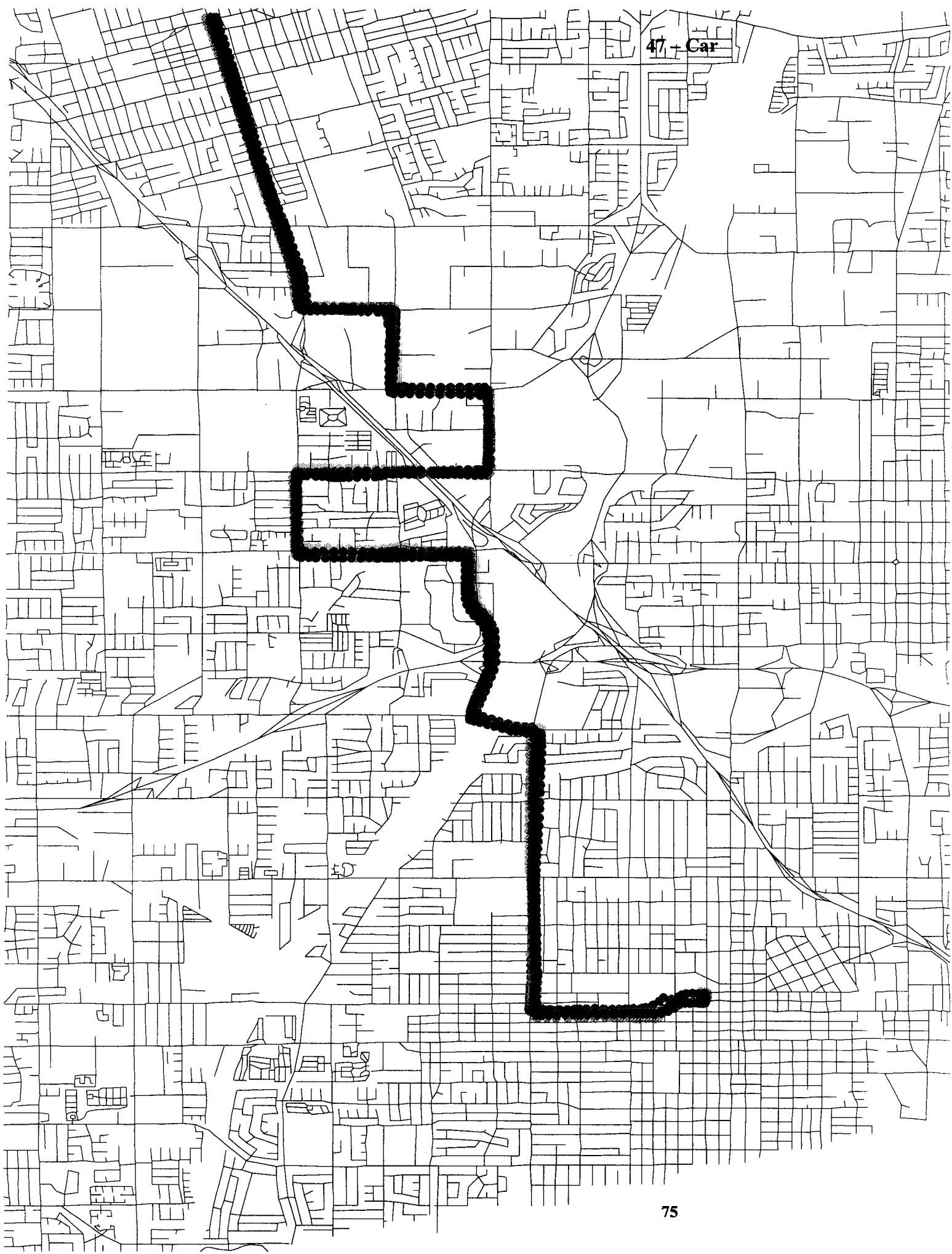




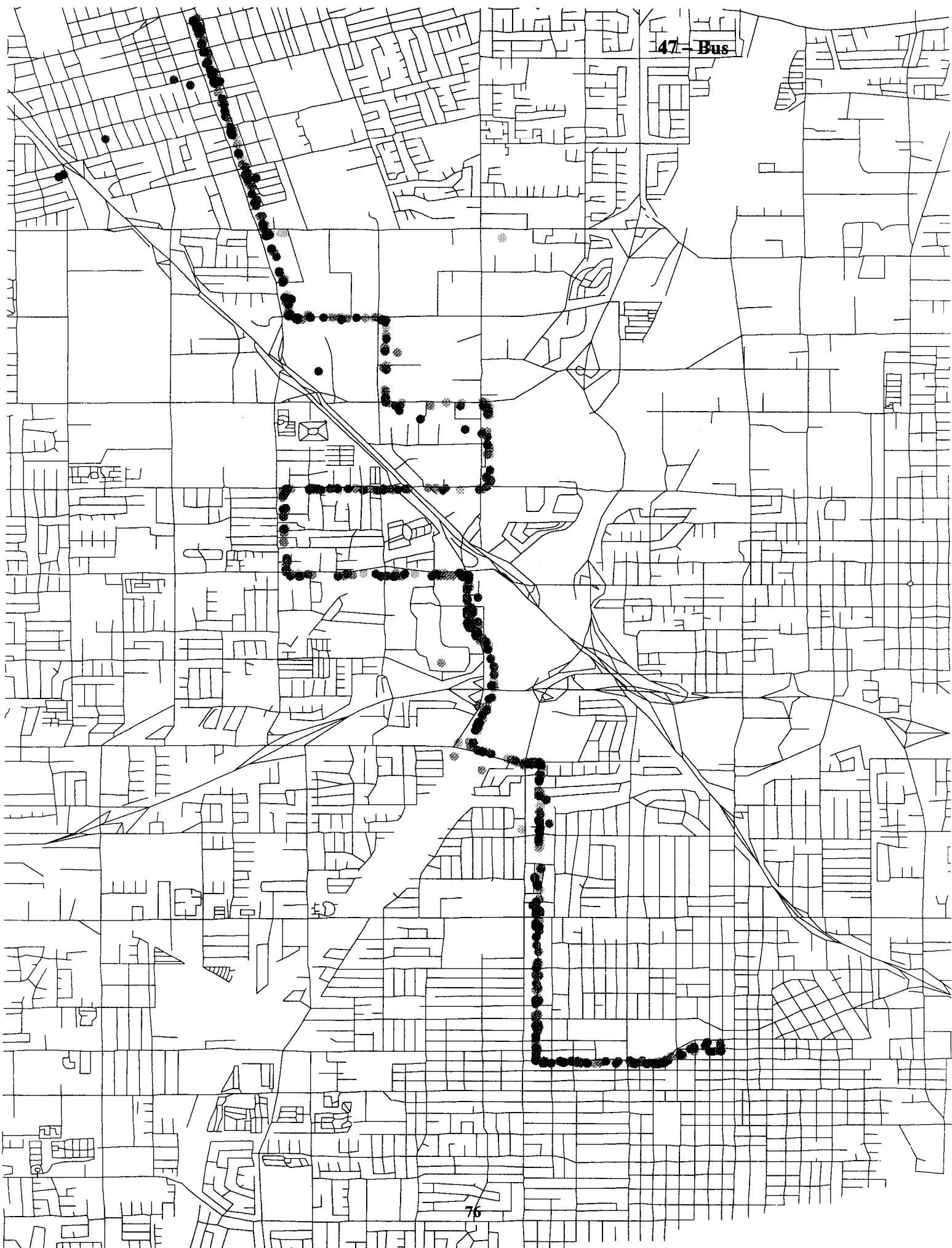




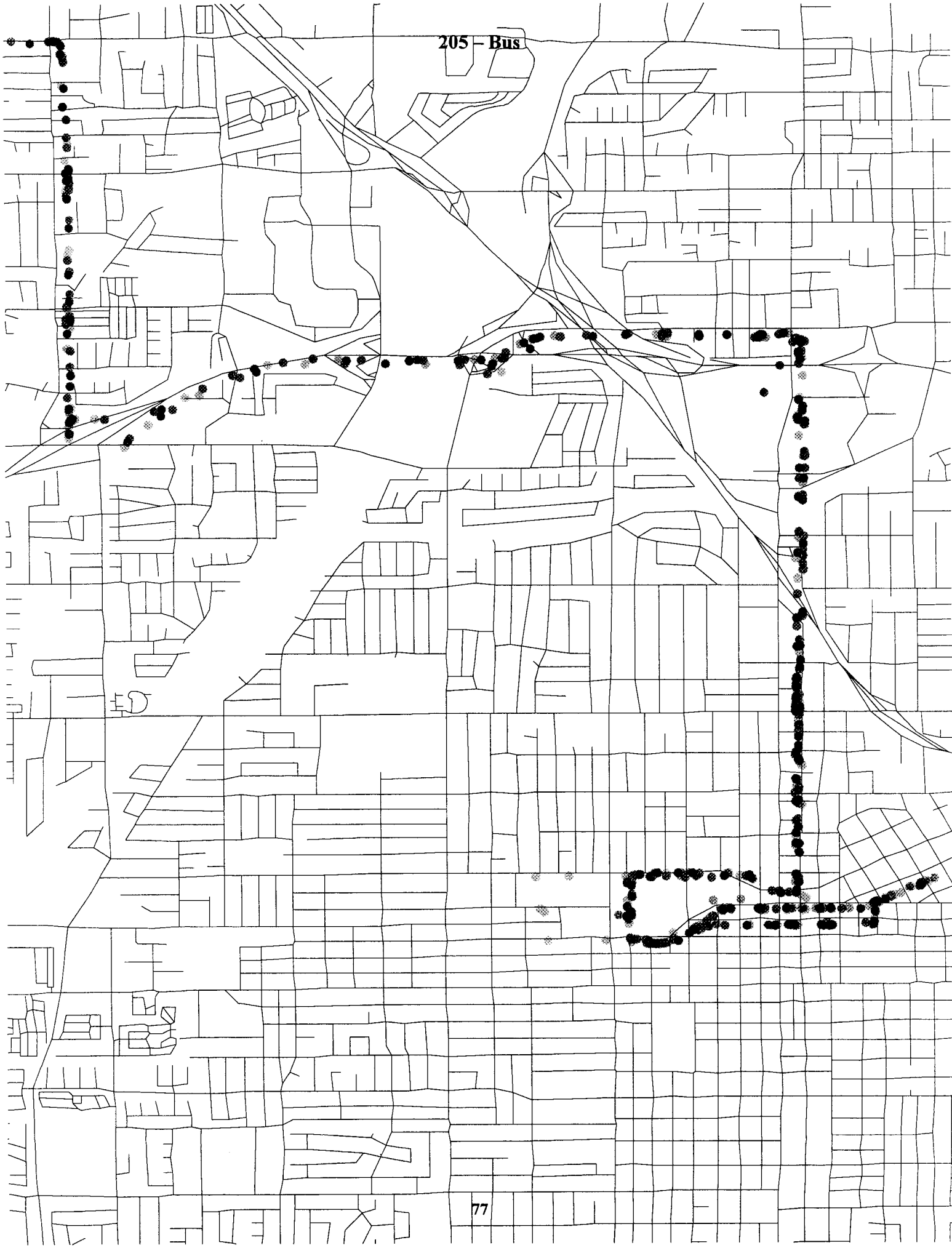


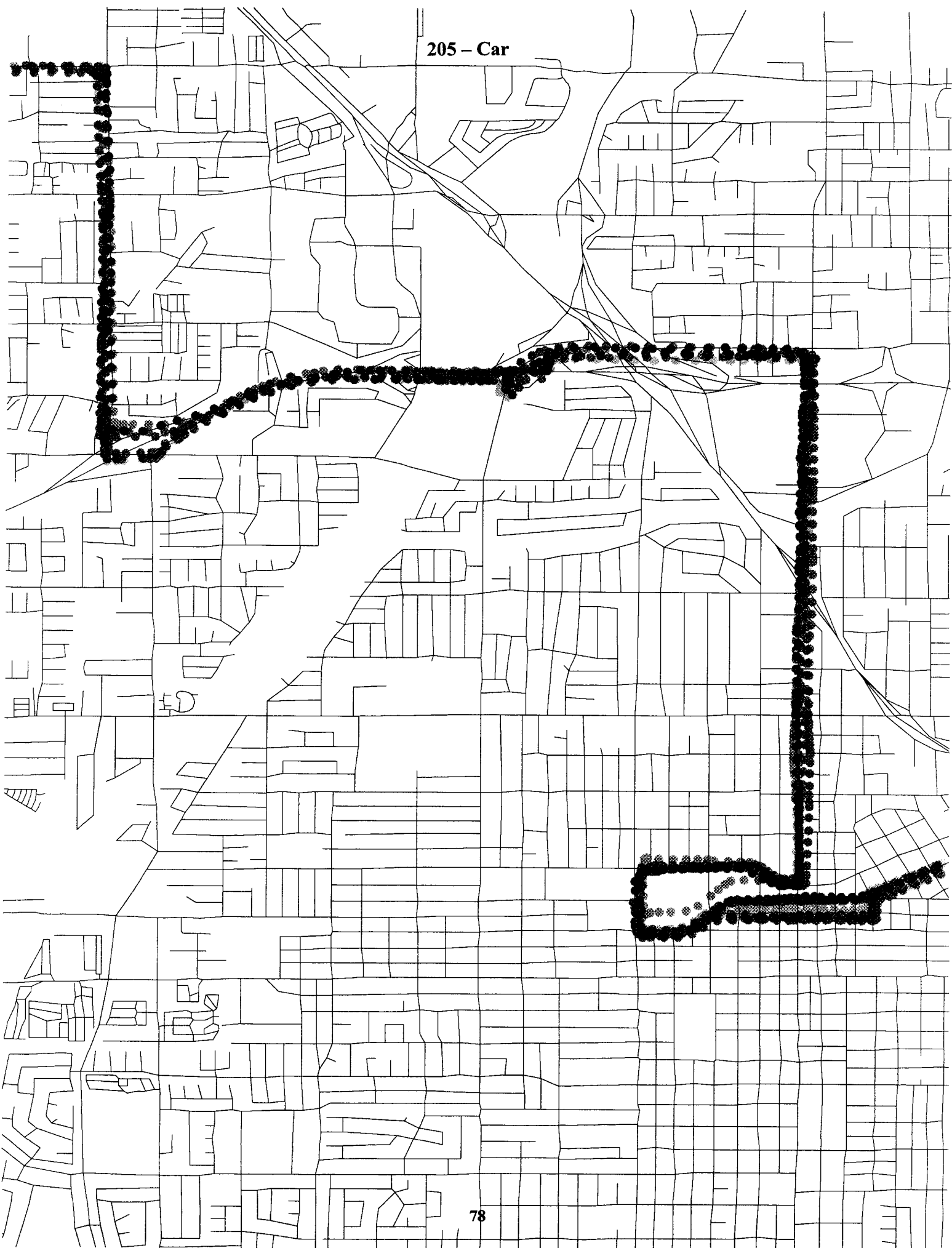


47-Bus



205 - Bus

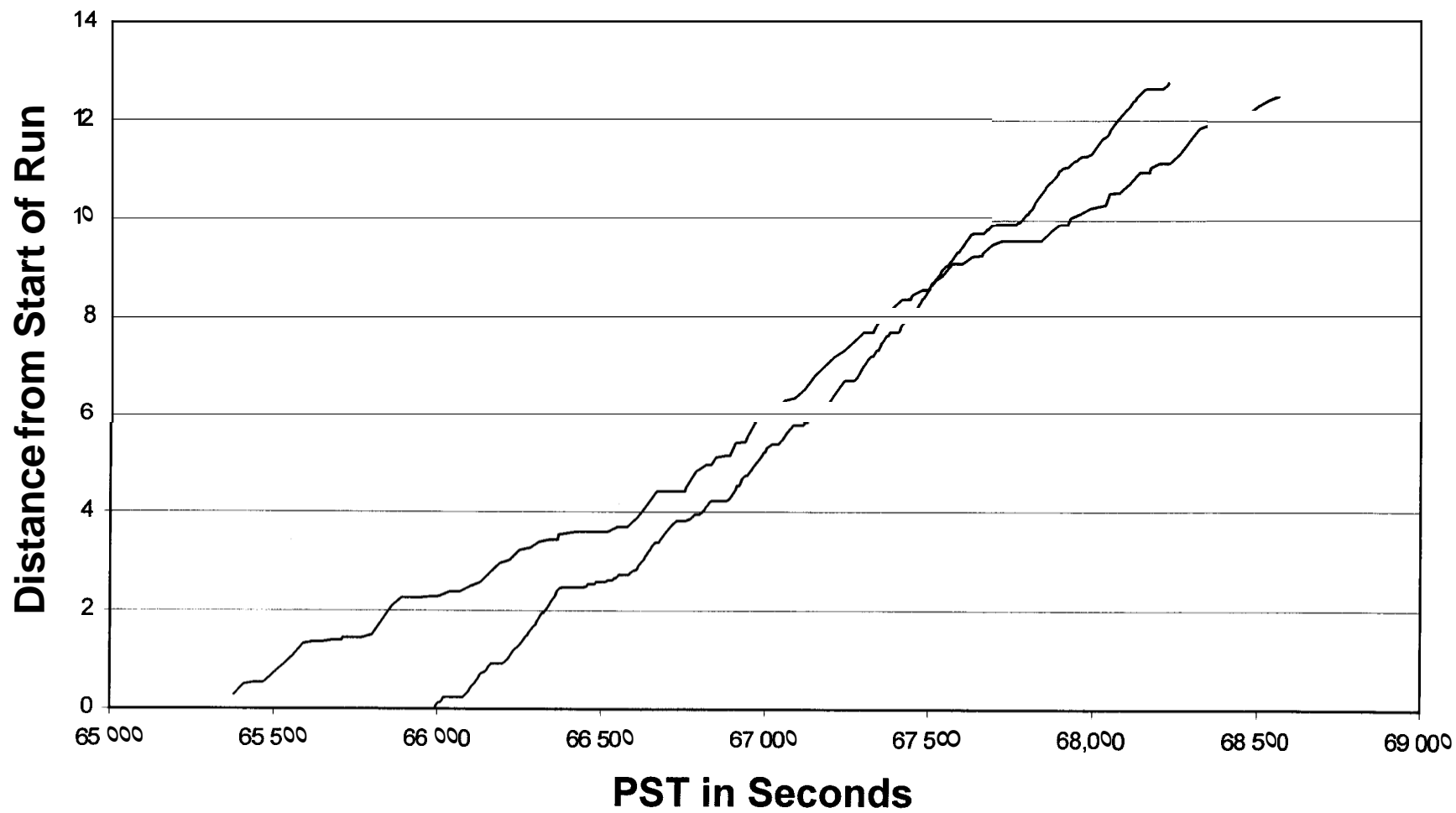




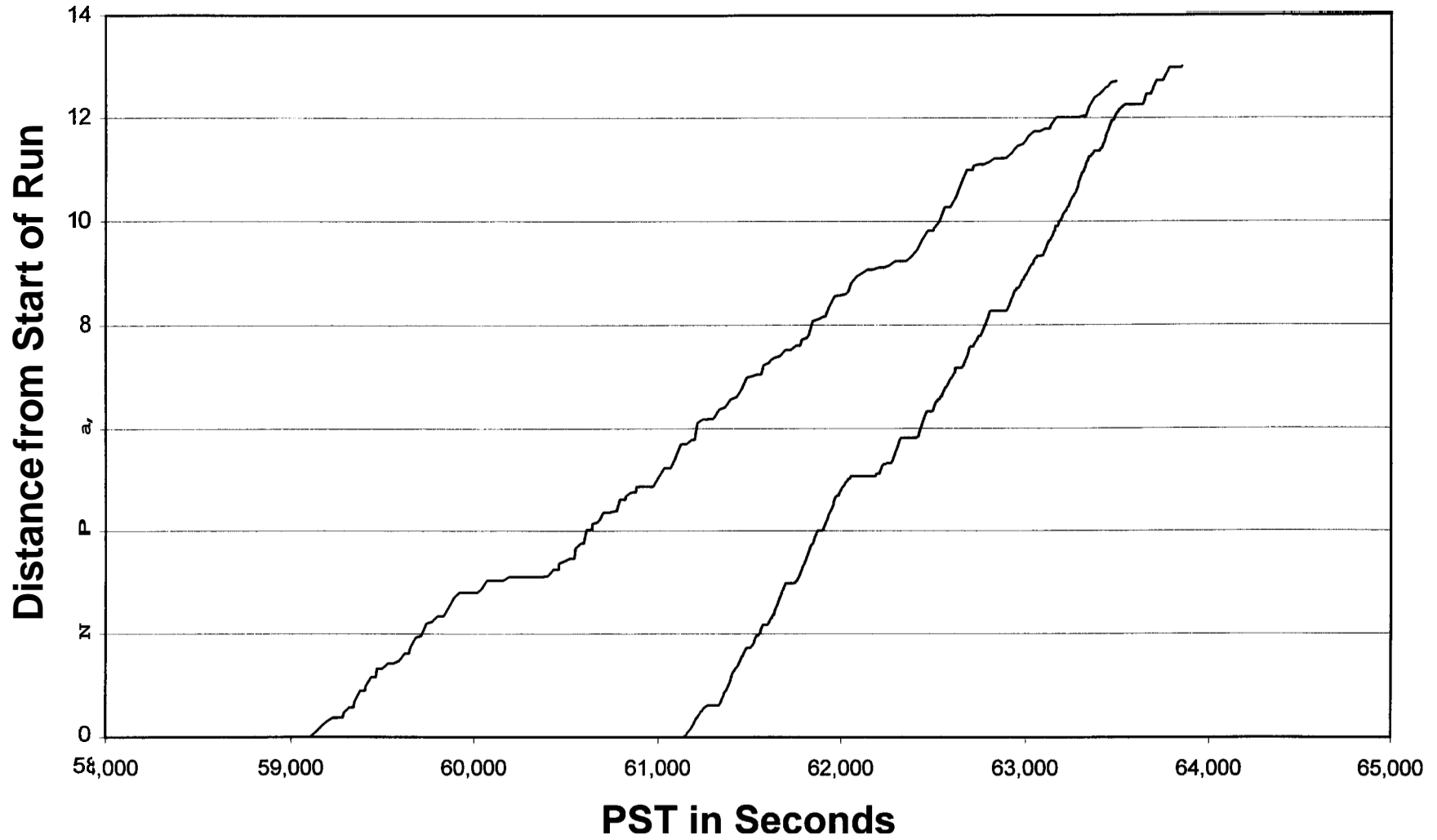
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APPENDIX B. CAR AND BUS TRAJECTORIES

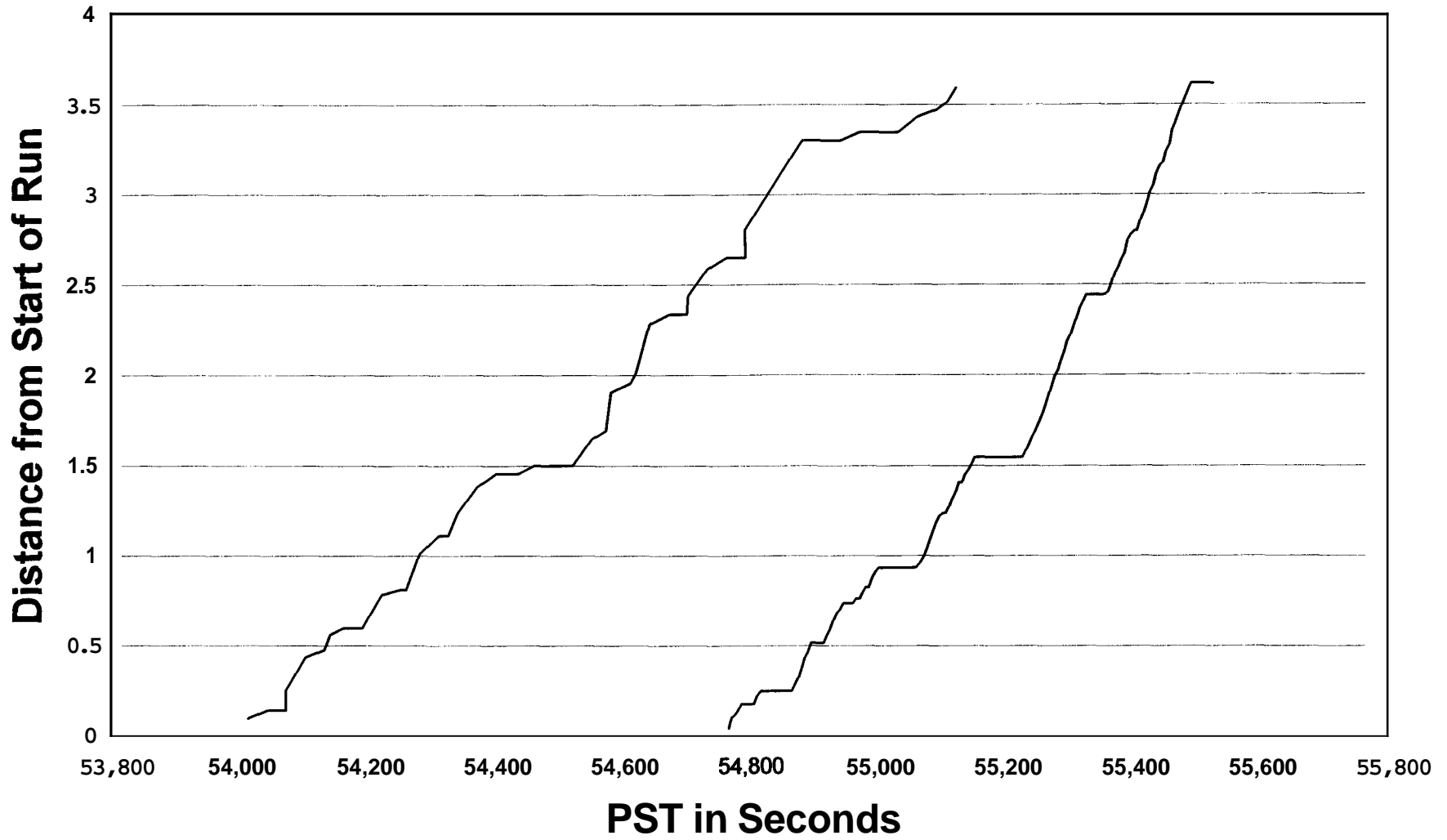
Line 47 - Plot 1



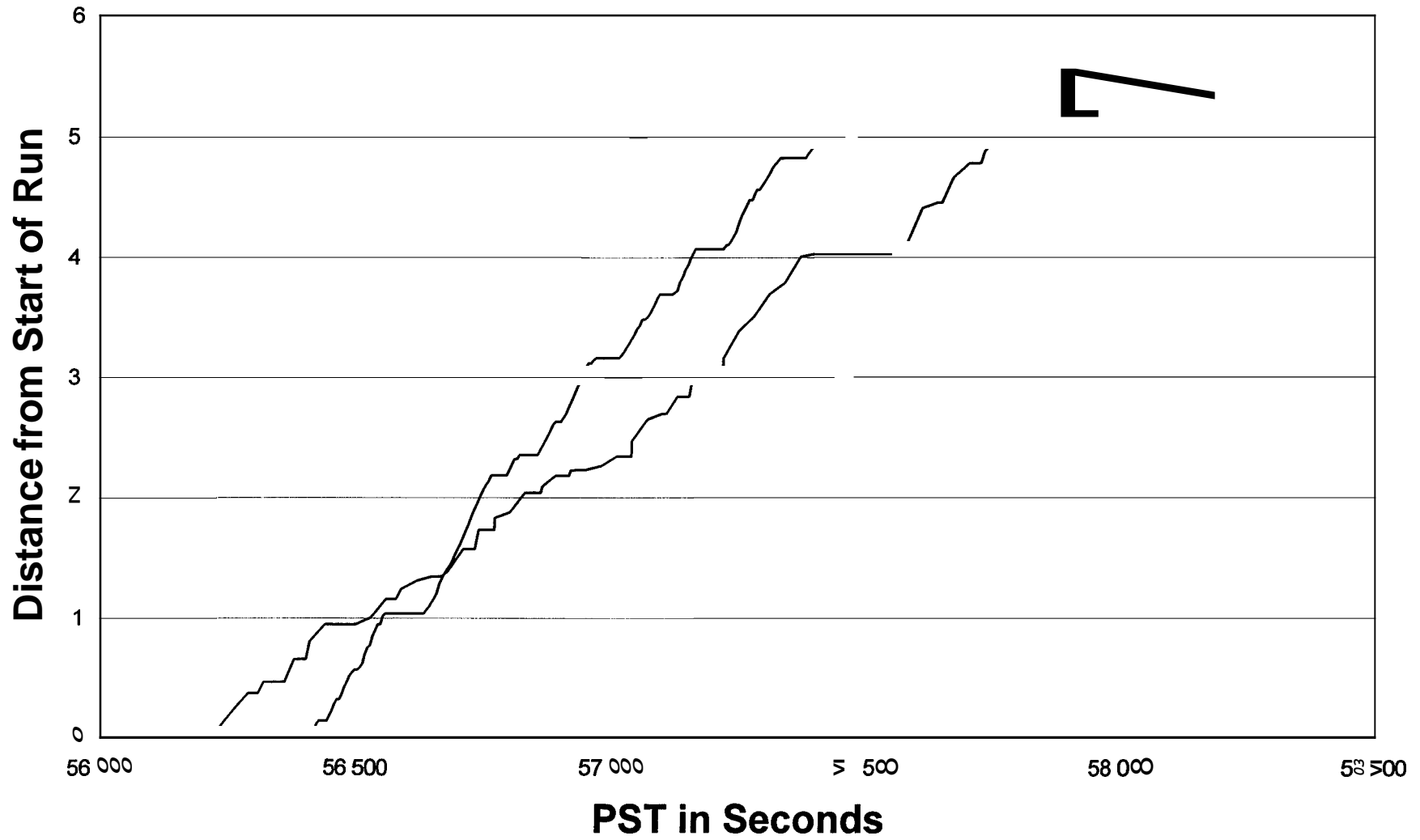
Line 47 - Plot 2



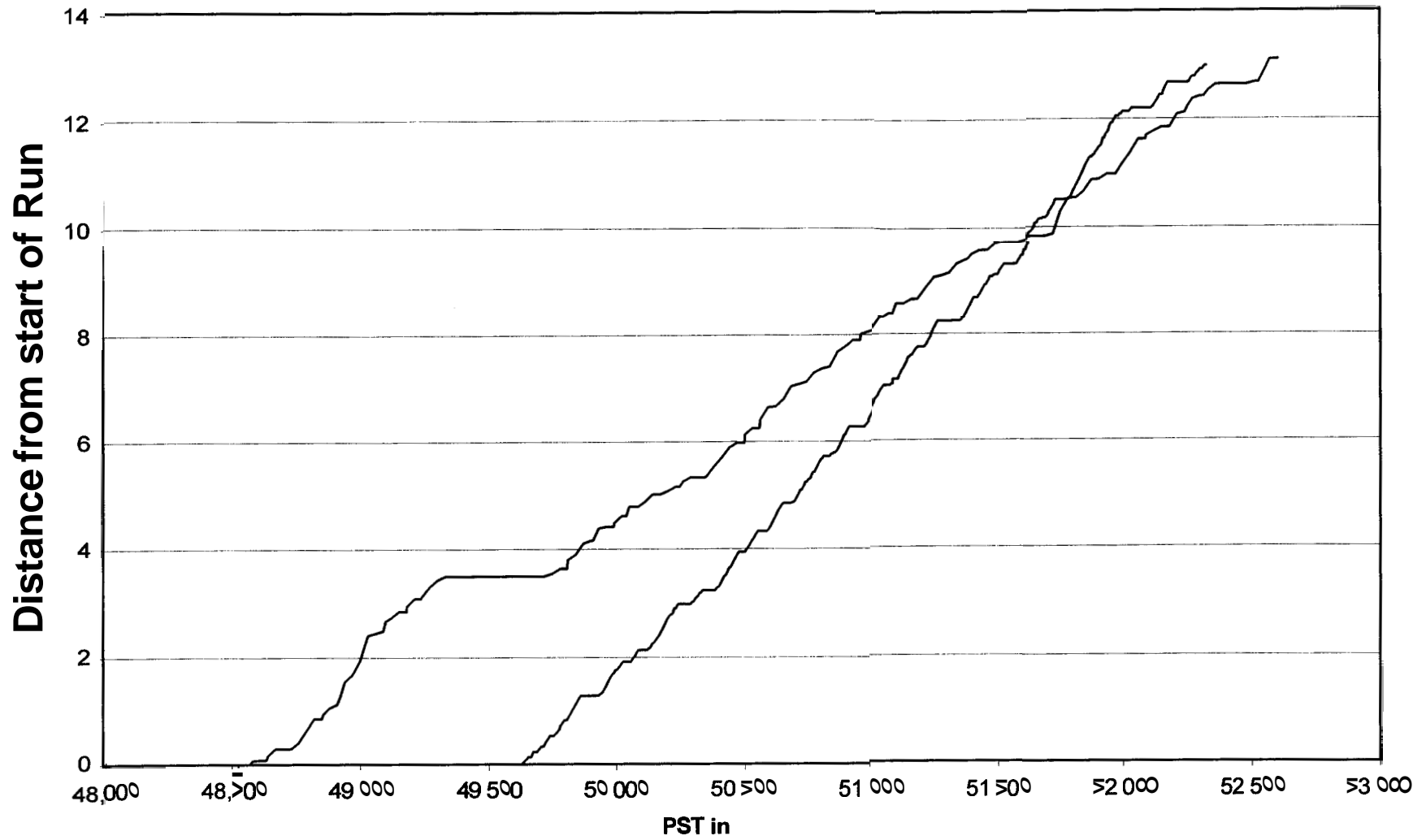
Line 47- Plot 3-1



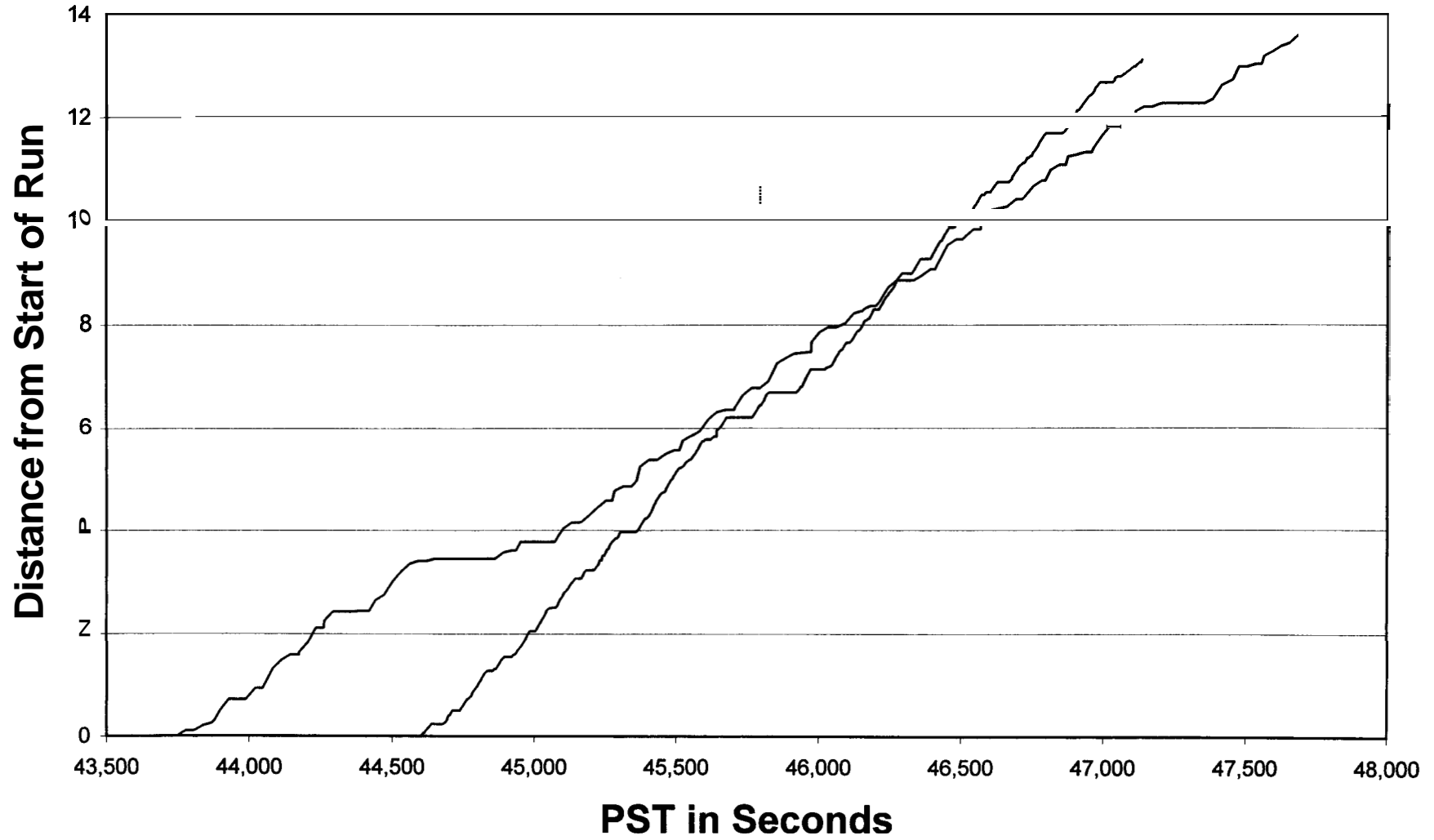
Line 47 - Plot 3-2



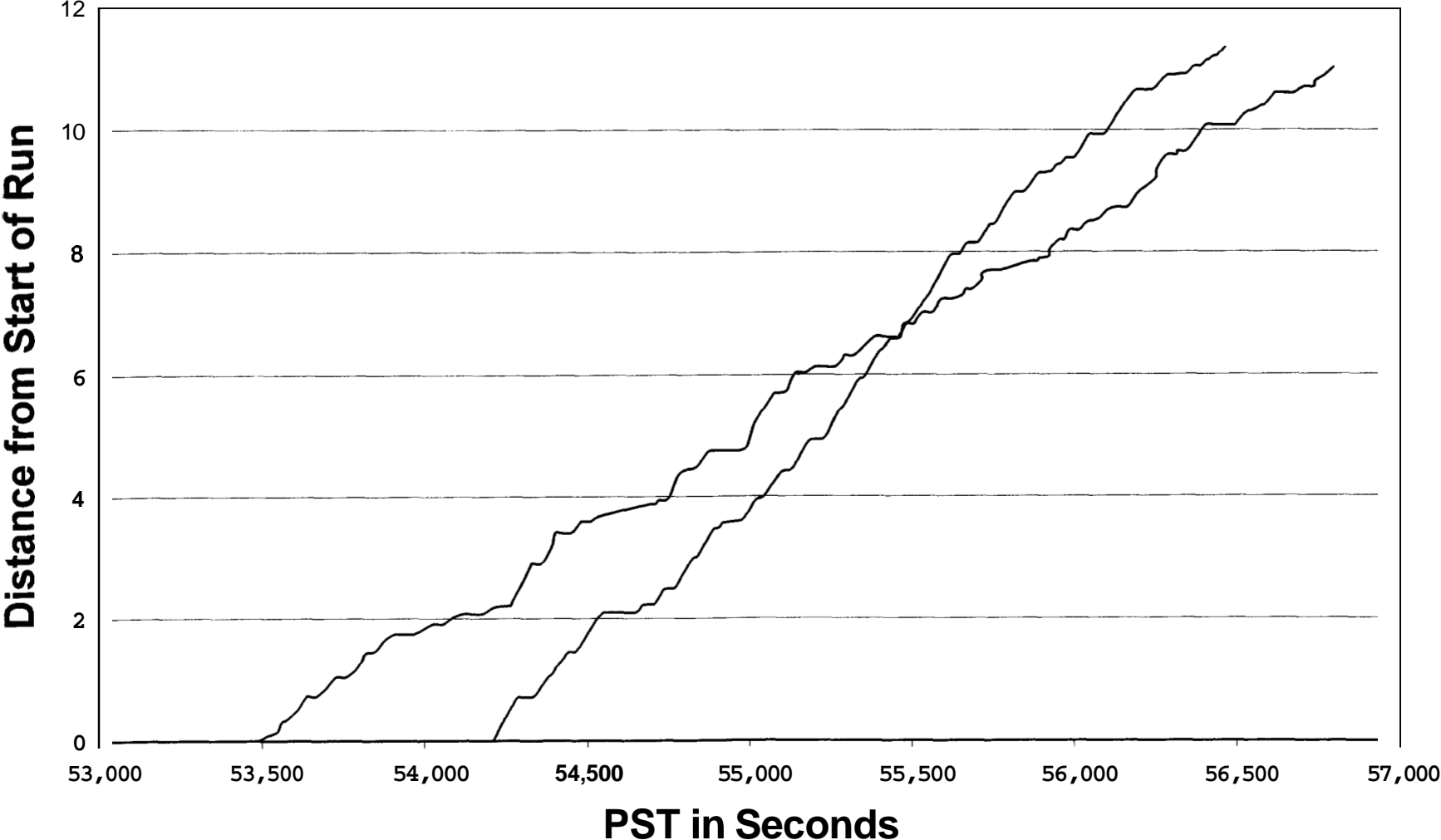
Line 47 - Plot 4



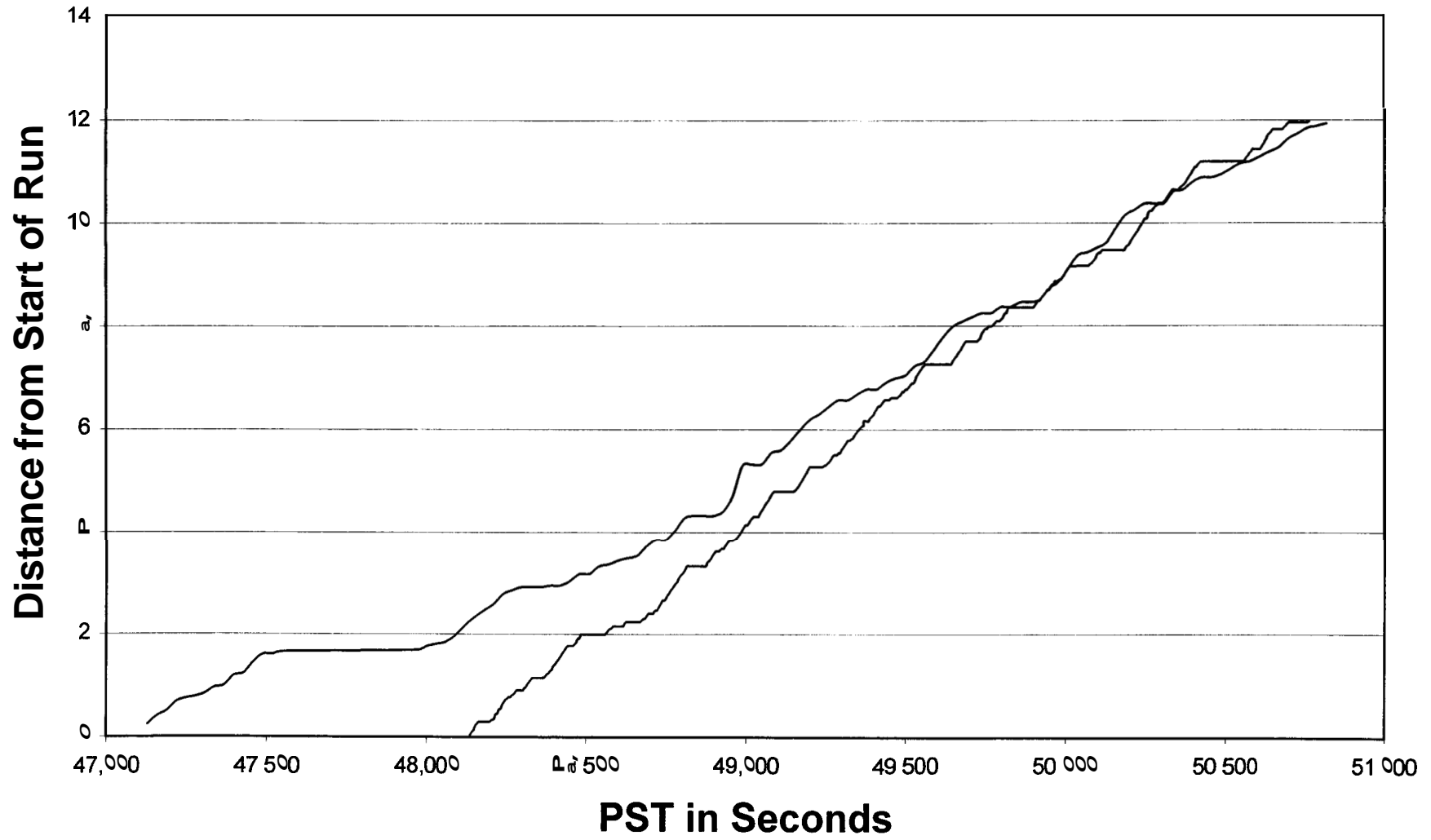
Line 47 - Plot 5



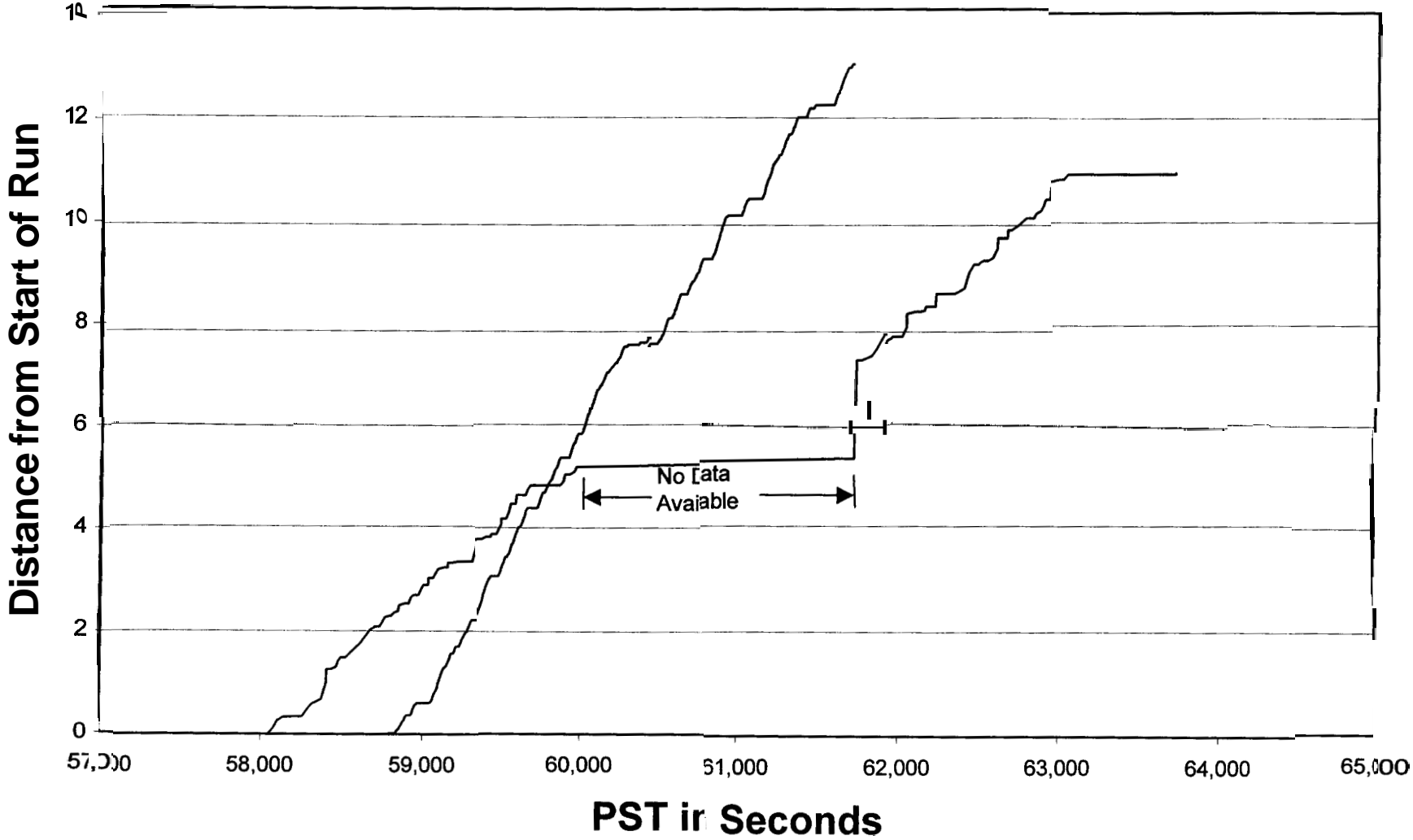
Line 47 - Plot 6



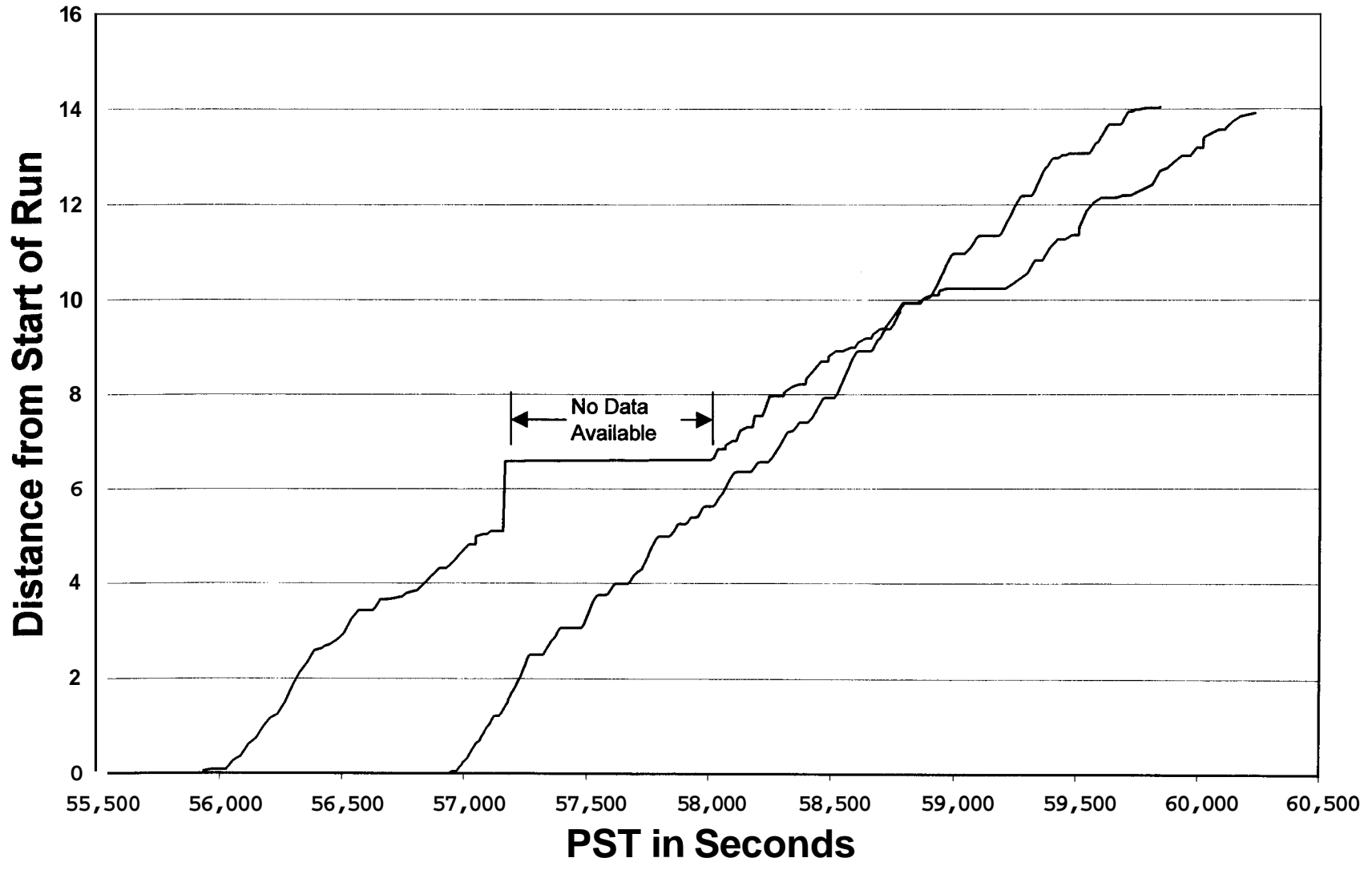
Line 47 - Plot 7



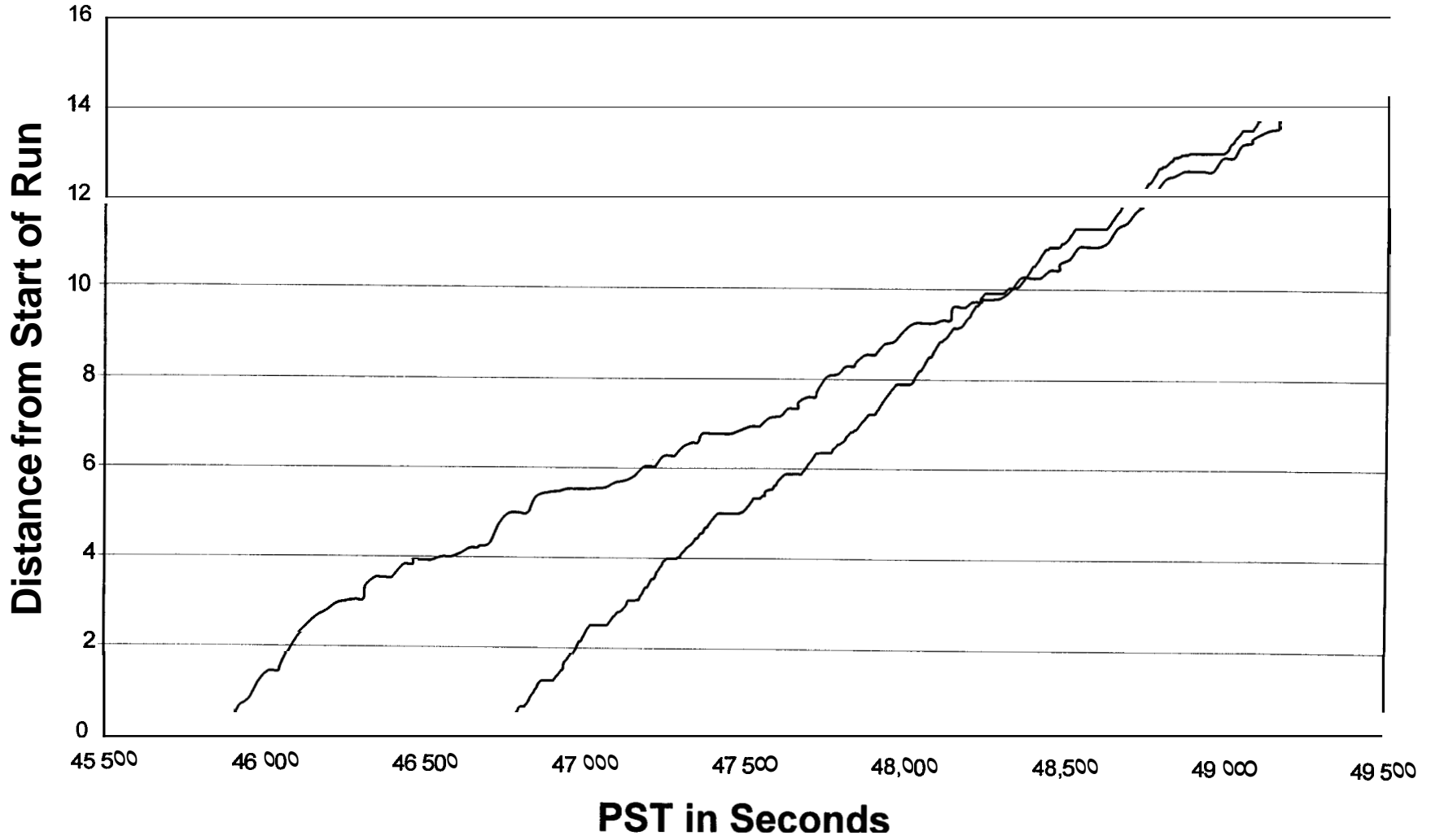
Line 47 - Plot 8



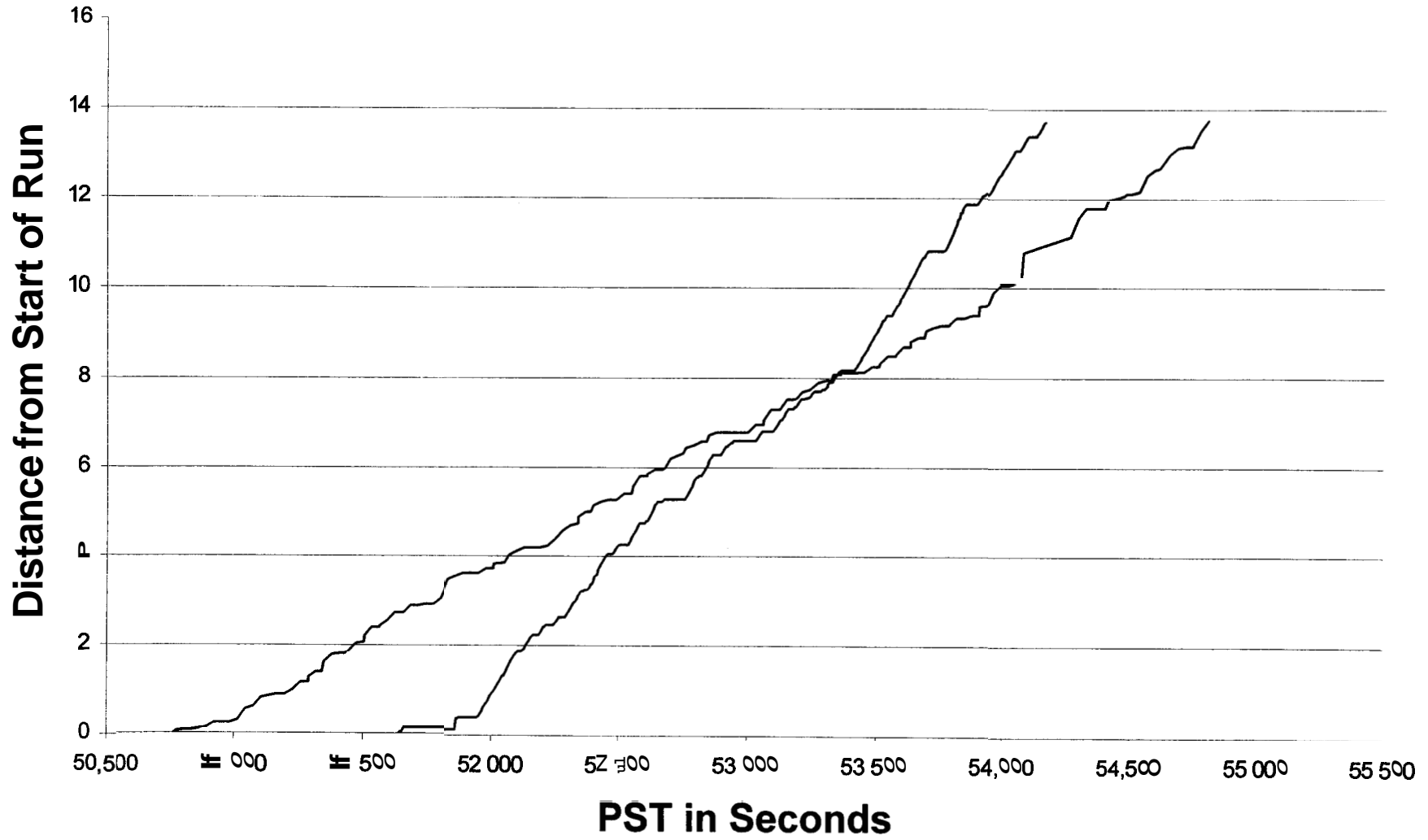
Line 49 - Plot 1



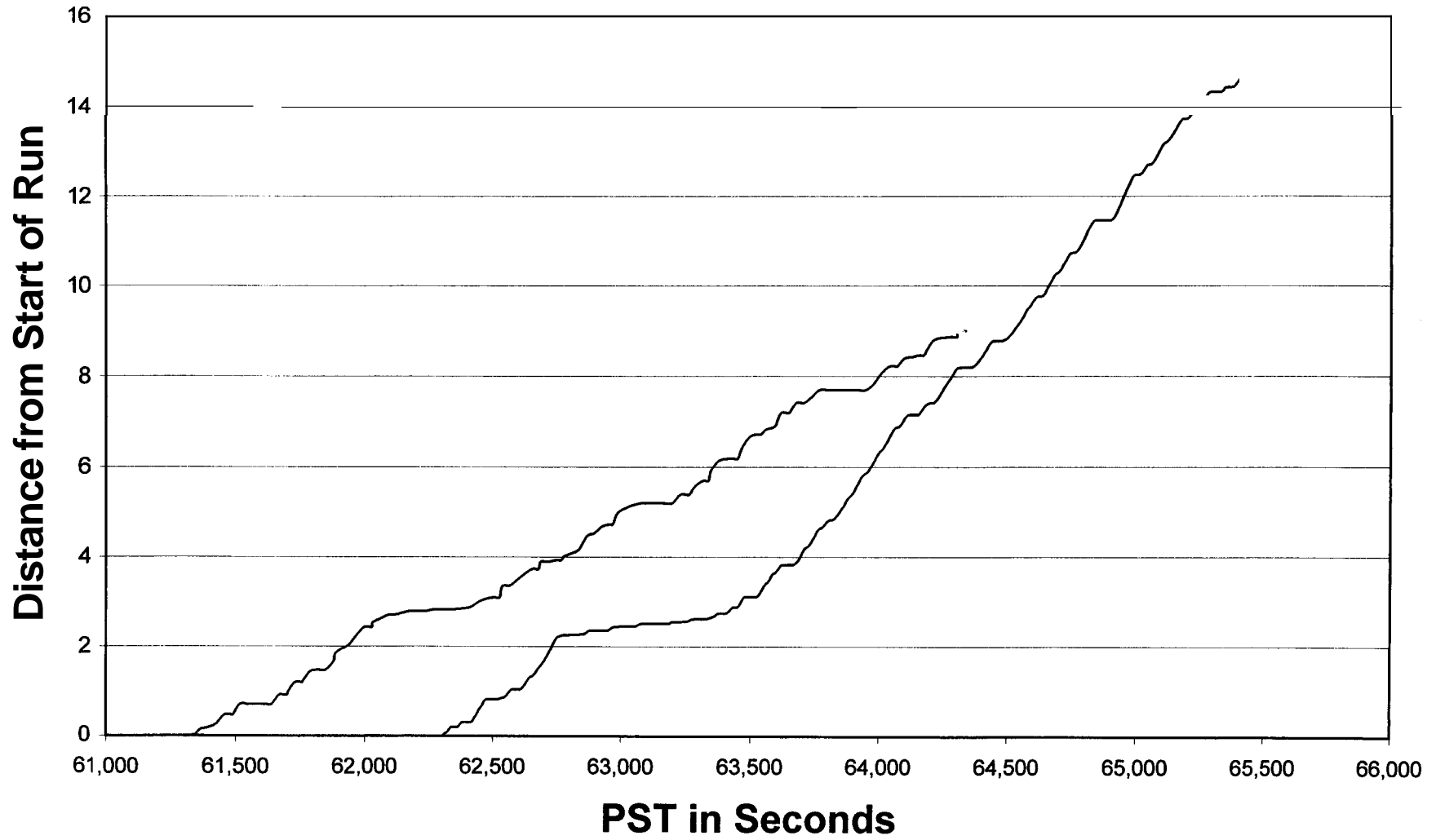
Line 49 - Plot 2



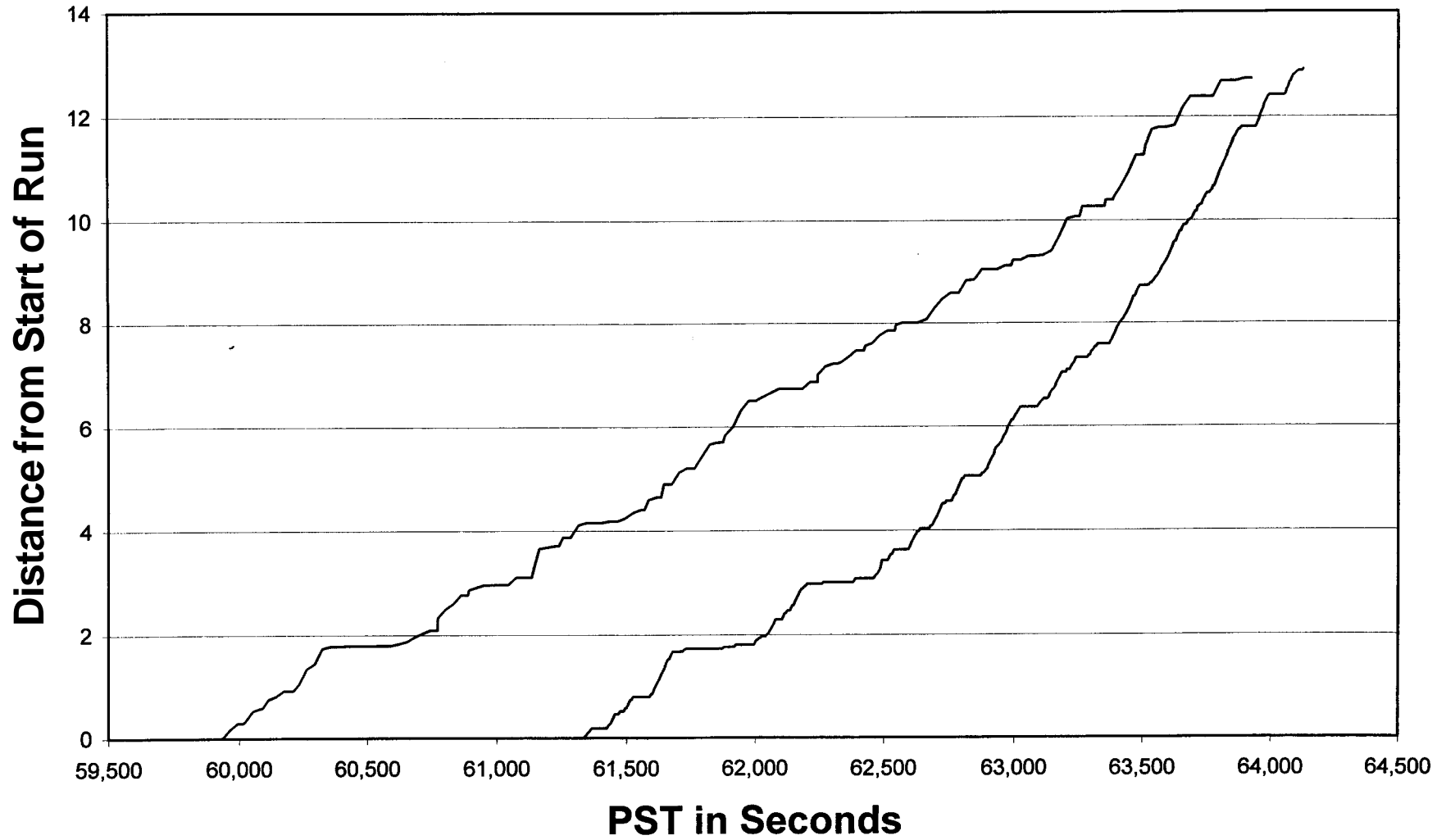
Line 49 - Plot 3



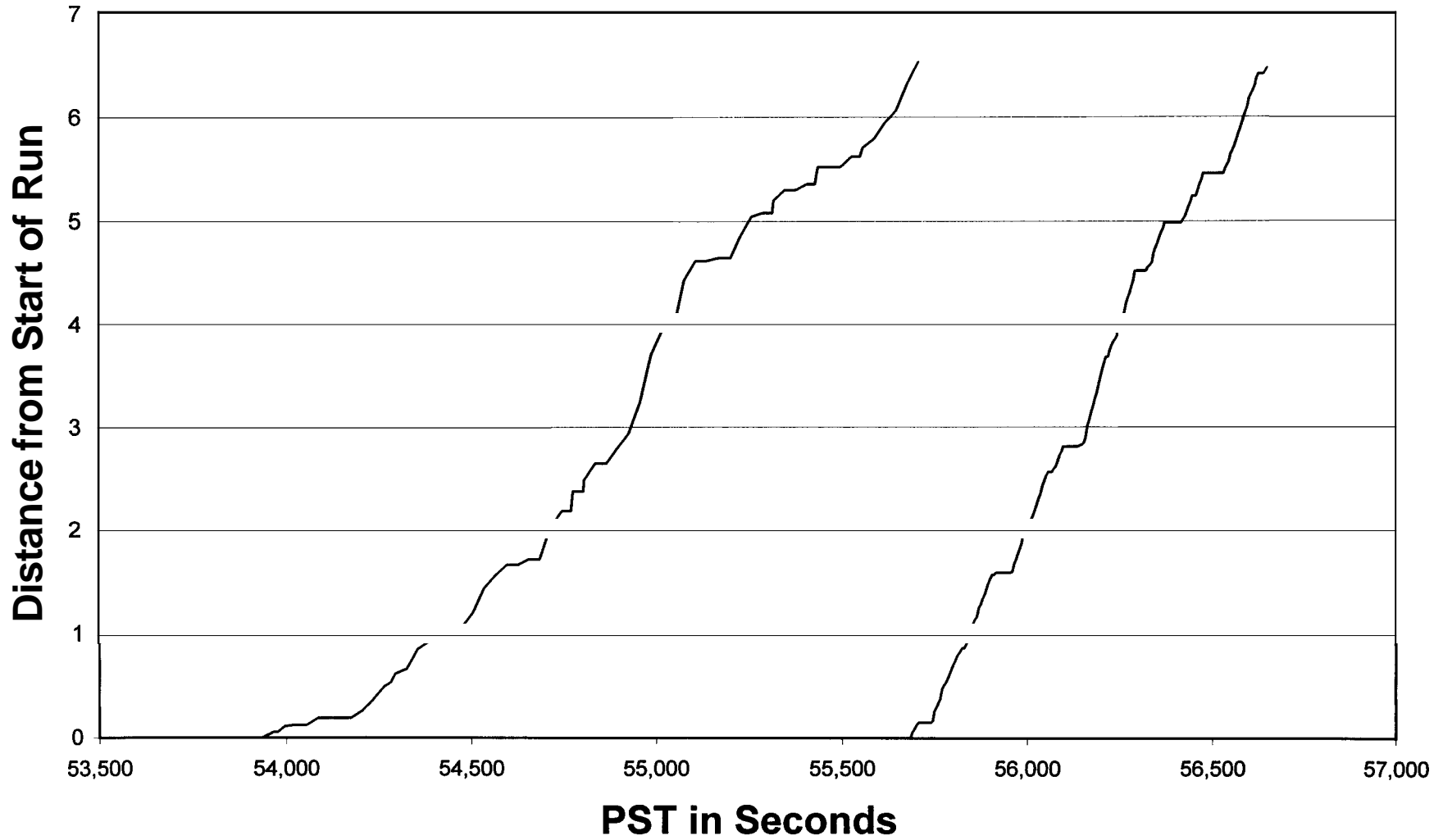
Line 49 - Plot 4



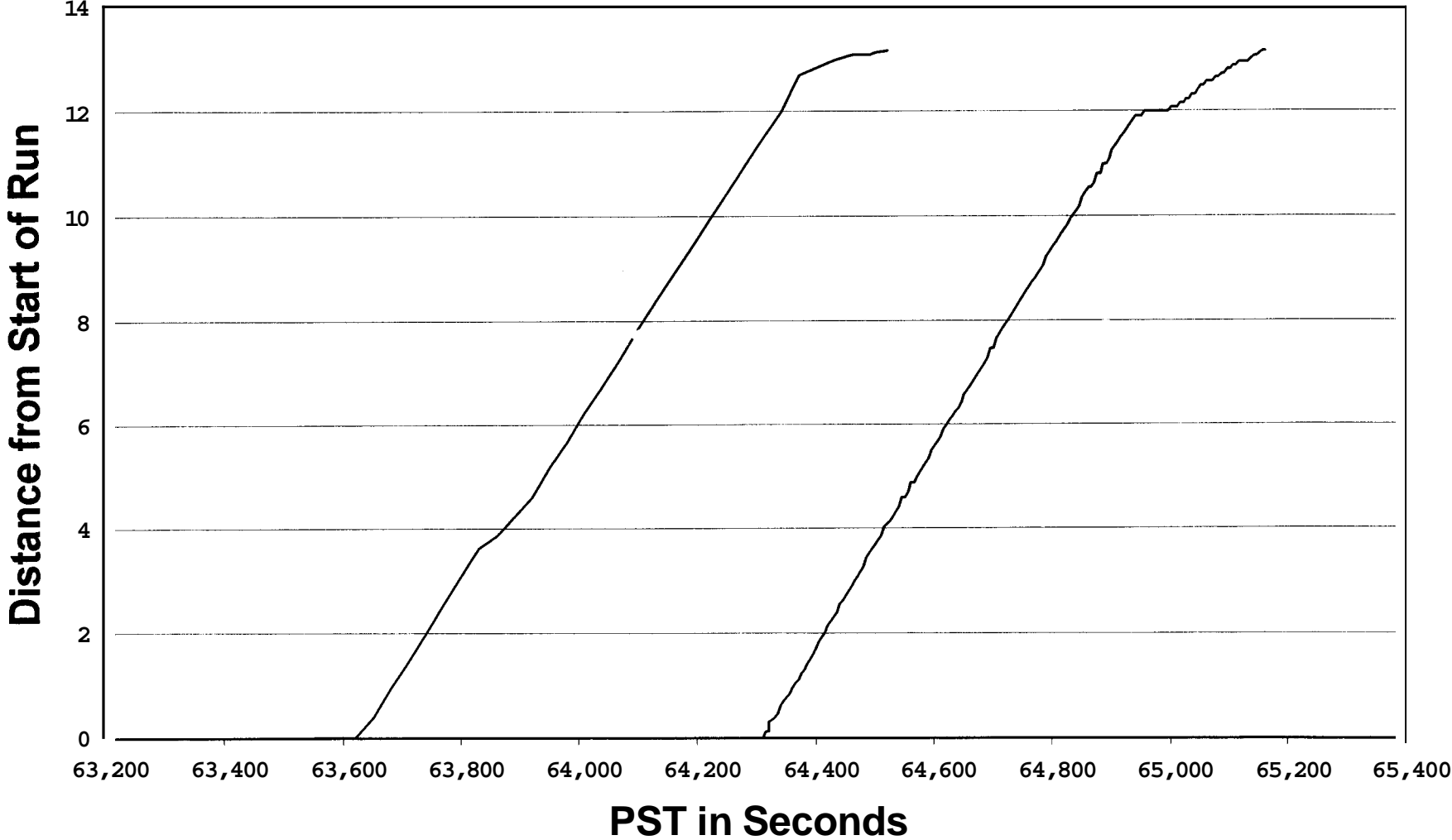
Line 49 - Plot 5



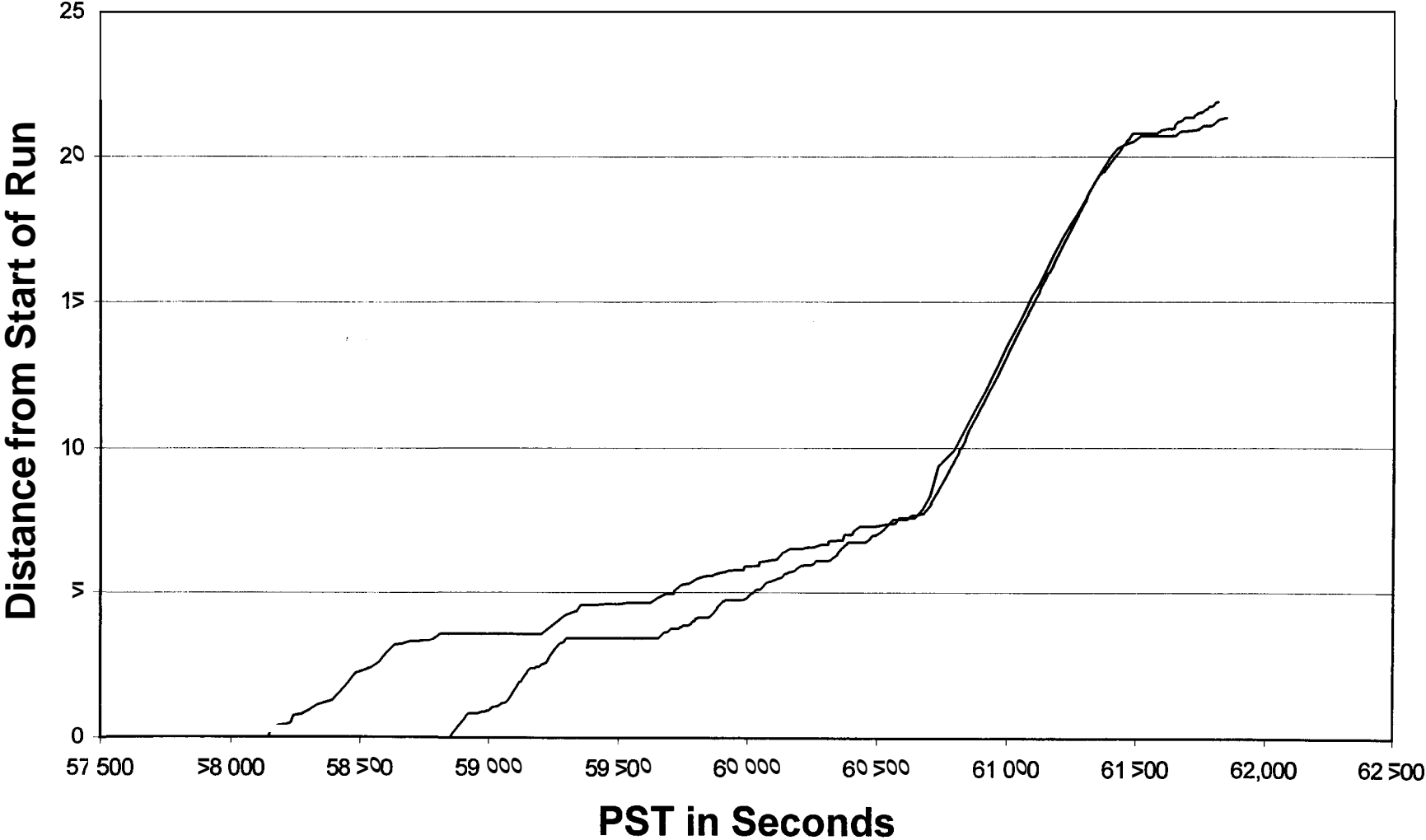
Line 49 - Plot 6



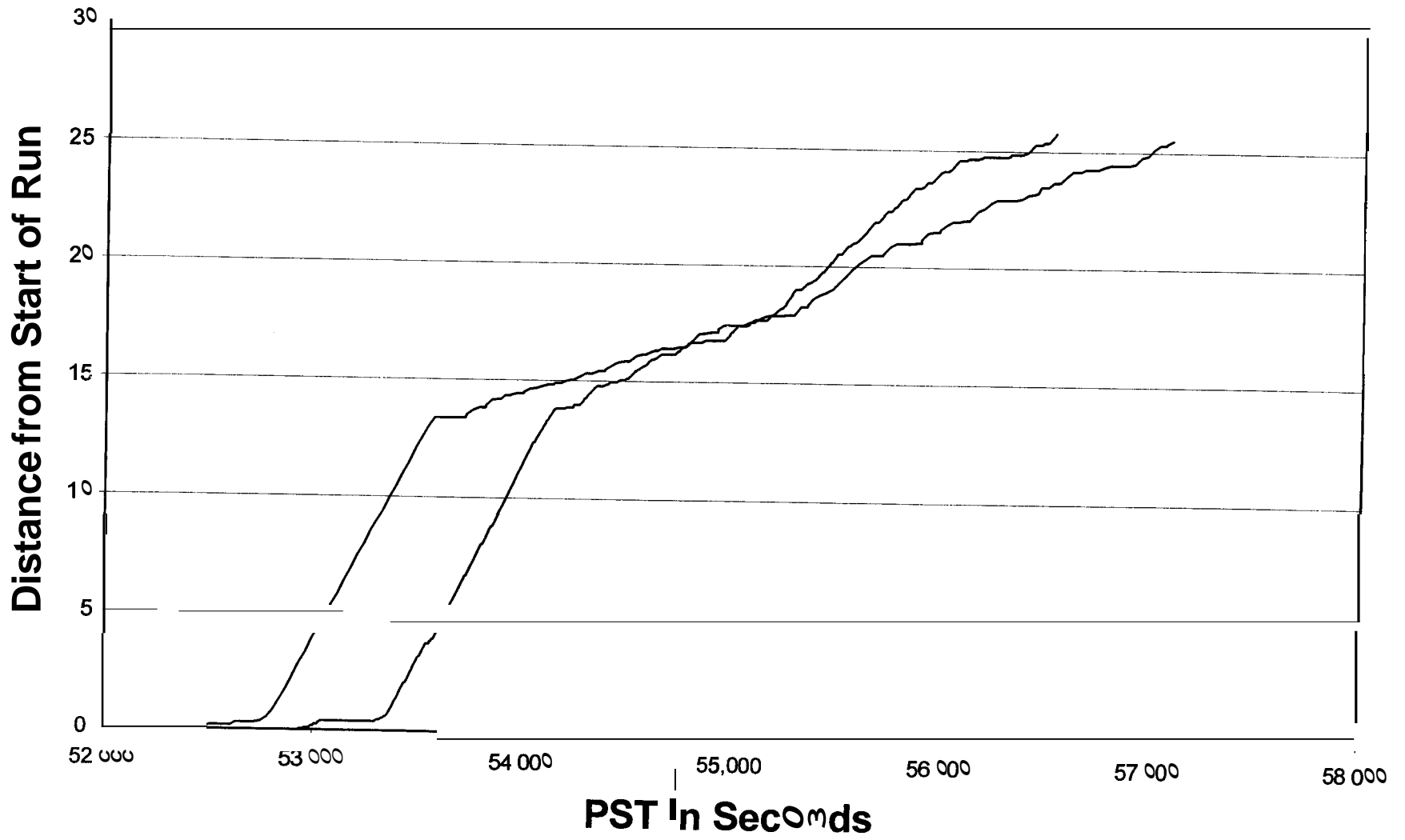
Line 205 - Plot 1



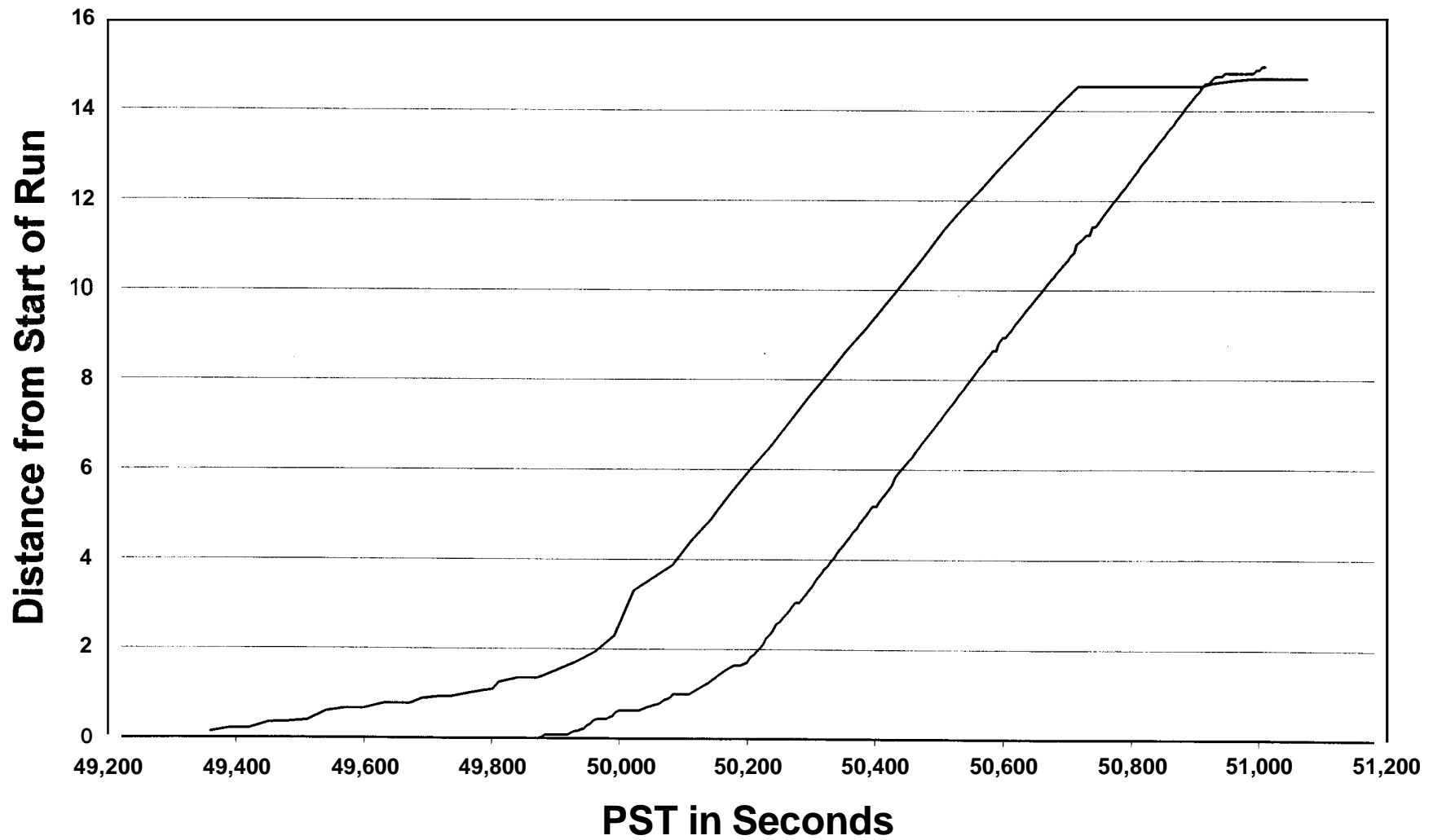
Line 205 - Plot 2



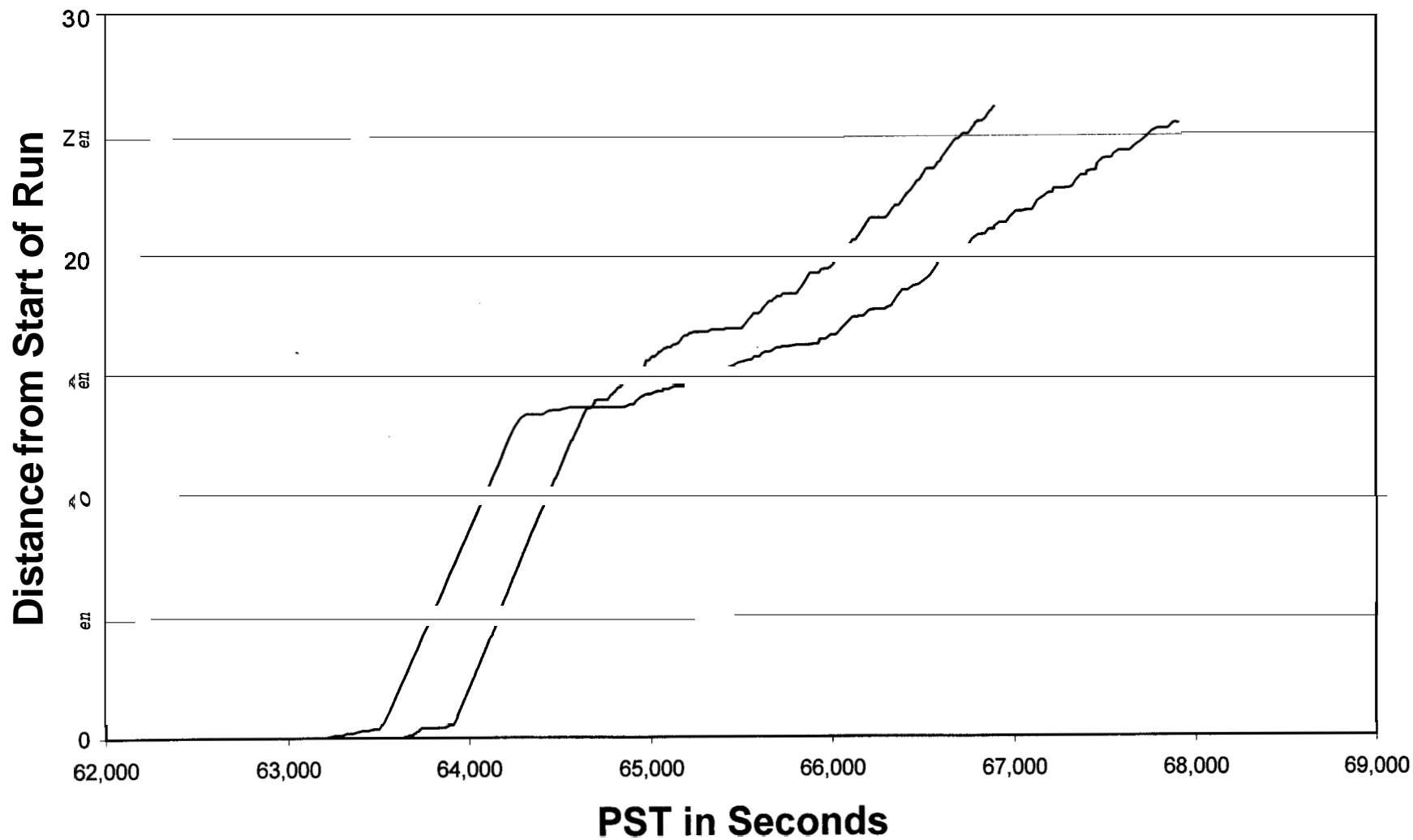
Line 205 - Plot 3



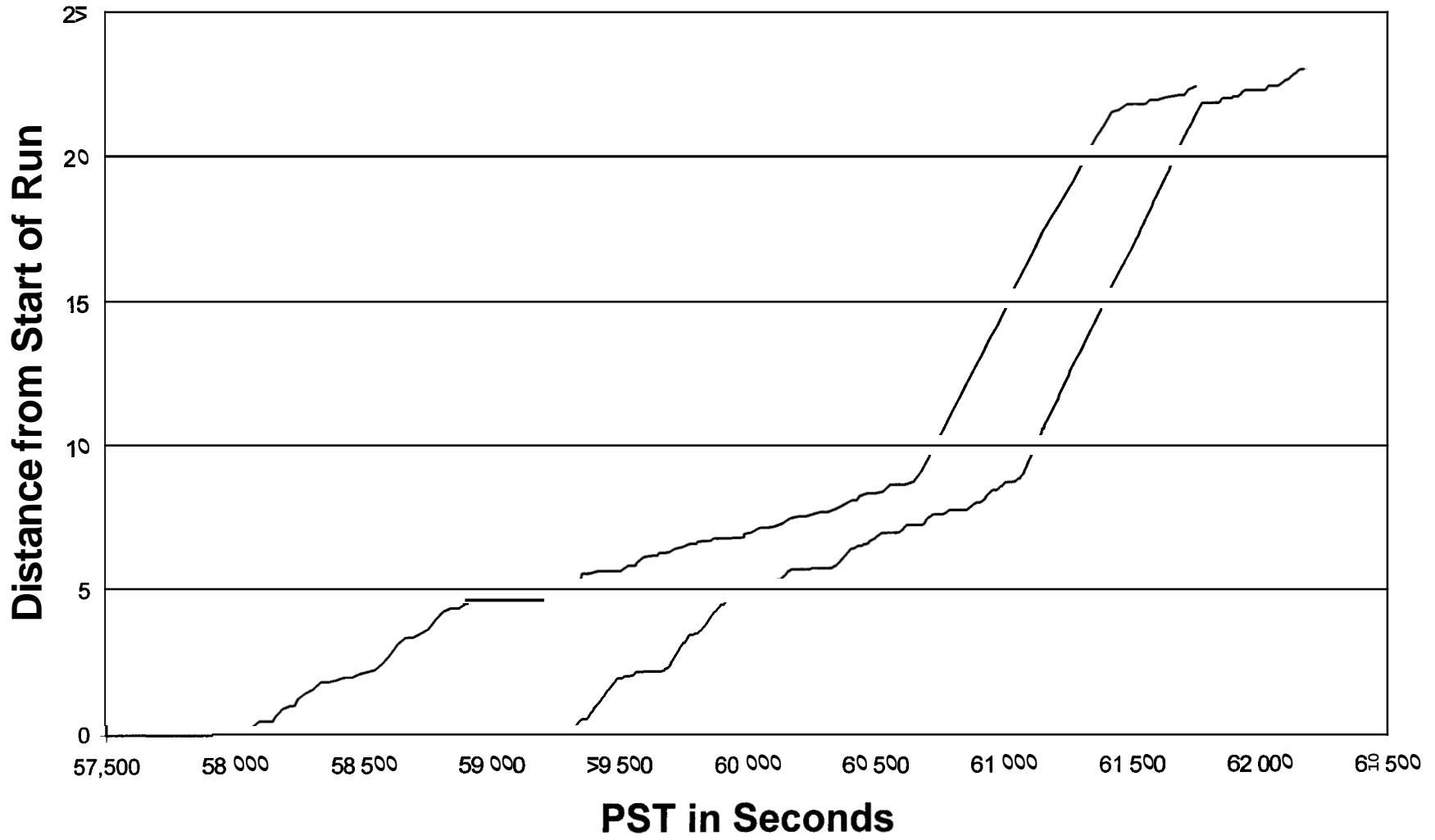
Line 205- Plot 4



Line 205 - Plot 5

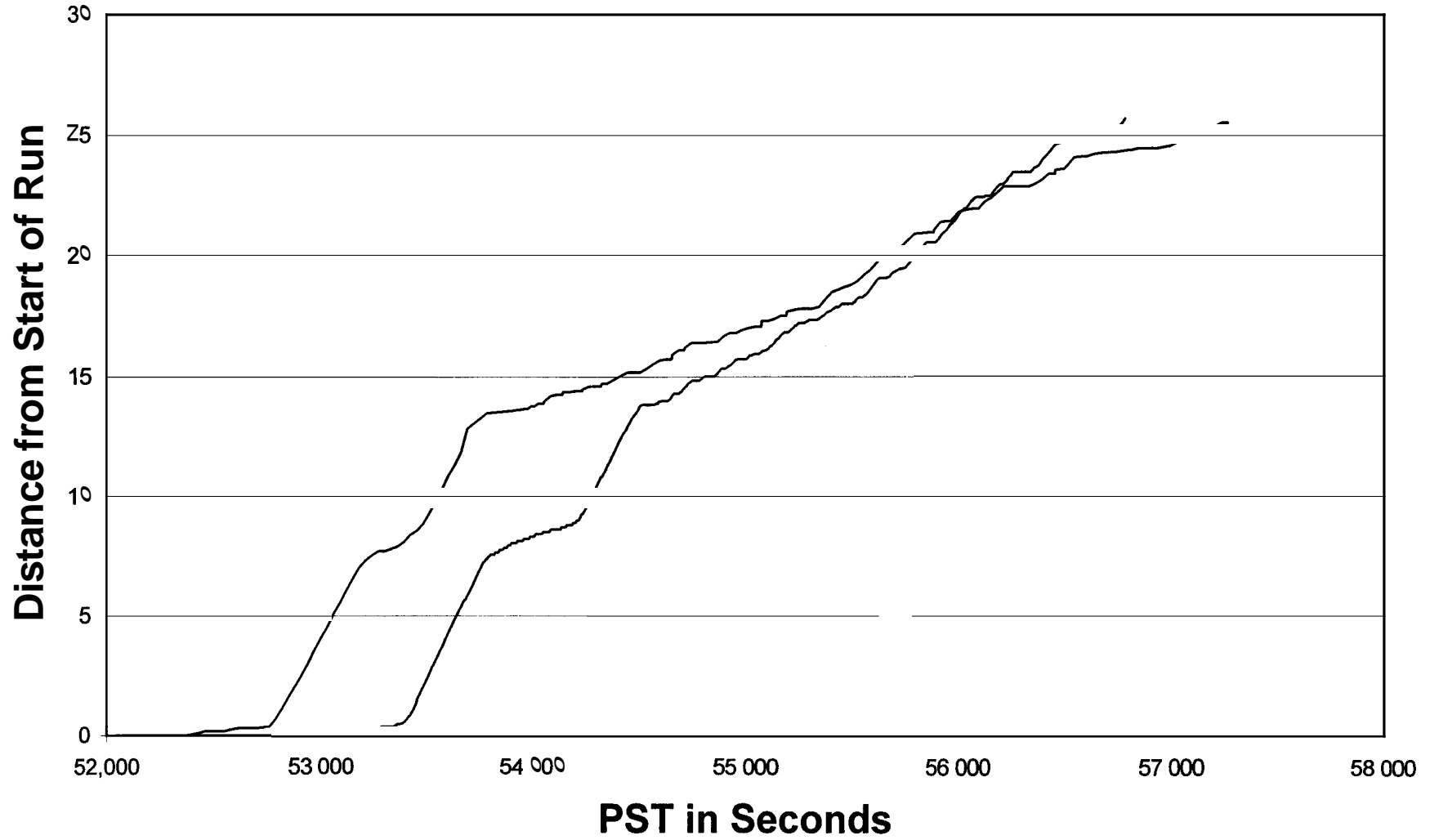


Line 205 - Plot 6

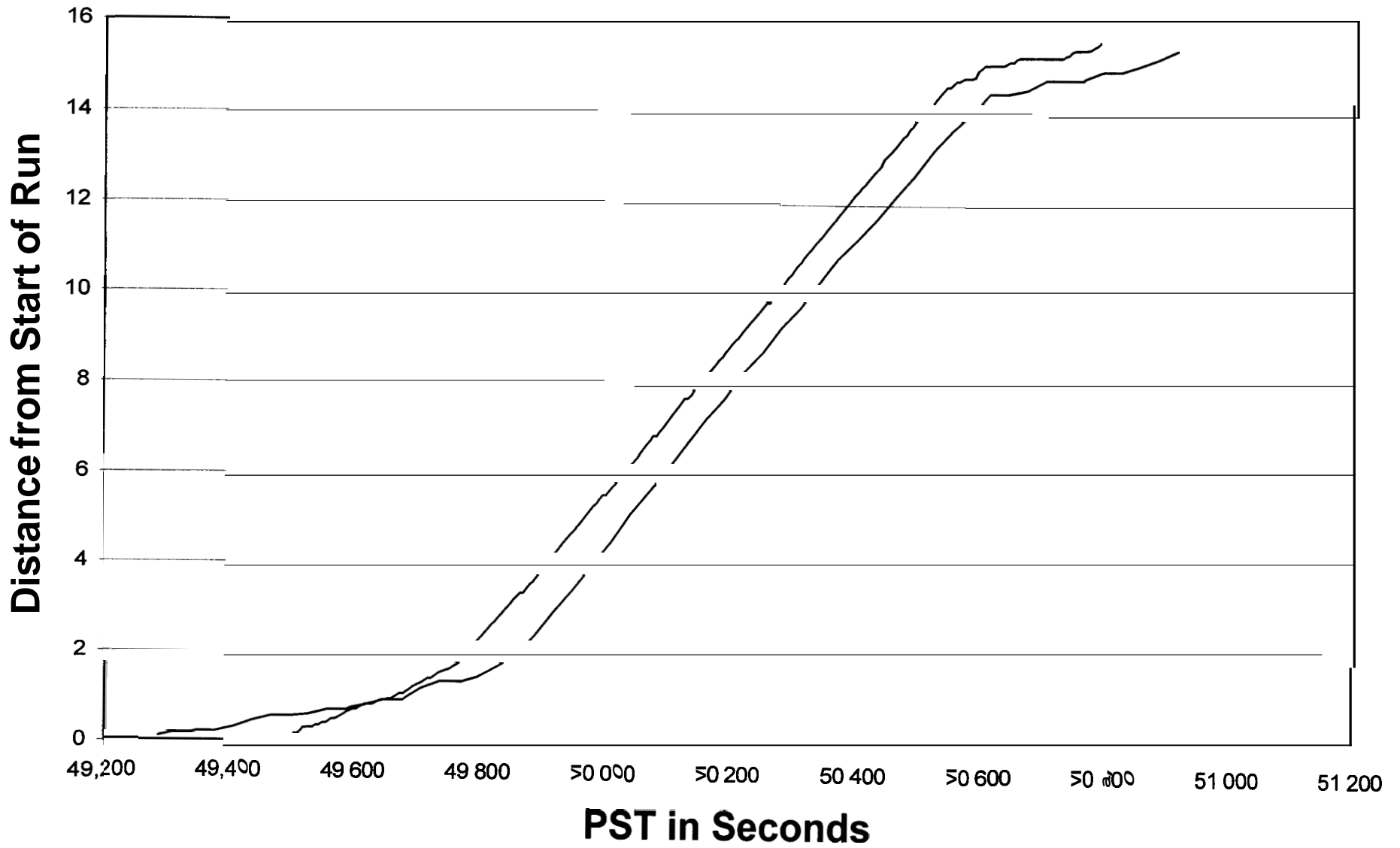


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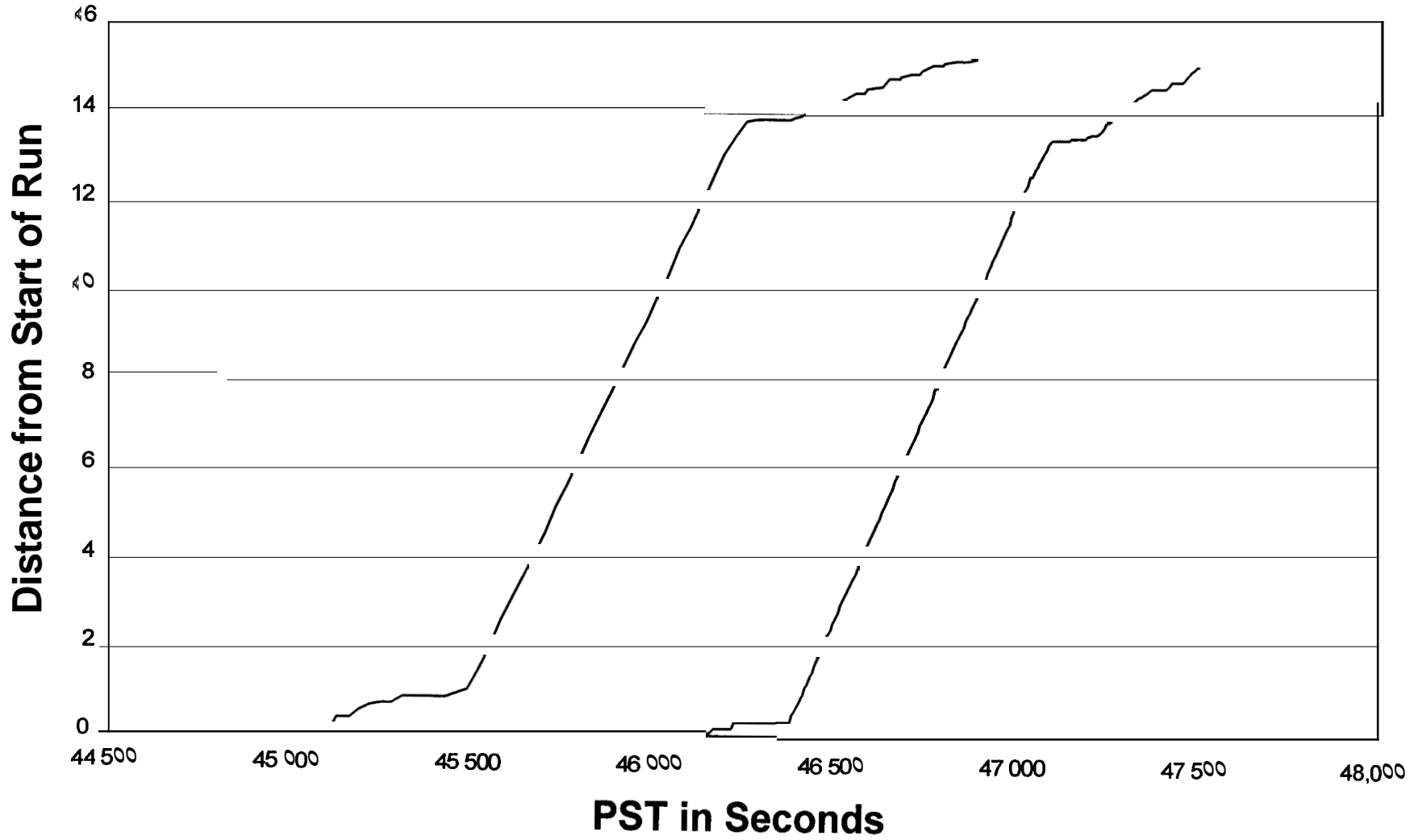
Line 205 - Plot 7



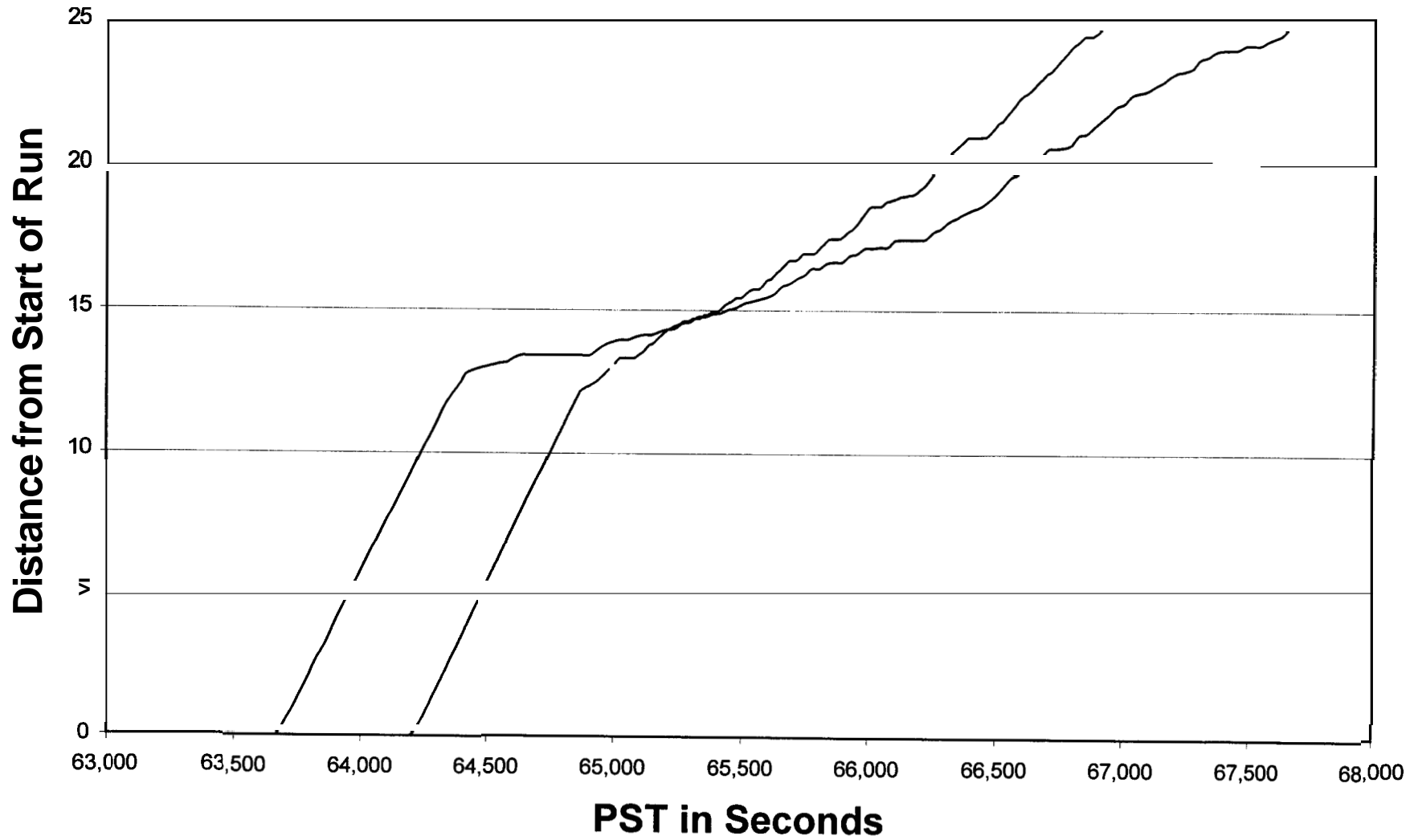
Line 205 - Plot 8



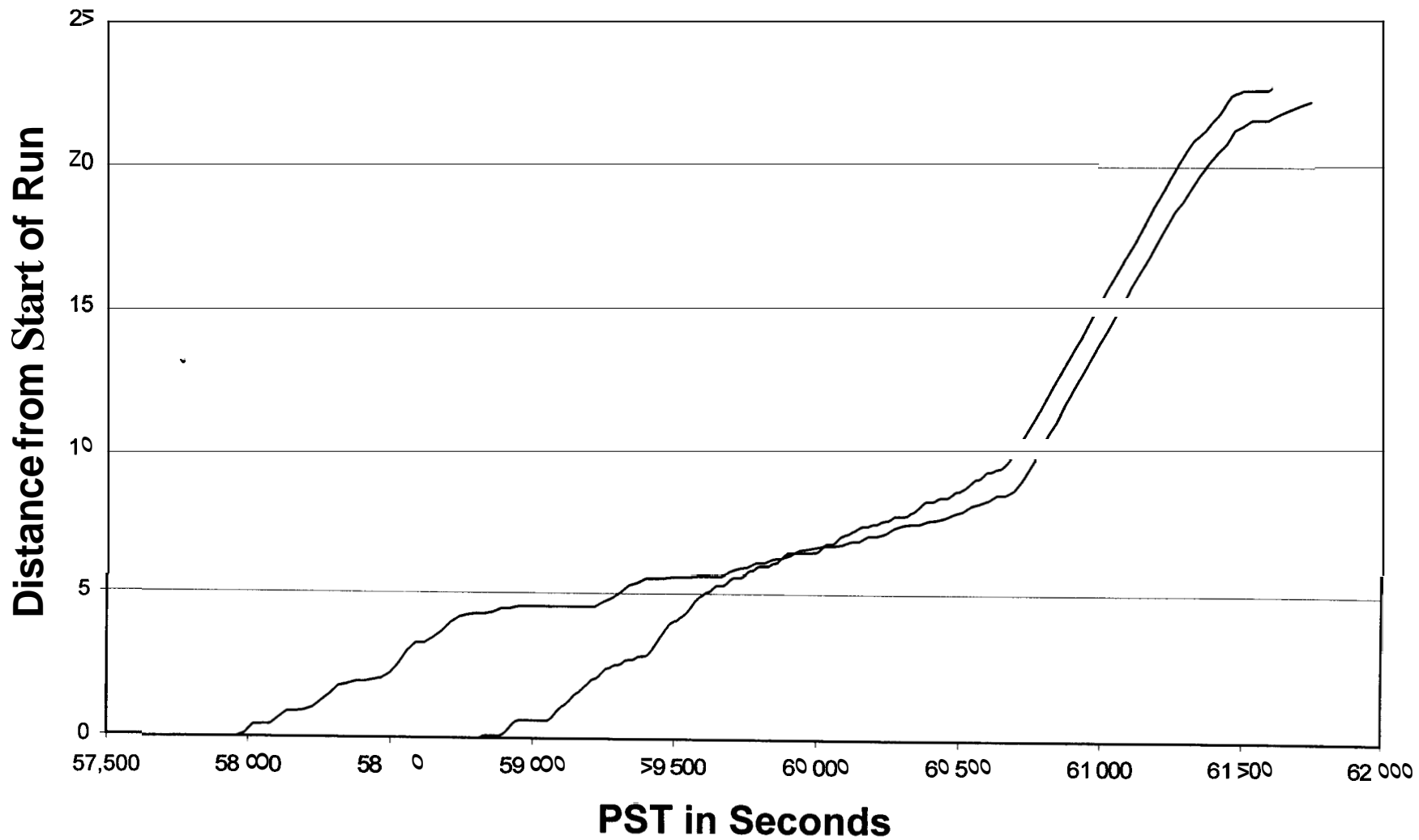
Line 205 - Plot 9



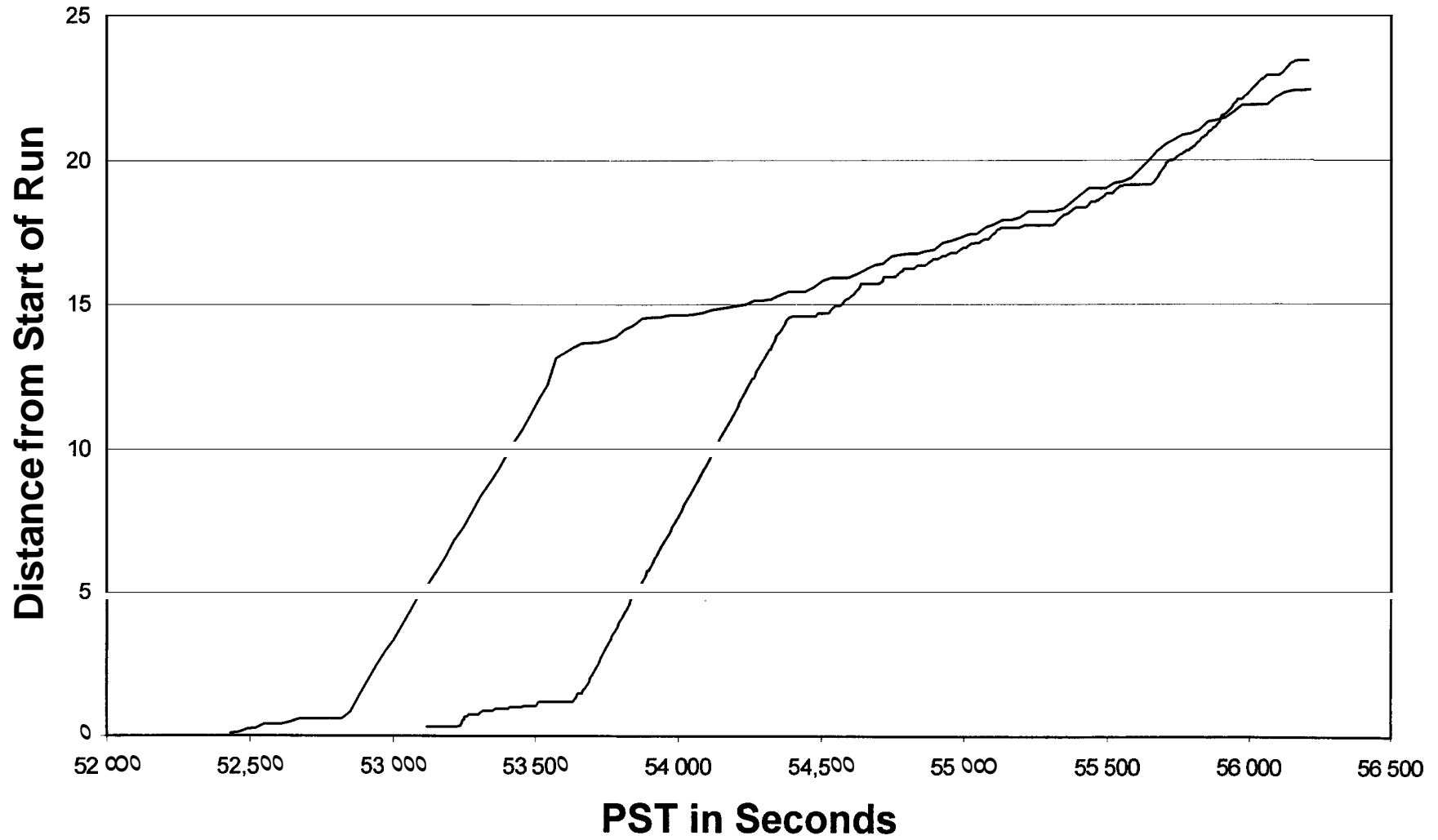
Line 205 - Plot 10



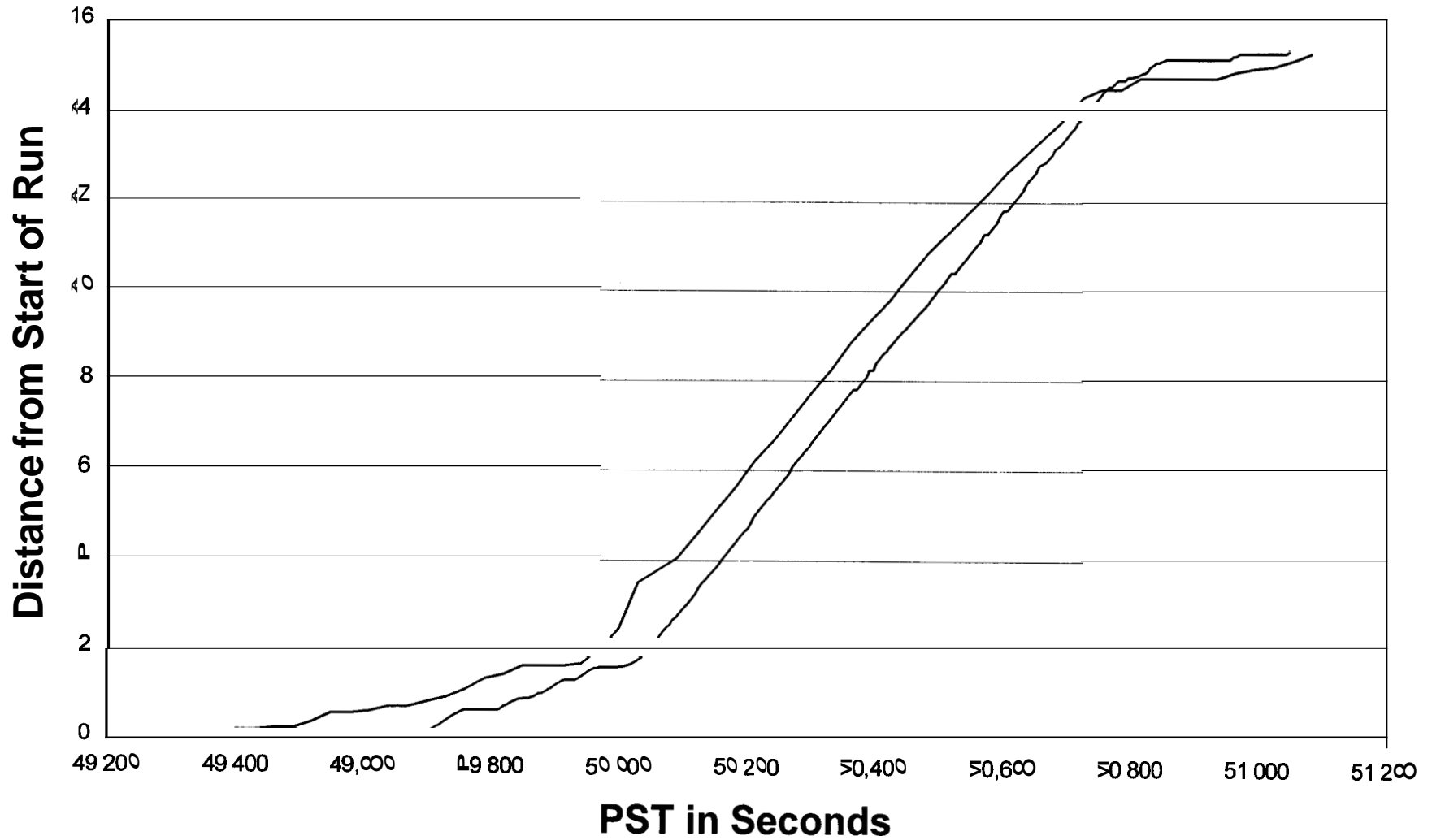
Line 205 - Plot 11



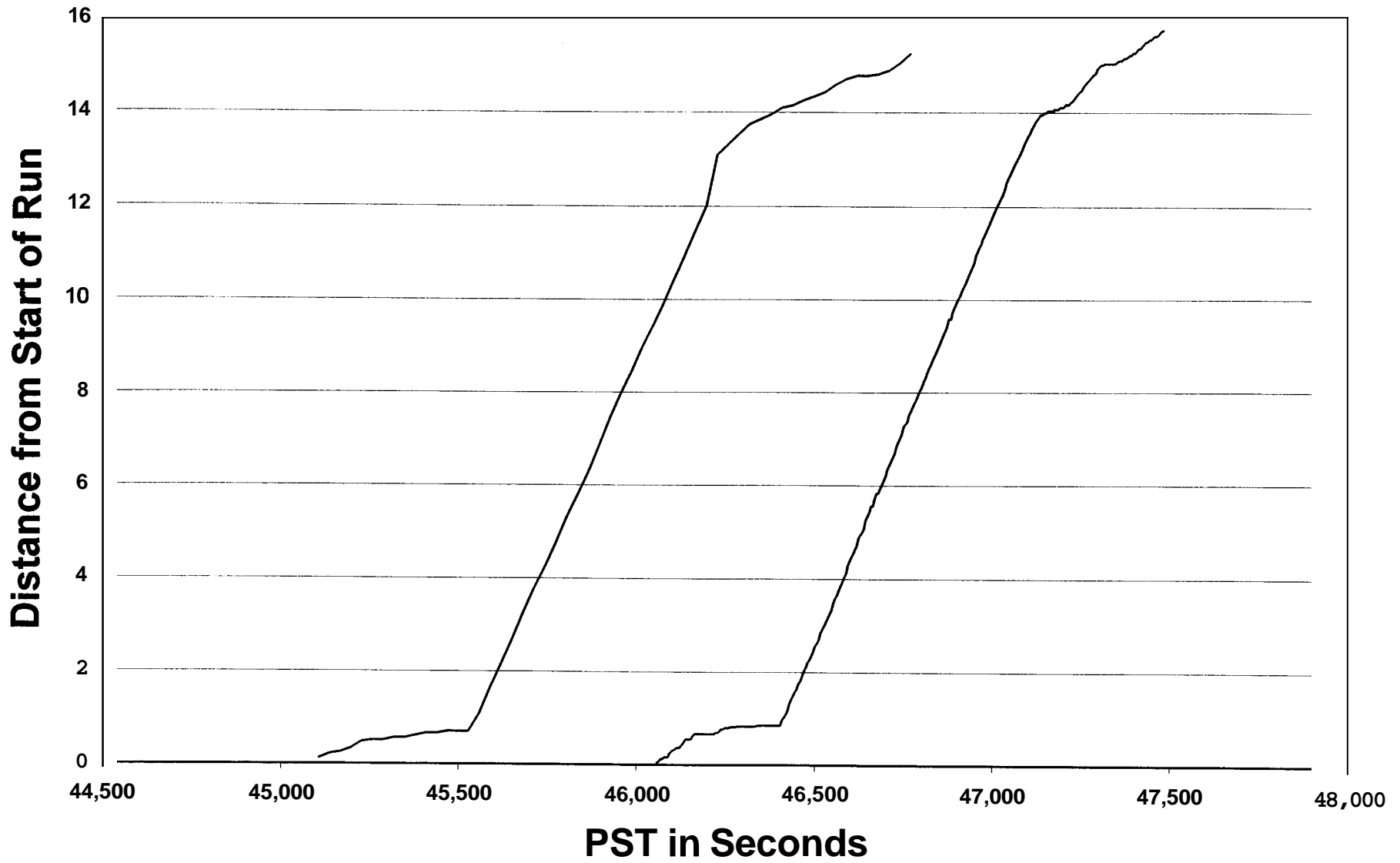
Line 205 - Plot 12



Line 205 - Plot 13



Line 205 - Plot 14



APPENDIX C: SURVEY FORMS



The Orange County Transportation Authority (OCTA) wants **YOUR** help to improve transit services by completing this questionnaire and returning it to a surveyor before you **leave** the bus.

Please answer the following questions for the bus you are riding on right now.

1999 Route Study

You will receive a coupon for a **FREE RIDE** just for filling out **this** survey.

Assignment number			Trip number

1. Where did you get on this bus?

Street _____
Cross Street _____

2. Where will you get off this bus?

Street _____
Cross Street _____

3. Before you rode the bus today, did you first.. (check all that apply)

- 1 Call OCTA for information
- 2 Look at the bus book
- 3 Look at the bus schedule
- 4 Ask someone for directions
- 5 None of the above

4. Did you know the bus schedule before you arrived at the bus stop where you boarded?

1 Yes 2 No

→ If yes, when was the bus scheduled to arrive?
_____ : _____ AM/PM

5. About how long did you wait at the bus stop before your bus arrived? (check one)

- 1 No wait
- 2 Less than 5 minutes
- 3 6 to 10 minutes
- 4 11 to 20 minutes
- 5 21 to 30 minutes
- 6 More than 30 minutes

6. Was the bus.. (check one)

- 1 Early
- 2 On-time (less than 2 minutes late)
- 3 Late
- 4 Don't know

→

6a. If late, how many minutes? (check one)

- 1 2-5 minutes
- 2 6-10 minutes
- 3 11-20 minutes
- 4 21 minutes or more

7. How did you get to the bus stop where you boarded this bus? (check one only)

- 1 Walked
- 2 Transferred from a different bus route (which one? _____)
- 3 Someone gave me a ride to the bus stop
- 4 Drove myself
- 5 Rode a bicycle
- 6 Other (how? _____)

8. Did you consider walking instead of riding this bus?

1 Yes 2 No

9. Where are you going on this trip? (check one only)

- 1 To school
- 2 To work
- 3 Shopping
- 4 To a medical appointment
- 5 Home
- 6 To recreation/social visit
- 7 Other _____

10. Do you need to arrive at your destination by a certain time?

1 Yes 2 No

→ If yes, when do you need to get there? _____ : _____ AM/PM

When do you think you will get there? _____ : _____ AM/PM

11. Will you be transferring to a different bus route?

1 Yes (which one? _____) 2 NO

12. How many times have you used this bus route?

- 1 First time ever on this route
- 2 2-10 times
- 3 More than 10 times

13. Does this bus usually arrive... (check one)

- 1 Within 2 minutes of scheduled time
- 2 Within 3-5 minutes of scheduled time
- 3 6 or more minutes late
- 4 Don't know

14. Have you noticed any lights that tell the driver when the bus is late or early?

1 Yes 2 No

15. How would you rate service on this route compared to one year ago?

- 1 On-time more than it used to be
- 2 On-time less than it used to be
- 3 On-time about the same
- 4 Don't know

16. How old are you?

- 1 17 or under 3 35-64
- 2 18-34 4 65 and over

17. Are you?

1 Male 2 Female

18. What is your primary language?

- 1 English
- 2 Spanish
- 3 Other

Thank you very much for completing this survey!
Please turn it in to a surveyor in order to receive a free ride ticket!

Español →

OCTA Intercept Survey

1. How easy is it to find out when your bus **departs** compared to **phoning the OCTA information line**?
 Kiosk easiest 1 c 1 2 3 4 5 info line easiest

2. How easy is it to find out when your **bus departs** compared to using the **OCTA Bus Book**?
 Kiosk easiest 1 2 3 4 5 Bus Book easiest

3. Would you use this kiosk again to find out when your **bus departs**?
 Yes No Maybe

4. How easy is it to find out how to **get to your destination** compared to **phoning the OCTA information line**?
 Kiosk easiest 1 2 3 4 5 info line easiest

5. How easy is *it* to find out how to **get to your destination** compared to using **OCTA's Bus Book**?
 Kiosk easiest 1 2 3 4 5 Bus Book easiest

6. Would you use this kiosk again to find out how to **get to a destination**?
 Yes No Maybe

7. How easy are the **maps** to understand compared to using **OCTA's Bus Book**?
 Kiosk easiest 1 2 3 c 1 4 5 Bus Book easiest

8. Would you use this kiosk again to **look at a map**?
 Yes No Maybe

9. What do you **like most** about this kiosk? _____

10. How would you **change** the kiosk to **improve it**? _____

11. How **often** will you use this **kiosk** in the future?
 Never 1-4 times/month 5 or more/month

12. How **long** have you used **OCTA buses**?
 Less than 6 months 6- 12 months 1 year or more

13. How many **times per week** do you use **OCTA buses**?
 1st time today 1- 4 times /week 5 or more/week

14. How **often** do you use the **Santa Ana Transit Terminal**?
 1st time today 1- 4 /month 5- 10 / month More than 10 / month

15. How old are you?
 17 or less 18-34 35-64 65+

16. Male Female

17. Primary Language: Spanish English Other