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Assessment of METROLift Automatic Vehicle Location System

TTI/ITS RCE-95/02

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16. Abstract

This report examines the use of an automatic vehicle location (AVL) system with the paratransit services operated by the Metropolitan Transit Authority of Harris County (Houston METRO). METRO provides specialized paratransit services to individuals with special needs within the Houston metropolitan area. The service, which is called METROLift, provides pre-scheduled, curb-to-curb transportation for individuals who are unable to ride accessible fixed-route buses. METROLift provides approximately 2,300 daily trips utilizing 153 vehicles. In 1993, METRO initiated the use of an AVL system with the METROLift service.

This report examines the use of the AVL system and its impact on the METROLift service. It includes an assessment of the performance of the AVL system; changes in METROLift response times, customer complaints, backup taxi service, and the ratio of passenger miles to revenue miles; and the reaction of operating personnel. It also identifies additional enhancements to specialized transportation services through the application of ITS technologies. Transit systems throughout the United States and the world are examining methods to improve the responsiveness of specialized paratransit services, while at the same time maximizing the efficiency of the services. The results from this research study indicate that an AVL system can help in meeting these objectives.

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SUMMARY

Introduction

Providing public transportation services to individuals with special needs continues to be a priority of federal, state, and local governments, transit operators, advocacy groups, and users. Federal regulations require that public transit systems provide both mainline accessible service and paratransit or other specialized service. Improving the responsiveness and timeliness of paratransit services and maximizing the operating efficiency of these services are major goals of transit agencies throughout the country.

The application of intelligent transportation systems (ITS) and other advanced technologies may help transit systems realize these goals. The use of automatic vehicle location (AVL) systems may enhance the ability of paratransit services to respond to changes in client travel schedules and to improve service productivity. Further, when used in combination with other technologies, such as advanced paratransit scheduling packages, AVL systems may grant the opportunity to provide dynamic scheduling and other service enhancements.

This report documents the use of an AVL system with METROLift, the specialized paratransit service operated by the Metropolitan Transit Authority of Harris County (METRO) in Houston, Texas. In 1993, METRO initiated the use of the AirTouch Teletrac AVL System with the 153 vehicle METROLift fleet. The Texas Transportation Institute (TTI), a part of The Texas A&M University System, through the Texas A&M ITS Research Center of Excellence and METRO, evaluated the impact of the AVL system on METROLift services. The research was funded by METRO, the Federal Highway Administration (FHWA), and the Texas Department of Transportation (TxDOT).

The METROLift automatic vehicle location (AVL) system provides one example of how intelligent transportation systems (ITS) and other advanced technologies can enhance the effectiveness and efficiency of specialized paratransit services. The METROLift AVL system has helped METRO meet increasing demands for service in a time of limited resources. METRO is better able to manage METROLift fleet requirements and vehicle dispatch functions with the AVL system.

Background

METRO has provided specialized paratransit services to individuals with special needs since 1979. The METROLift service provides pre-scheduled, curb-to-curb transportation for individuals who are unable to ride accessible fixed-route buses. Approximately 2,300 daily trips are provided utilizing 153 minivans and sedans, and backup taxi services. METROLift customers call 24 hours in advance to schedule trips.

Like most transit agencies in the country, METRO has experienced a steady increase in demand for METROLift service. In 1985, the METROLift system provided approximately 25,000 passenger trips a month. By 1992, monthly ridership had grown to some 50,000, and by 1994, approximately 70,000 riders a month were using the system.

In 1993, METRO initiated the use of the AirTouch Teletrac AVL system with the METROLift service to enhance the efficiency of the system. The AirTouch Teletrac AVL system uses a subscriber-based radio trilateration technology. The system uses a network of 25 radio towers in the Houston area, a location unit on the individual vehicle, and central computer tracking and mapping functions. The digital trans-receiver, called a vehicle location unit, is attached to an automobile, bus, or minivan. The vehicle's location is tracked using a software program on a personal computer linked to a central computer by a modem.

When the location of a vehicle is requested, the vehicle location unit receives a page and transmits a digital code which is received by radio towers in the vicinity. At least four towers must receive a signal to tri-laterate on the vehicle's position, but more towers provide increased accuracy. The system can page and locate a single vehicle, a group of vehicles, or all vehicles within the service area. The system also provides an emergency call button that an operator can push to receive immediate attention from the control center. This feature is not currently used with the METROLift vehicles, however.

Currently, 153 METROLift minivans, sedans, and taxicabs are equipped with the AirTouch vehicle location units. Within the METRO offices, the METROLift dispatchers work stations have two computer screens. One screen displays METROLift customer information, and the other is linked to the AVL system. A dispatcher can request and display the location of METROLift vehicles on the computer screen using the AirTouch AVL system and the ETAK map. The present system configuration allows the dispatchers to page and locate single or multiple METROLift vehicles.

The dispatchers also have telephones and two-way radios available to communicate with METROLift operators. Further, Mobile Data Terminals (MDTs) located on the METROLift vehicles, are used to send messages to operators. The operators can send pre-coded responses over the MDTs, but these appear only on one screen at the METROLift offices.

METROLift dispatchers and operators are using the AVL system in two ways. These are to give directions to operators to help them find a rider's address and to provide customers with information on the status of a vehicle for a trip request.

First, dispatchers are able to provide assistance to operators who are lost or cannot find a rider's address. In response to a request from an operator over the radio, a dispatcher is able to page the vehicle, display its location on the map, and provide verbal directions to the operator.

Second, the dispatcher can use the system to provide information to customers concerning the status of a vehicle. In response to a customer calling METROLift to inquire about a late vehicle or the status of their service, the dispatcher is able to page the vehicle, display its location on the map, and provide information to the customer on the estimated time of arrival.

METROLift AVL System Performance

A number of tests were conducted to assess the performance of the AVL system. METRO is primarily interested in the locational accuracy of the system, which AirTouch stated as 46 meters, at 2 sigma of the vehicle's actual position. A 2 sigma level of accuracy means that 95 percent of the locational readings obtained from the system should be within the stated range. AirTouch notes that this level of accuracy may not be met in downtown areas, however, due to possible interference from tall buildings.

The AirTouch AVL system presents vehicle location in either latitude and longitude coordinates or street locations. The locational accuracy of the system was assessed through tests comparing the latitude and longitude coordinates of readings taken with the AirTouch AVL system with those taken with a Differential Global Positioning System (DGPS). The GEOD software package, developed by the United States Geological Service (USGS), aided in this analysis.

The AVL system was tested under a number of different conditions. These included both a stationary vehicle and a moving vehicle. Additional tests included a vehicle traveling on the edge of the service area, as well as a vehicle located in a parking garage and in an underground parking area. The AirTouch and DGPS AVL system readings were compared at 53 sites, which were selected to provide a mix of locations within the Houston area, as well as different environments.

Twenty of the tests were taken at bus stops along the METRO 2 Bellaire Route-Dairy Ashford Branch. This route serves the southwest area of the city and includes low density areas, the Texas Medical Center, and downtown Houston. METRO park-and-ride lots and transit centers comprised 26 of the test sites. These are located primarily in less dense suburban areas of the city. Parking structures in downtown Houston, Greenway Plaza, and the Galleria were tested. Two sites in southwestern Houston were used for the moving vehicle tests.

Although the exact approach varied slightly with the different tests, similar procedures were followed at the various sites. At each location, readings were taken using the AirTouch and the DGPS. A portable AirTouch AVL, connected to a 12-volt battery, was used in the tests. The battery was tested and recharged if necessary before readings were taken. In addition, a few tests were taken with the VLU connected to the cigarette lighter in a vehicle with the motor running. Both the VLU and the DGPS were placed at the same location. One system was tested first, and then the other unit was located at the same spot and readings were taken. At least 20 readings were taken at each site, and tests were completed on two different days.

The AirTouch readings were generally within the accuracy of 46 meters at 2 sigma for all of the tests, except in the downtown area or other locations with tall buildings. Although some readings in the downtown area were within 150 of the DGPS readings, others were not. Signal interference from tall buildings or other structures influenced results in these areas.

Since the DGPS cannot operate in an underground garage or a parking structure, these tests simply measured the ability of the AirTouch AVL system to obtain a reading. In these tests, the AirTouch system was able to locate a vehicle both one floor down in the underground parking garages and in the parking structure. The system was not able to locate a vehicle two floors underground or two floors below the roof of a parking garage.

Impact of METROLift AVL System

The impact of the AVL system on METROLift services was examined from three different perspectives. A series of performance measures including service efficiency, as measured by the ratio of passenger miles to vehicle revenue miles and the use of taxi backup service, and on-time performance were assessed. Second, the reaction from METROLift dispatchers and operators was examined through surveys and interviews. Finally, customer reactions were noted through a review of changes in the number and types of complaints and a general telephone survey on METROLift services.

The results of this analysis indicate that the METROLift AVL system has allowed METRO to better manage fleet requirements and vehicle dispatch functions. As a result, METRO has been able to better meet increasing demands for service in a time of limited resources. METROLift dispatchers and operators have also noted improved productivity and enhanced capabilities for the system.

Changes in Service Efficiency

The impact of the METROLift AVL system on service efficiency was assessed using three general measures. Changes in the ratio of passenger miles to vehicle revenue miles, the use of taxi backup services, and on-time performance were examined to assess the possible impacts of the AVL system on vehicle efficiency.

The ratio of passengers to vehicle revenue miles provides an indication of the efficiency of a paratransit system. Higher ratios indicate that more passengers are being carried per mile. Monthly METROLift vehicle revenue miles and passenger miles for October 1992 to October 1994 were examined. The monthly and annual ratio of passenger miles to vehicle revenue miles were calculated and graphed.

The results of this analysis indicate that the ratio of passenger miles to vehicle miles increased from the period before implementation of the system to 1994. The annual ratio of passenger miles to vehicle revenue miles for the two years before the AVL implementation were 1.11 and 1.04, while the ratio for Fiscal Year 1994, after the AVL system was implemented, was 1.21. This change represents a significant improvement.

The second efficiency measure examined was the use of backup taxi services. METROLift utilizes taxi service to help meet peak demands for service. When trip requests cannot be met by METROLift minivans, backup taxi services are employed. The use of taxis should decline if the AVL system increases the efficiency of METROLift vehicles, unless ridership continues to increase—placing more demands on the system.

Monthly records on taxi trips were examined for the period from August 1993 to November 1994. The use of taxi service increased significantly from August of 1993 to May of 1994. This increase appears to be the result of a change in policy by METRO to deploy additional taxis to address increases in demand and customer complaints. Since May of 1994, however, the use of backup taxi service has declined. Although current use of taxi service is higher than in 1993, the AVL system has allowed METRO to better manage vehicle demands, including taxi service.

The on-time performance of METROLift service was examined for the pre- and post-AVL time periods. METRO considers a trip late if a vehicle does not arrive within 15 minutes of the scheduled pick-up time, a log is maintained of customers calling to report late trips. The METROLift late trip records provided the information needed to calculate the percentage of late trips on a monthly basis.

The percent of reported late trips declined from approximately 4.5 percent in October of 1993, to 3.4 percent in September of 1995. The percent of late vehicles dropped to a low of around 1 percent during March and April of 1994. This corresponds to the time period when more taxis were also being utilized. The decrease in late calls during this time can be attributed to the deployment of additional taxis and the AVL system.

Reaction of METROLift Dispatchers and Operators

Interviews were conducted with METROLift dispatchers and operators to determine their reaction to the AVL system. Information was obtained on use of the system, ease of operation, problems or issues with the system, and any recommendations for improvements or changes. Twelve of the 14 dispatchers were interviewed, along with 30 of the approximately 220 METROLift operators. The overall response to the AVL system was very positive from both groups.

All of the dispatchers interviewed indicated that the AVL system is easy to use. Further, most indicated that it had only taken a day or two to learn the system and to become comfortable with the different features. The eight dispatchers who had worked at METROLift before the system was implemented reported that their job was much easier. Numerous benefits were noted related to the fast and reliable information about the location of vehicles provided by the system. The key advantages identified included the enhanced ability to give operators directions to find addresses, the capability to provide customers with better information on the status of vehicles, and reduced telephone and radio time with both operators and customers. The dispatchers also noted reductions in paperwork and job stress, along with less worry about making mistakes.

METROLift dispatchers did identify a few areas for improvements, however. They noted some errors in the map, primarily with problems resulting from roadway construction, new developments, and changes in traffic patterns. The need to update the map on a regular basis was the most frequently cited area for improvement by the dispatchers.

The response from METROLift operators was also positive. Most of the operators found the system easy to use and indicated that it has simplified their job. The ability to get directions quickly was identified as one of the major benefits of the system. The majority of the operators interviewed also noted they felt more secure with the system, especially with the emergency help feature which was used initially.

The operators identified a few improvements to the system. The major issue raised by the operators concerned the location of the mobile data transmission (MDT) unit. Many of the operators noted the position of the MDT inside the vehicle was too high, making it difficult to read and send messages. Suggested changes included moving the unit closer to the dashboard or radio and locating it on the engine boot. The small type size was also noted as a problem with the MDT.

Reaction of METROLift Customers

METRO has conducted METROLift customer satisfaction surveys on a periodic basis. The most recent of these surveys were conducted in 1994 and 1995. Since the AVL system has been used primarily as an internal management tool, METROLift customers have not been informed of its use. As a result, no questions were included in the customer surveys specifically related to the AVL system. A number of questions did relate to general customer satisfaction, however.

The survey results provide an indication of some improvements that may be attributed to the AVL system. For example, overall customer satisfaction was up slightly from the previous year. A 5 percent increase was recorded in the number of respondents indicating that the service was much better than the previous year, and 3 percent more stated it was somewhat better. In addition, a 3 percent improvement was recorded in those reporting an excellent rating for METROLift on-time performance.

Changes in the number and the nature of customer complaints provides a second measure of rider satisfaction. METRO classifies complaints into six general categories of service: driving safety, driver behavior, routing and scheduling, equipment, and miscellaneous. The number of complaints related to service and routing and scheduling declined in the months after the introduction of the AVL system.

Conclusions

The overall results of the assessment indicate that the performance of the AirTouch AVL system generally met the stated accuracy requirements of 46 meters at 2 sigma, except in the downtown area and other locations with tall buildings, and that the system has had a positive impact on METROLift service. The AVL system has allowed METRO to better manage the METROLift fleet and dispatch functions in a time of increasing demand on the system. Although not the sole reason, the AVL system contributed to the increase in ratio of passenger miles to vehicle revenue miles, and the reduction in backup taxi services and late trips. Further, the response from METROLift dispatchers and operators has been very positive.

METRO can realize further benefits through more extensive use of the AVL system capabilities. For example, further improvements could be realized through real-time scheduling and by combining the AVL system with an advanced paratransit scheduling software package.

The results of this assessment indicate that ITS technologies can improve the operations of paratransit services. Additional applications of ITS technologies should further enhance the ability of individuals with special needs to utilize paratransit services and accessible regular route services. For example, *Smart Cards*, automatic stop annunciator systems, talking bus stops, in-vehicle systems, and advanced trip planning systems, can increase the mobility of individuals with special needs.

The continued deployment of ITS technologies with paratransit and accessible fixed-route transit services represents one approach to help address the mobility needs of special user groups. Further, these technologies can enhance the operating efficiencies of all types of transit services. Additional operational tests, demonstration projects, and full deployment activities will assist in supporting these efforts.

CHAPTER ONE—INTRODUCTION

Providing public transportation services that are accessible to individuals with disabilities has been an ongoing concern of federal, state, and local governments, transit operators, and advocacy groups. Current federal regulations require that transit systems provide both main line accessible service and paratransit or other specialized service to individuals with disabilities. Many transit agencies in the United States are working to improve the responsiveness and timeliness of paratransit systems, while at the same time maximizing the efficiency of these services. The use of automatic vehicle location (AVL) technologies may provide numerous benefits for paratransit services. These include enhancing service productivity, responding to changes in client travel schedules, and improving the safety of operators and passengers. Furthermore, when combined with advanced paratransit scheduling programs and other ITS technologies, AVL systems may allow transit agencies to provide dynamic paratransit scheduling and other service enhancements.

In October 1993, Texas Transportation Institute (TTI), a part of The Texas A&M University System, was notified by the Federal Highway Administration (FHWA) that it had been selected as one of three Intelligent Transportation Systems (ITS) Research Centers of Excellence. Public transportation services represented one of the three major focus areas in TTI's application, which was supported and endorsed by a number of public and private organizations, including the Metropolitan Transit Authority of Harris County (METRO) and the Texas Department of Transportation (TxDOT). METRO committed to providing funding to support the public transportation focus area and assisted with the identification of critical issues and projects to be examined in the Center's research program.

One of the elements included in the work program for the first year focused on the use of ITS technologies to improve specialized transportation service delivery. This project included an examination of the use of an AVL system—AirTouch—with METROLift, METRO's specialized paratransit service. An assessment of the performance of the AVL system and the impact the system has had on METROLift service was conducted. The potential expansion of the current AVL system to the full METRO fleet or the use of other AVL technologies on a system-wide level was also explored. Finally, possible applications of other ITS technologies to enhance specialized transportation services were reviewed.

Organization of this Report

The remainder of this report is organized into six chapters. Following this introduction, Chapter Two provides an overview of the METROLift system, AVL technologies, the AirTouch AVL system, and the test procedures utilized in this assessment. Chapter Three presents the results of the assessment of the AirTouch AVL system used with the METROLift service. Included in this chapter is an examination of the performance of the AVL system under the different conditions and an analysis of the digital map used with the system. Chapter Four examines the impact of the AVL system on METROLift service. The impact of the AVL system on several performance measures is explored, along with the reaction of METROLift dispatchers and operators, and METROLift customer responses.

Chapter Five examines the potential use of an AVL system with the full METRO fleet. This is followed in Chapter Six by an examination of other ITS technologies to enhance specialized paratransit services. Finally, the report concludes with a summary of the major items examined in the study and the identification of areas for further research and potential demonstration projects.

CHAPTER TWO—BACKGROUND ON METROLIFT SERVICES AND AVL SYSTEMS

This chapter provides an overview of the METROLift system, the different types of AVL technologies currently available, the AirTouch AVL system and its use with METROLift, and the test procedures utilized in the assessment of the AVL system. This background information helps establish the context for the METROLift AVL assessment conducted in this study.

METROLift

METRO initiated the METROLift service in 1979 to provide specialized paratransit services to individuals with special needs. METROLift provides pre-scheduled, curb-to-curb transportation for individuals who are unable to ride accessible fixed-route buses. METROLift carries approximately 3,200 daily riders in a 443-square mile service area utilizing 120 minivans and sedans, and backup taxi services. METROLift customers call one day in advance to schedule trips.

Like most transit agencies in the country, METRO has experienced a steady increase in demand for METROLift service. In 1985, the METROLift system averaged approximately 25,000 passengers a month. By 1992, monthly ridership had grown to some 50,000, and by 1994, approximately 70,000 riders a month were using the system (1). In an effort to enhance the efficiency of METROLift services, METRO implemented an AVL system with the METROLift system in 1993.

Automatic Vehicle Location Systems

AVL systems provide a mechanism for monitoring the location and movement of transit vehicles. Although AVL systems have been used for military purposes and with rail systems for a number of years, applications with transit buses and paratransit vehicles are more recent (2,3). A variety of technologies are available for use with AVL systems. Regardless of the exact technology, however, all AVL systems include four general components. These are a method for determining the position of a vehicle, a method for communicating this real-time information to a central dispatcher, a central processing computer for storing and transmitting the information, and a method for communicating between the central dispatcher and the vehicle operator. The two major types of AVL systems—ground-based and satellite-based—are briefly described next.

Ground-Based AVL Systems

Ground-based AVL systems include three general technologies. These are proximity beacons, dead reckoning, and trilateration. Figure 1 provides an illustration of the general configuration of ground-based AVL systems, although some differences exist between the various technologies. This section briefly describes the major characteristics of each approach, along with some of the advantages and disadvantages of the different technologies.

Proximity beacons, also referred to as signpost technologies, are transmitting devices located on signposts or overhead wires at strategic points along a transit route. The signposts emit a unique code identifying their specific locations. Buses are equipped with receivers, and a message is sent to the central control facility each time a bus passes a signpost. The tags or receivers on the vehicle may be passive or active. A signpost must send a signal to activate a passive receiver before transmitting data. Further, enhanced technologies may receive, store, and process information, in addition to just transmitting a signal (2,4,5). Different radio frequencies or microwave signposts may also enhance the accuracy and coverage of the system (6).

Many of the early transit AVL systems used signpost technologies. An advantage of this technology is that it is a relatively simple approach with a short implementation period. In addition, signpost AVL systems are generally lower in cost than other technologies, although the cost can increase significantly if a large number of signposts are required (4,6). Proximity beacons or signpost AVL systems have limitations, however. For example, the system only locates vehicles at signposts. A bus between signposts cannot be located. Thus, this approach cannot monitor a vehicle that is off its route or is experiencing difficulties between beacons. In addition, maintenance may be a problem. If one or more signposts are not working, the central computer may miscalculate the actual position until a working beacon picks up the vehicle's location (6). Further, the signposts must also be relocated if routes change.

Dead reckoning AVL systems are based on measurements made by distance and heading sensors on a vehicle, which continuously compute the location relative to a known starting point. Electronic odometers usually provide the distance measurement, and magnetic compasses commonly provide the heading sensors for this approach (4). When a vehicle leaves a known starting point, the odometer and compass monitor both the distance and the direction traveled.

Dead reckoning AVL systems may be lower in cost compared to other technologies. This approach has a number of disadvantages, however. First, dead reckoning AVL systems provide the location status of a vehicle relative only to the original starting point. Further, accuracy problems may emerge due to variations in the earth's magnetic fields, which may interfere with the compass readings. This problem, combined with the need to periodically readjust vehicle odometers, often results in dead reckoning systems accumulating errors with distance traveled. Re-initialization can overcome these concerns, or a signpost system may be used in combination with a dead reckoning system to increase the overall accuracy (4,6).

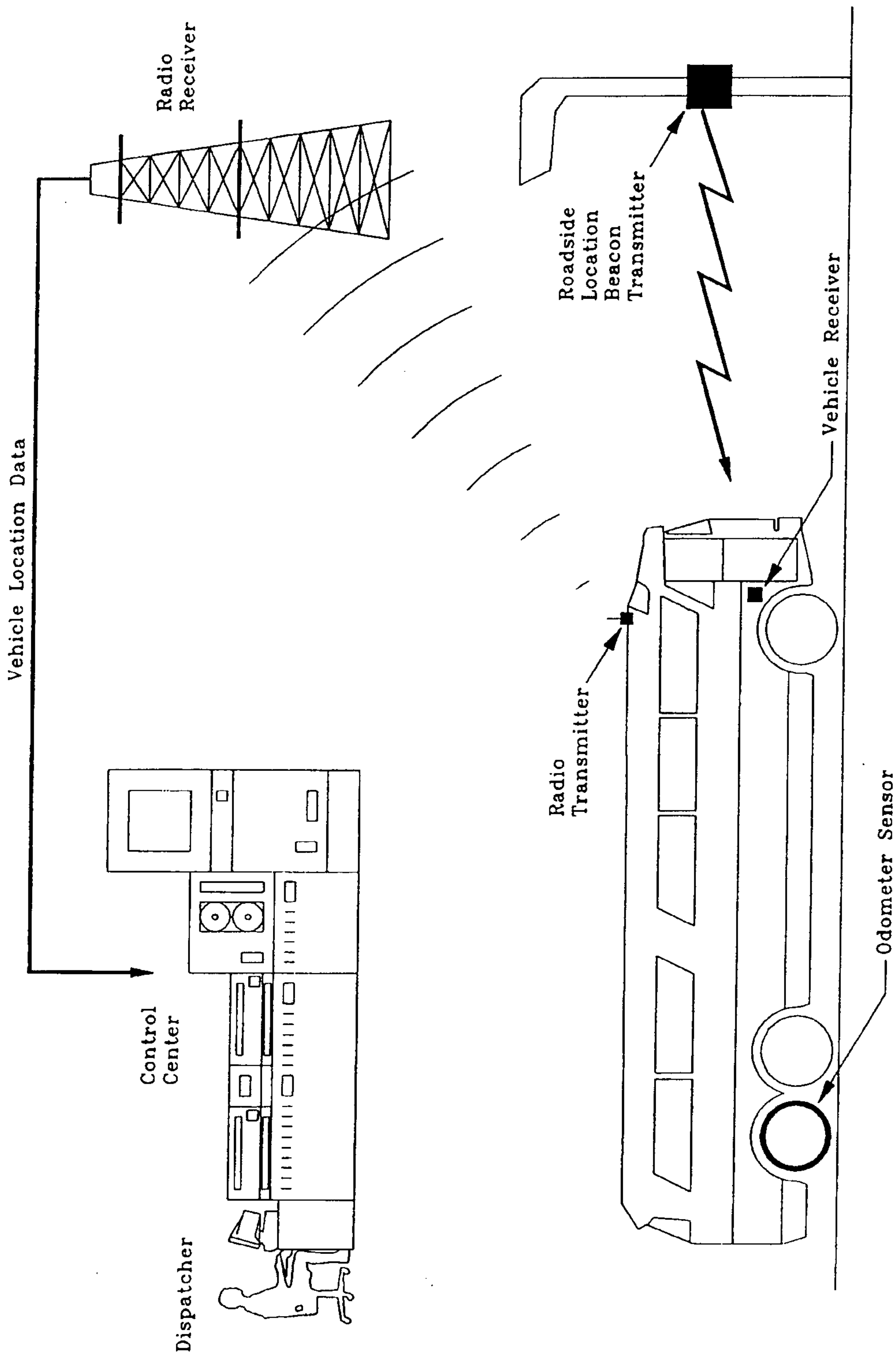

Figure 1. Example of Ground-Based AVL System

Trilateration or multilateration location techniques utilize radio frequency transmissions from three or more points. The location of a vehicle is established by calculating the differences in the position of a vehicle to a fixed point. Existing navigation networks, such as LORAN-C, are usually used with trilateration AVL systems (4). LORAN-C positioning systems have been used in both marine and aircraft navigation since the 1950s. More recently, the development of lower cost high-performance receivers has resulted in the use of this technology with commercial vehicle fleets (6).

In addition, a related AVL system has recently been implemented using subscriber-based radio location systems. These systems provide both vehicle location and transmission medium for the end users that do not require a dedicated radio frequency. The AVL system used in the METROLift demonstration represents one example of this type of technology. The AirTouch system is described in more detail later in this chapter.

Technologies using trilateration or multilateration may be lower in cost than other AVL systems. Problems which may emerge with trilateration AVL systems include the potential to lose vehicles due to signal interference from high-rise buildings or in areas with difficult topography (4).

Satellite-Based AVL Systems

As shown in Figure 2, satellite-based AVL systems follow the same principle as trilateration systems, except that satellites, rather than ground-based transmitters, establish the position of a vehicle. The Department of Defense's Navstar Global Positioning System (GPS) is being used with most satellite-based AVL systems. Passive receivers are used with GPS AVL systems. GPS receiver technologies have improved over the last few years, and the costs have been lowered. Recent developments include smaller, low-cost, multichannel receivers (2,4).

GPS-based AVL systems are relatively accurate, with most systems currently providing the location of a vehicle within approximately 300 feet (4). Currently, there is no charge for the use of the satellite signals. Advantages of GPS-based systems include greater flexibility over signpost technologies and reduced maintenance costs.

GPS systems do have some drawbacks, however. For example, NavStar may provide greater accuracy for military users. Thus, one of the problems with this type of system is that it is currently dependent on access through the military, which may decide to make changes in the future. This limitation may be removed in the future, however, with greater commercial applications of NavStar.

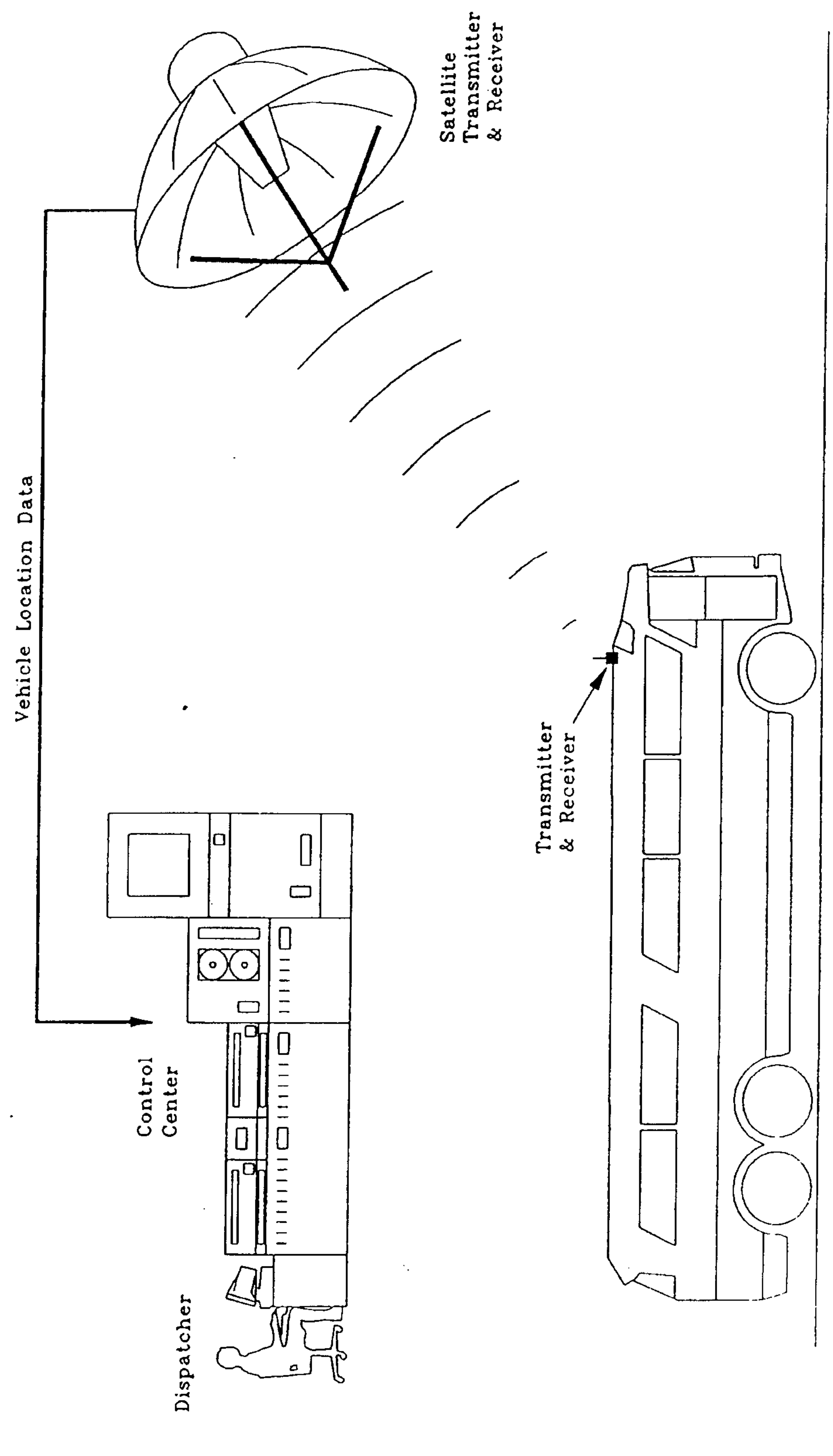

Figure 2. Example of Satellite-based AVL System

AirTouch Teletrac AVL System

The AirTouch Teletrac AVL system is a subscriber-based radio location technology. The system uses a network of 25 radio towers in the Houston area, a location unit on an individual vehicle, and central computer tracking and mapping functions. The digital transceiver, called a vehicle location unit (VLU), attaches to an automobile, bus, or minivan. The location of the vehicle is tracked using a software program on a personal computer connected to a central computer by a telephone line. Figure 3 illustrates the various components of the AirTouch system.

When the location of a vehicle is requested, the VLU receives a page and transmits a digital code which is received by radio towers in the vicinity. At least four towers must receive a signal to triangulate on the vehicle's position, but more towers are usually used to provide increased accuracy. The system can page and locate a single vehicle, a group of vehicles, or all vehicles within the service area. The system also provides an emergency call button that an operator can push to receive immediate attention from the control center (7). The METROLift system does not use this feature, however.

Figure 4 identifies the AirTouch service area in the Houston region. The AirTouch system claims a vehicle location accuracy of within 46 meters, at 2 sigma of the vehicle's actual position, at vehicle speeds of 0 to 100 miles per hour (7). A 2 sigma level of accuracy means that 95 percent of the location readings obtained from the system should be within the stated accuracy range.

METROLift AVL System

Currently, 153 METROLift minivans, sedans, and taxicabs are equipped with the AirTouch vehicle location units. Within the METROLift offices, the work stations for the METROLift dispatchers include two computer screens. One screen displays METROLift customer information, and the other is linked to the AVL system. Dispatchers can request and display the location of METROLift vehicles on the computer screen using the AirTouch AVL system and the ETAK digital map. The present system configuration allows the dispatchers to page and locate vehicles.

The dispatchers also have telephones and two-way radios available to communicate with METROLift operators. Further, Mobile Data Terminals (MDTs), located on the METROLift vehicles, are used to send typed messages to operators. The operators can send pre-coded responses over the MDTs, but these appear only on one screen at the METROLift offices.

METROLift dispatchers and operators are using the AVL system in two ways. These are to give directions to operators to help them find a rider's address and to provide customers with information on the status of a vehicle for a trip request.

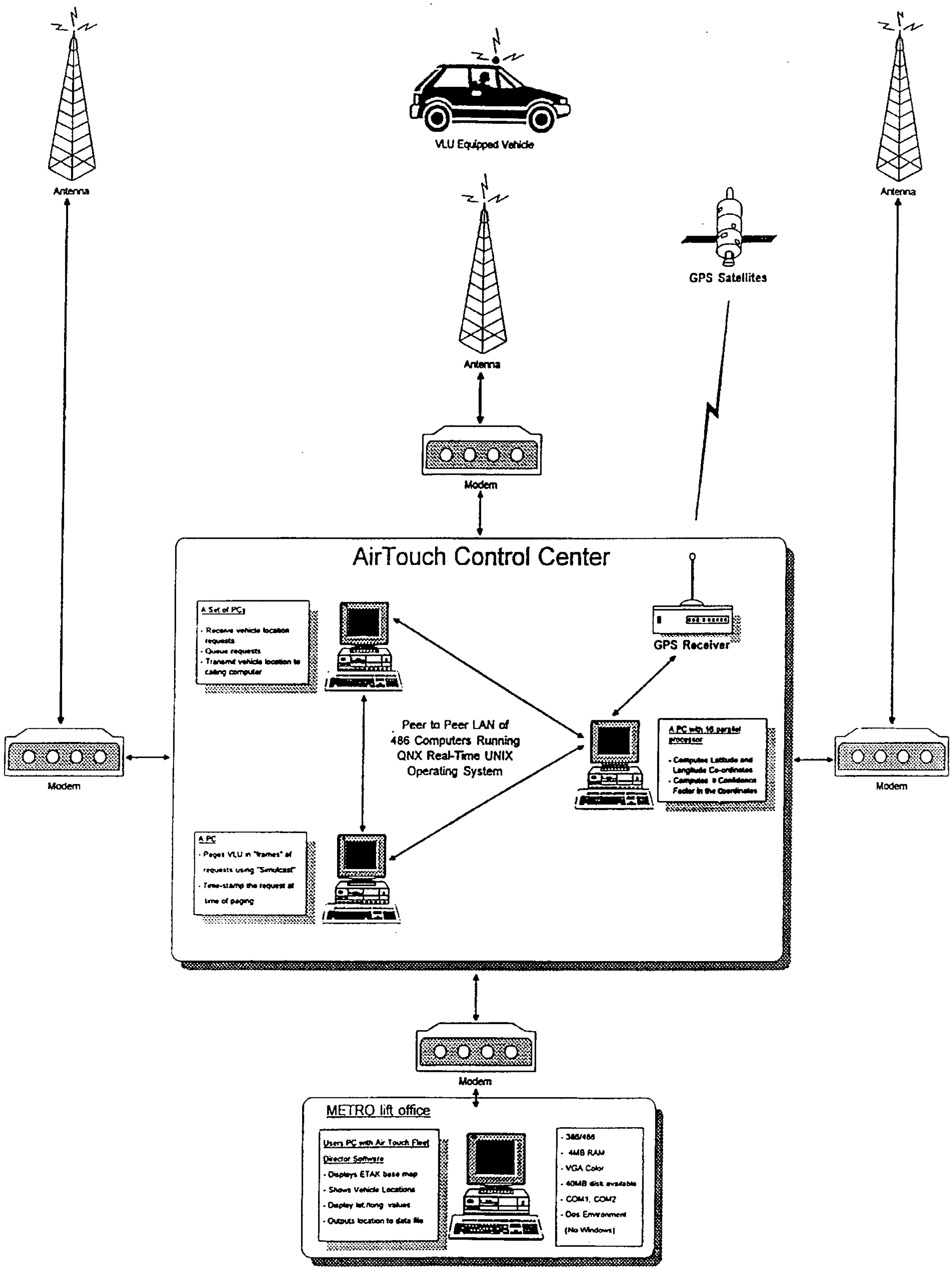

Figure 3. AirTouch AVL System

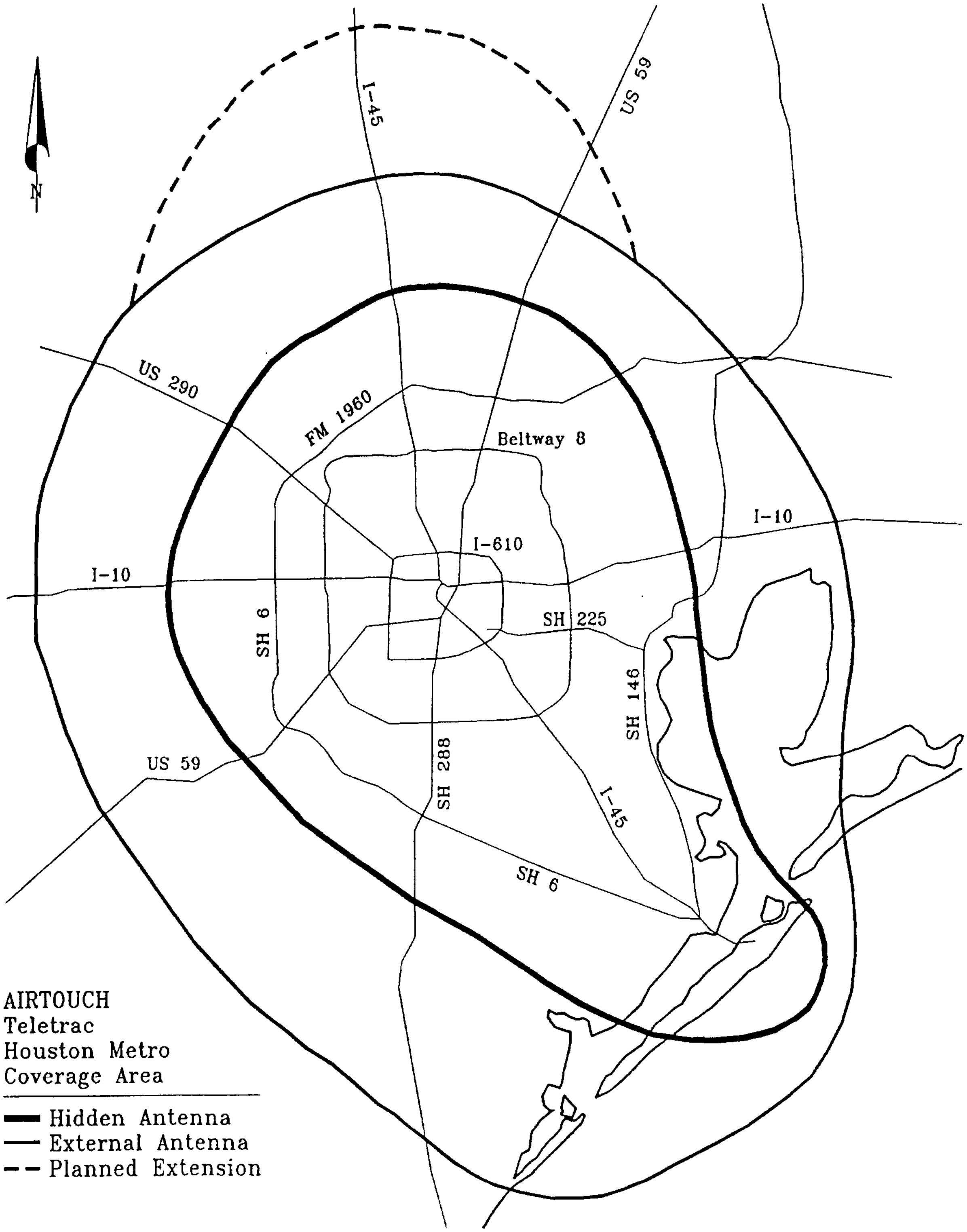

Figure 4. AirTouch AVL System Service Area

First, dispatchers are able to provide assistance to operators who are lost or cannot find a rider's address. In response to a request from an operator over the radio, a dispatcher can page the vehicle, display its location on the map, and provide verbal directions to the operator.

Second, the dispatcher can use the system to provide information to customers concerning the status of a vehicle. In response to a customer calling METROLift to inquire about a late vehicle or the status of their service, the dispatcher can page the vehicle, display its location on the map, and provide information to the customer on the estimated time of arrival.

Initially, an emergency request feature was also used. This allowed operators to notify dispatchers of an emergency. This feature was removed, however, due to potential liability concerns.

The AVL system has not been used during the demonstration for real-time scheduling or other related applications. It appears that there are a number of ways AVL technology could further enhance the effectiveness and efficiency of paratransit services. The potential to utilize the AVL system for additional functions is discussed later in the report.

The AVL system was initiated without an evaluation plan, and data were not collected on many elements of the METROLift service before implementation. As a result, much of the information on conditions and service measures prior to use of the AVL system had to be reconstructed. Obtaining information on the pre-AVL conditions was sometimes difficult, limiting some aspects of the evaluation.

Test Procedures

The performance of the AirTouch AVL system was assessed through a number of tests. METRO was primarily interested in the locational accuracy of the system, which AirTouch states as 46 meters, at 2 sigma of the vehicle's actual position (7). A 2 sigma level of accuracy means that 95 percent of the locational readings obtained from the system should be within the stated range. AirTouch notes that this level of accuracy may not be met in downtown areas, however, due to possible interference from tall buildings.

The AVL system was tested under a number of different conditions. These included both a stationary vehicle and a moving vehicle. Additional tests focused on vehicles traveling on the edge of the service area, as well as vehicles located in a parking garage and in an underground parking area. A total of 53 sites were tested to assess the AirTouch system. The selected sites provided a mix of locations within the Houston area, as well as different environments.

The purpose of the tests, which are described in more detail later in this section, was to compare the latitude and longitude readings obtained from the AirTouch AVL system with those taken with a differential Global Positioning System (DGPS) or those provided previously to METRO by E-Systems for another project. These sources provided "known" latitude and longitude readings for comparisons with those obtained from the AirTouch AVL system.

Although the exact approach varied slightly with the different tests, the same general procedures were followed at each site. At the locations where latitude and longitude data were available from E-Systems, AirTouch readings were taken for comparison. At all other locations, readings were taken using both the AirTouch and the DGPS. At most sites, the AirTouch antenna was attached by its magnetic base to the top of a TTI vehicle. The vehicle's cigarette lighter powered the vehicle location unit. At a few sites, however, the absence of either a safe parking spot or the ability to park at the "known" location required removing the antenna from the vehicle and using a portable 12-volt battery. The battery was tested and recharged, if necessary, before each measurement.

The potential influence of the different test practices was assessed in a number of ways. First, the impact of antenna strength was examined. For this test, AirTouch provided three antenna—one similar to those used with the METROLift vehicles, one with improved transmitting strength, and one to simulate poor antenna placement. Second, the influence of different vehicle operating conditions, such as a running motor and the use of other electrical systems, was assessed.

The results from these tests indicate that the readings were similar under the different operating conditions. The most accurate results were obtained with the antenna attached to the top of the vehicle and the system powered through the cigarette lighter. The use of the 12-volt battery only varied the results from 1 to 5 meters, however, indicating that both approaches provided fairly consistent results. The detailed results from these tests are provided in Appendix A.

For stationary tests conducted at the park-and-ride and transit center locations, the AirTouch vehicle location unit and the DGPS were placed at the same location. The DGPS was always tested first, followed by the AirTouch AVL system. At least 25 readings were taken with the AirTouch system, and approximately 500 readings were taken with the DPGS. E-Systems provided "known" locations at bus stops along the 2 Bellaire Route-Dairy Ashford branch. Again, at least 25 AirTouch readings were taken at each site along the Bellaire route on two different days for comparison with the known data.

The AirTouch AVL system presents vehicle locations in terms of either latitude and longitude coordinates or street locations, as specified by the user. The GEOD software package, developed by the United States Geological Service (USGS), was used in this analysis. The software, when given the appropriate parameters, computes the distance between any two sets of latitude and longitude coordinates by solving differential equations. The computations take into account the curvature of the earth and are accurate to within a few centimeters. The data generated by the AirTouch Fleet Director software were converted into a format that could be read by the GEOD software. For each site, the data file contained the known latitude and longitude and the latitude and longitude generated by the AirTouch AVL system. These values were expressed in degrees with minutes and seconds represented by a decimal fraction.

For each test location, the GEOD software compared the latitude and longitude obtained by the GPS with the latitude and longitude generated by the AirTouch Fleet Director software. The distance in meters between the two sets of coordinates was computed and plotted. The results were examined to determine if they fell within the 46 meters at 2 sigma accuracy range.

The accuracy of the readings obtained by the DGPS and E-Systems were verified first. This was accomplished in two ways. First, the latitude and longitude readings obtained from the DGPS were compared with those of two National Geographical Survey (NGS) markers. At both locations, the TTI vehicle was parked over the NGS marker. The DGPS antenna was placed on top of the vehicle and 100 readings were taken. The results indicated that the DGPS provided accurate readings. At one site, the DGPS average readings were within 2 meters of the NGS marker latitude and longitude, while the average at the second site was within 4 meters.

The coordinates provided by E-Systems were compared with those recorded by the DGPS at one location. The E-Systems coordinates were within 2 meters of those obtained by the DGPS, indicating that the data provided by E-Systems were also accurate. A more detailed description of these tests and the results are provided in Appendix B.

One last potential issue was considered in the test procedures. Both the DGPS and the AirTouch readings measure location in three dimensions—latitude, longitude, and altitude. Trimble software removes the altitude measure to leave two-dimensional position coordinates. This can result in a slight distortion of data—much the same as when the globe is made into a two-dimensional map. A geographical *datum* algorithm translates the three-dimensional information into the two-dimensional latitude and longitude readings. Several of the different datum algorithms are currently in use, including NAD-27, NAD-83, and WGS-84. The AirTouch system uses NAD-27, while the DGPS and E-Systems map use NAD-83. In order to ensure compatibility between these two datum algorithms, a software package—CorpsCon–was used to express the DGPS and E-Systems NAD-83 data as NAD-27 data. Thus, the results of all the tests used a similar datum algorithm.

The general nature of the tests and the procedures used with each are briefly described next. Additional information is provided in Chapter Three.

- **Stationary Vehicle**. The accuracy of the AirTouch AVL system at locating a stationary vehicle was tested at the 53 sites shown in Figure 5. The sites were selected to provide a variety of physical environments within the Houston metropolitan area. Twenty of the sites were bus stops on the METRO 2 Bellaire Route-Dairy Ashford Branch. Twenty-seven sites were at METRO Park-and-Ride lots and Transit Centers and other locations in downtown Houston and in the Galleria area. Six were at highway intersections located close to the stated limits of the AirTouch service area. The procedures described previously were used with these tests.

- **Edge of Service Area**. This test examined the reach of the AirTouch system. The six sites on the edge of the service area are shown in Figure 5. Further, a vehicle traveling from Houston to College Station was monitored to determine how far the AirTouch signal was recorded.

- **Ability to Locate Vehicle in Underground Parking Garage and Parking Ramp**. The ability of the AirTouch system to locate a vehicle in an underground parking garage and in a parking ramp was tested at three locations. As shown in Figure 5, these were at the Galleria, Greenway Plaza, and downtown Houston. The DGPS will not operate in either an underground environment or in a parking structure. Thus, this test simply examined if the AirTouch AVL system functioned in these conditions.

- **Moving Vehicle**. This test assessed the accuracy of the AVL system when a vehicle was moving at speeds of 10, 20, 30, 40, and 50 miles per hour (mph). This test was conducted near the intersection of the South Freeway (SH) 288 and Farm to Market (FM) 518. The location of these sites are shown in Figure 5. The two sites were selected to reduce the effects of the urban environment, such as possible interference from surrounding buildings, on the accuracy of the system. The volume of traffic at the locations was relatively low, which facilitated the testing procedure. Finally, the two roads allowed testing for two directions of vehicle travel. For one site, the vehicle traveled in a North-South direction; for the other, the vehicle traveled in an East-West direction. Figure 6 illustrates the detailed test site.

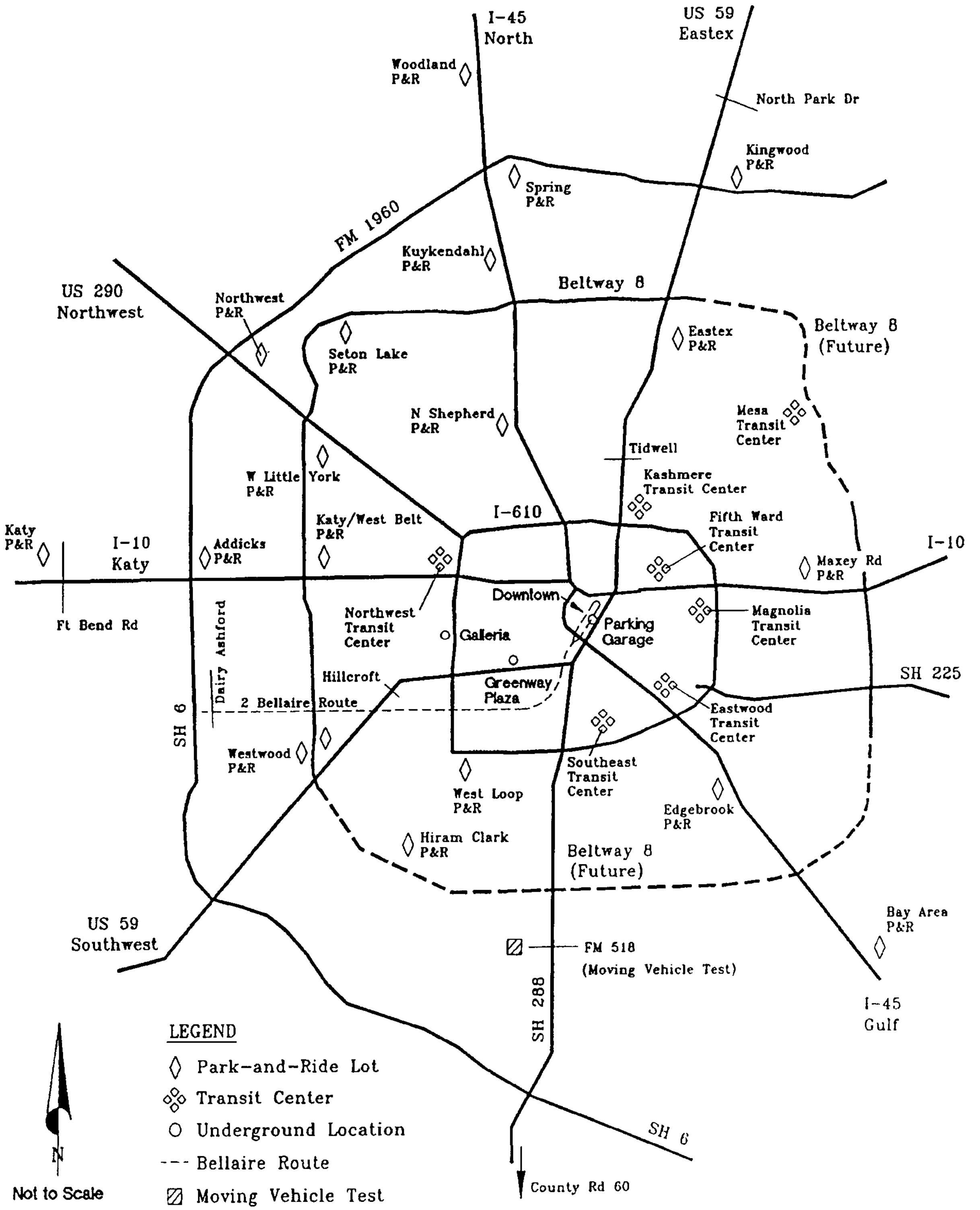

Figure 5. AVL System Accuracy Test Locations

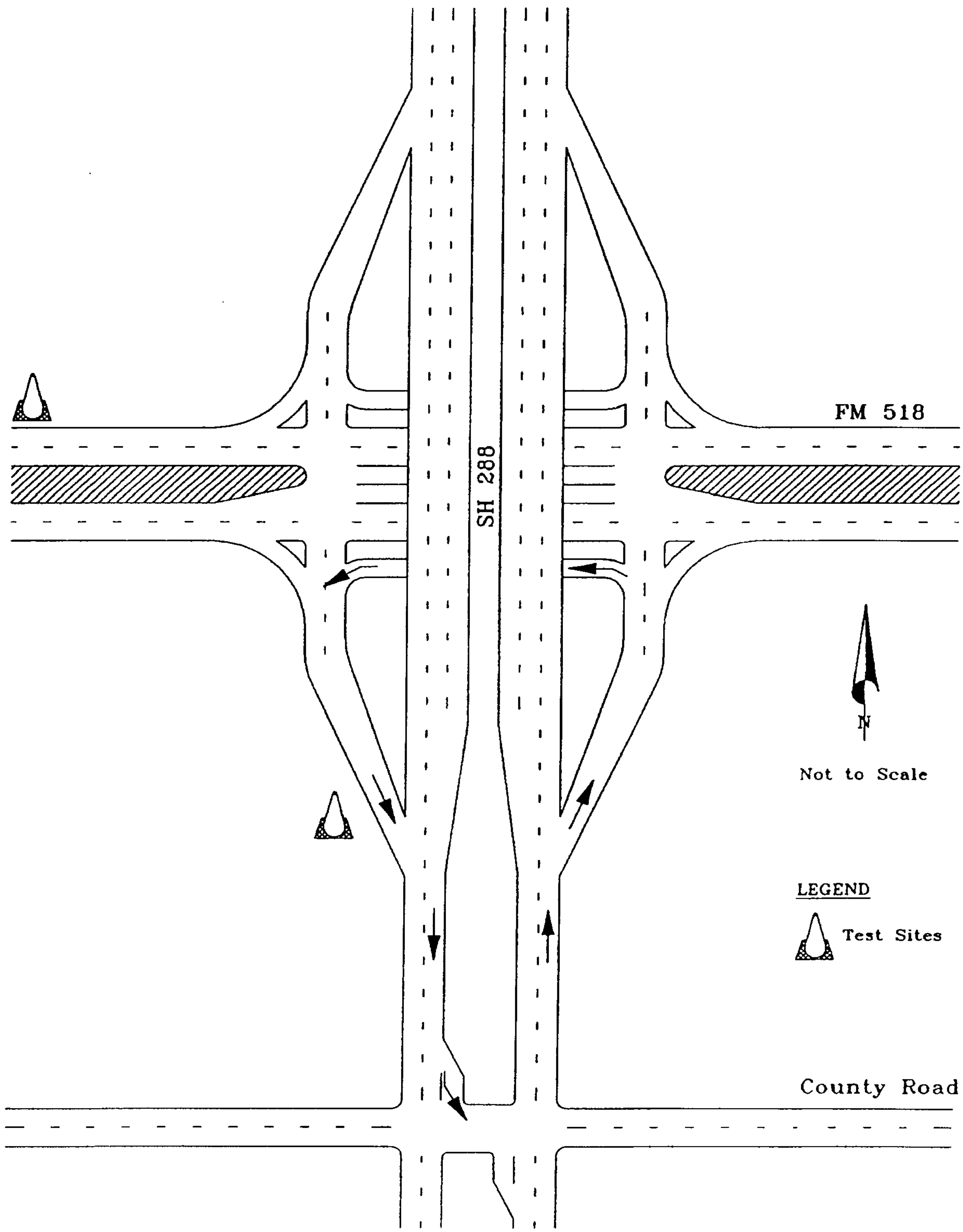

Figure 6. Detail of Site for Moving Vehicle Location Accuracy Tests

The moving vehicle test required a different procedure than the one used with the stationary vehicle tests. In the stationary-vehicle location tests, the vehicle location unit aboard the test vehicle was paged remotely from the same computer terminal which would then receive the location data. The time delays associated with this method prevented its use in the moving-vehicle tests. Instead, a vehicle location unit equipped with a keypad was utilized. Pushing the locate key on the keypad sends a signal directly to the AirTouch radio towers, communicating the vehicle's location at the instant the key was pressed. This location data appears on the Fleet Director computer terminal a short time later.

At each of the two sites, the test vehicle was parked while GPS readings were taken. A traffic cone was placed at the edge of the road, parallel with the position of the GPS antenna on the test vehicle. Once GPS readings were completed, the GPS antenna on the vehicle was replaced with the AirTouch VLU antenna, and twenty AirTouch readings were taken at the site while the vehicle remained stationary.

To obtain each test reading, the vehicle was driven past the traffic cone at one of the predetermined speeds: 10, 20, 30, 40, or 50 miles per hour. As the vehicle passed the cone, the passenger initiated the AirTouch system by pressing the appropriate key on the AirTouch unit, and the location of the vehicle was recorded by the central computer. Twenty readings were taken for each speed at both testing sites.

CHAPTER THREE—ASSESSMENT OF THE METROLIFT AIRTOUCH AVL SYSTEM

This chapter presents the analysis of the four different tests conducted on the accuracy of the AirTouch AVL system. A discussion of the data throughput capabilities of the system, and an assessment of the ETAK map used in the METROLift demonstration, are also provided. Appendix C presents samples of selected plots from the tests described in this chapter. The plots from all the tests are contained in a separate document, *Technical Appendix: METROLift AVL System Assessment.*

Accuracy—Locating a Stationary Vehicle

The first set of tests examining the accuracy of the AirTouch system at locating a stationary vehicle encompassed 20 locations along the 2 Bellaire Route-Dairy Ashford Branch. Two tests using the same procedure and the same sites were conducted approximately one month apart.

As described previously, a portable vehicle location unit connected to a 12-volt battery, was used to conduct this analysis. At each of the 20 locations along the bus route, the unit and antenna were placed next to the bus stop signpost. When the unit was in place at a site, personnel in the TTI Houston office were called by cellular telephone and a page of the unit was initiated. The AirTouch Fleet Director software on a personal computer in the TTI office paged the vehicle location unit at 10 second intervals. The location data received from each page was recorded.

For each site, the latitude and longitude values recorded by the AirTouch readings were compared with the E-Systems coordinates that had previously been provided to METRO for another project. The GEOD software calculated the distance between the two sets of coordinates.

The results from both sets of tests are provided in Tables 1 and 2. The distance between the E-systems coordinates and the average of the AirTouch readings ranged from 11.282 meters to 195.077 for the first set of tests. Of the 20 sites along the Bellaire route, eleven showed average errors less than 46 meters, and 4 met the 46 meter accuracy for 95 percent of the readings at the 2 sigma criteria. The locations with the poorest accuracy were those in the downtown or other areas with tall buildings. Although not specifically noted in the AirTouch literature, AirTouch representatives indicated that they do not claim the same accuracy in these areas (8).

The results from the second tests on the Bellaire route indicated that 10 sites showed average errors within the 46 meter window, while 4 met the window at the 2 sigma level of accuracy. Like the first test, the primary reason for the differences can be attributed to interference from buildings or power lines in the downtown area and other locations.

Table 1. Differences Between E-Systems and AirTouch Readings: 2 Bellaire Route - Dairy Ashford Branch, First Test (Values in Meters)

Location	# of Trials	Mean Deviation	Std. Deviation	Minimum	Maximum
Bellaire - Dairy Ashford	21	71.090	8.7347	51.364	87.477
Bellaire - Wilcrest	25	11.282	5.9433	1.114	29.464
Bellaire - Gessner	20	51.583	8.6801	37.223	73.254
Bellaire - Cannock	23	15.189	9.5338	1.940	40.332
Bellaire - Bellaire Transit Center	22	34.799	11.3977	11.736	49.991
Bellaire - Buffalo Speedway	22	20.988	8.3003	10.575	36.925
Holcombe - Shamrock	20	55.678	8.4574	44.893	73.193
Fannin - Bates	23	39.988	15.3340	10.736	75.029
Fannin - Texas Children's Hospital	23	17.624	7.5671	5.632	36.636
Fannin - Ross Sterling	118	64.708	24.0273	9.570	133.044
San Jacinto - Wheeler	15	25.512	11.8477	4.595	63.178
Main - Calhoun	20	39.081	28.9232	2.361	117.656
Main - Clay	22	48.780	23.0238	21.509	129.037
Main - Dallas	23	71.408	38.2141	31.911	177.117
Main - Texas	45	31.032	17.7777	8.897	101.959
Congress - Smith	23	104.371	27.9508	19.739	159.344
Preston - Milam	24	195.077	15.4552	167.036	228.686
Fannin - Walker	24	82.280	23.4190	41.033	131.917
Fannin - Calhoun	21	39.033	28.5433	11.832	107.042
Fannin - Holcombe	21	73.293	61.3380	13.571	190.176

Table 2. Differences Between Known Site and AirTouch Readings: 2 Bellaire Route - Dairy Ashford Branch, Second Test (Values in Meters)

Location	# of Trials	Mean Deviation	Std. Deviation	Minimum	Maximum
Bellaire - Dairy Ashford	25	72.224	14.652	37.063	96.988
Bellaire - Wilcrest	25	14.153	6.922	5.950	33.371
Bellaire - Gessner	25	31.384	10.512	11.514	47.568
Bellaire - Cannock	25	260.671	354.081	5.982	785.741
Bellaire - Bellaire Transit Center	25	15.802	7.435	4.066	28.931
Bellaire - Buffalo Speedway	25	31.978	15.226	6.743	67.624
Holcombe - Shamrock	24	44.286	9.014	17.941	63.191
Fannin - Bates	25	38.450	17.397	3.329	82.429
Fannin - Texas Children's Hospital	25	49.966	41.073	2.935	166.415
Fannin - Ross Sterling	25	61.816	24.412	13.095	120.043
San Jacinto - Wheeler	25	37.326	29.491	10.053	139.532
Main - Calhoun	25	49.264	40.692	1.550	151.815
Main - Clay	20	28.813	18.015	9.359	88.271
Main - Dallas	24	110.509	48.006	54.949	200.394
Main - Texas	25	28.698	15.431	9.383	61.876
Congress - Smith	25	20.983	13.726	1.422	61.304
Preston - Milam	25	57.621	17.688	24.062	93.729
Fannin - Walker	24	70.700	21.877	33.486	123.708
Fannin - Calhoun	25	24.244	8.838	3.494	43.496
Fannin - Holcombe	25	25.665	9.095	9.338	41.305

The second set of tests compared the readings obtained from the AirTouch system with those obtained from a DGPS at 27 sites. As shown previously in Figure 5, these sites were at METRO Park-and-Ride lots, Transit Centers, downtown, and other locations. These tests followed the procedures described in Chapter Two. Table 3 provides the minimum, maximum, and average distances in the readings taken at each site.

In contrast to the Bellaire route tests, 22 of these 27 sites showed average errors within 46 meters, and 21 met AirTouch's standard of 95 percent at 2 sigma. In general, these sites were in more open areas, with no buildings close by. The sites which showed large average errors and wide scattering included downtown locations, such as the top of a parking garage on the corner of Milam and Clay, and the Greenway Plaza area.

Accuracy—Edge of Service Area

Six sites were selected that were at or beyond the edge of AirTouch's designated service area. Following the standard test procedures, readings were taken with a DGPS and the AirTouch system. As shown in Table 4, there was not a noticeable degradation in accuracy in the readings taken at these sites.

A second test tracked a TTI vehicle traveling from Houston to College Station. A vehicle, equipped with two AirTouch antennas of different strengths, was paged at one to two minute intervals as it traveled along U.S. 290 and SR 6. A signal was received until the vehicle reached the Hempstead bypass, approximately 20 miles past the stated edge of the service area.

Accuracy—Underground

This test focused on the ability of the DGPS and the Air Touch AVL systems to transmit signals in an underground parking garage and in an above ground parking structure. The DGPS was not able to transmit a signal in either of these environments. As shown in Table 5, the AirTouch AVL system was able to locate a vehicle parked under only one ceiling; either at the first level underground or at the first level down from the top in a parking structure. Contact was lost when the vehicle was moved to a lower level, and the AirTouch AVL system listed the vehicle as "out of service." The distances and standard deviations in Table 5 are calculated based on the average of the AirTouch readings for each of the three sites, since no other value was available for comparison.

Table 3. Differences Between DGPS and AirTouch Readings: Areawide Locations (Values in Meters)

Location	# of Trials	Average	Standard Dev.	Minimum	Maximum
Kashmere TC	24	12.9441	3.8143	4.677	19.076
Maxey Road PR	25	13.2437	4.5633	4.130	19.549
Mesa TC	25	17.2549	2.9878	8.719	21.849
Tidwell TC	26	21.5108	4.778	12.121	32.659
Eastex PR	25	30.4158	16.5422	15.502	99.826
Spring PR	24	77.5961	70.5252	9.357	225.255
Kuykendahl PR	25	21.1127	10.6791	5.844	46.742
N. Shepherd PR	25	7.4548	5.2931	0.232	18.937
Seton Lake PR	24	12.9392	4.3777	2.042	21.209
Northwest Station PR	25	7.6639	3.5877	2.532	15.398
W. Little York PR	25	8.0025	4.9932	2.743	18.709
Katy/West Belt PR	25	8.2048	3.4307	1.508	15.922
Addicks PR	25	6.4891	3.1553	1.084	13.850
Hillcroft TC	25	12.0918	4.6389	5.968	22.631
Bay Area PR	25	9.1242	5.0615	2.442	22.797
Edgebrook PR	25	7.8111	3.0802	2.508	13.755
Hiram Clarke TC	25	11.0702	3.1343	4.619	15.212
West Loop	25	89.9154	5.3232	77.150	97.278
Westwood	25	8.2508	3.08	1.209	12.502
Fifth Ward TC	25	12.6832	6.5254	2.175	26.901
Magnolia TC	25	11.0604	9.6511	1.664	52.439
Southeast TC	25	54.7972	20.7448	16.281	107.080
Eastwood TC	25	8.3057	6.2561	0.445	29.933
Northwest TC	25	15.3349	7.2803	1.555	31.063
Galleria	25	25.548	7.9968	8.072	43.824
Greenway Plaza	27	102.718	17.0274	70.036	129.719
Parking Garage Roof, Milam@Clay	26	73.526	40.8026	28.719	222.979

Table 4. Edge-of-Service-Area Test Results

Location	# of Trials	Average Distance	Std. Deviation	Minimum	Maximum
U.S. 59 @ North Park	24	36.8600	33.7006	3.376	139.935
Hwy. 288 @ Hwy. 6	25	37.8356	6.2937	27.051	54.000
Hwy 288 @ C.R. 10	26	15.1679	3.6583	7.410	22.757
Kingwood PR	26	8.4402	12.9146	0.889	69.944
Katy PR	24	20.5234	9.7274	4.008	40.389
Katy Fwy. at Roesner	25	37.2157	4.9735	30.358	47.765

Table 5. Underground Test Results

Location	# of Trials	Average Distance	Std. Deviation	Minimum Distance	Maximum Distance
Galleria (underground)	20	221.631	140.148	14.785	546.386
Greenway Plaza (underground)	24	61.641	55.750	5.828	257.790
Parking Garage, Milam @Clay (top covered level)	29	41.275	69.856	1.705	356.742

Accuracy—Moving Vehicle

Figure 7 shows the average error, in meters, measured between the DGPS coordinates and the coordinates provided by the AirTouch AVL system with a stationary vehicle and a vehicle traveling at speeds of 10, 20, 30, 40, and 50 mph. This value includes error both in the vehicle's direction of travel and perpendicular to the direction of travel. As expected, this error figure increases as vehicle speed increases, owing mostly to human error in activating the AirTouch system at the correct instant.

Figure 8 shows only the error that occurred perpendicular to the vehicle's direction of travel. This value should represent primarily any possible difference between the DGPS and the AirTouch systems. The possible error caused by the vehicle moving side-to-side in the lane of travel is limited to a few feet due to the width of the lane. In contrast to the previous graph, the error in Figure 8 follows no identifiable slope or pattern and is much smaller. The highs and lows in this graph appear to be random, which is consistent with the variability seen in previous readings with the AirTouch AVL system. These results support the statement by AirTouch that the performance of the system is unaffected at the tested vehicle speeds.

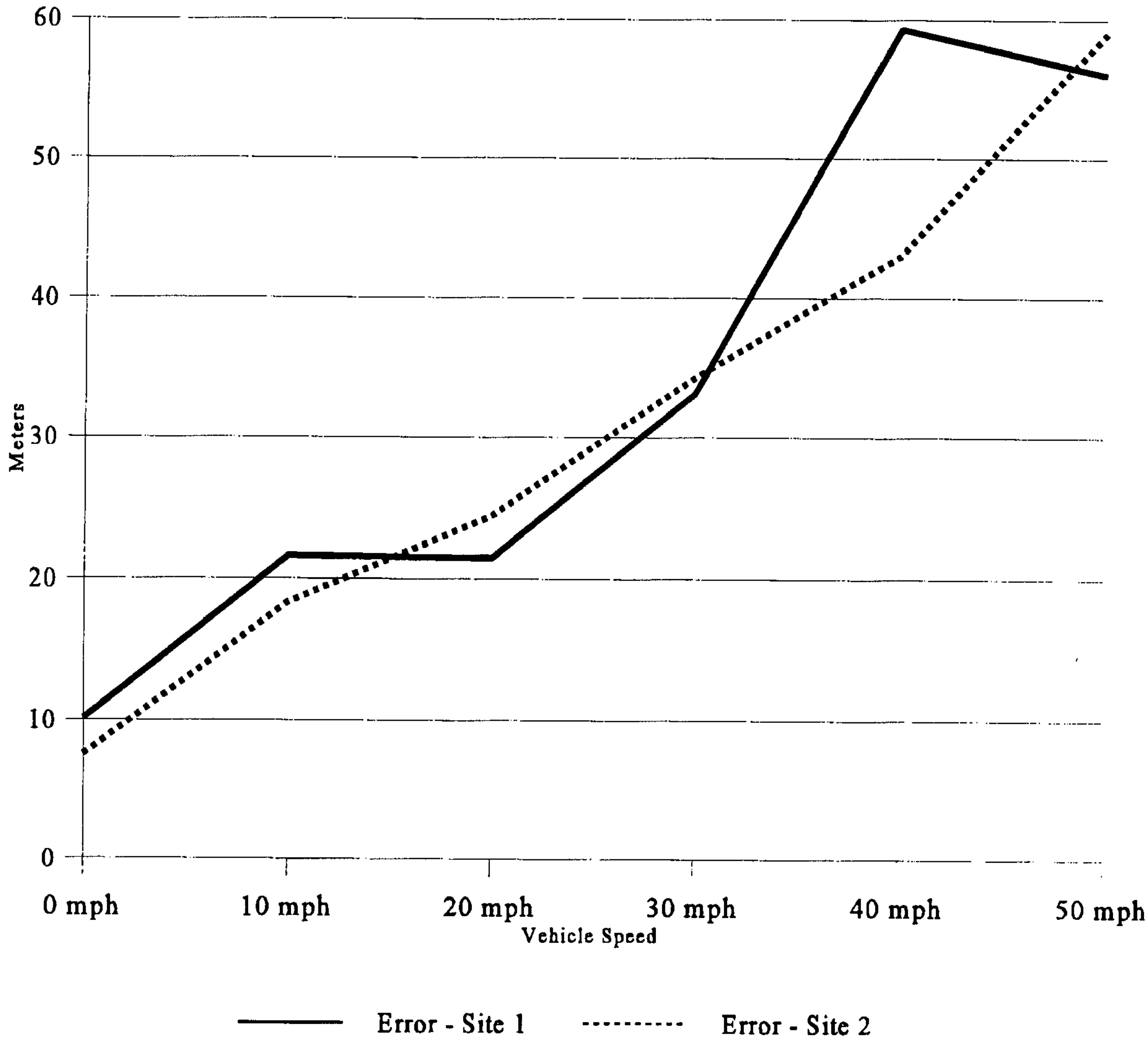

Figure 7. AirTouch Location Error for Moving Vehicle (Meters)

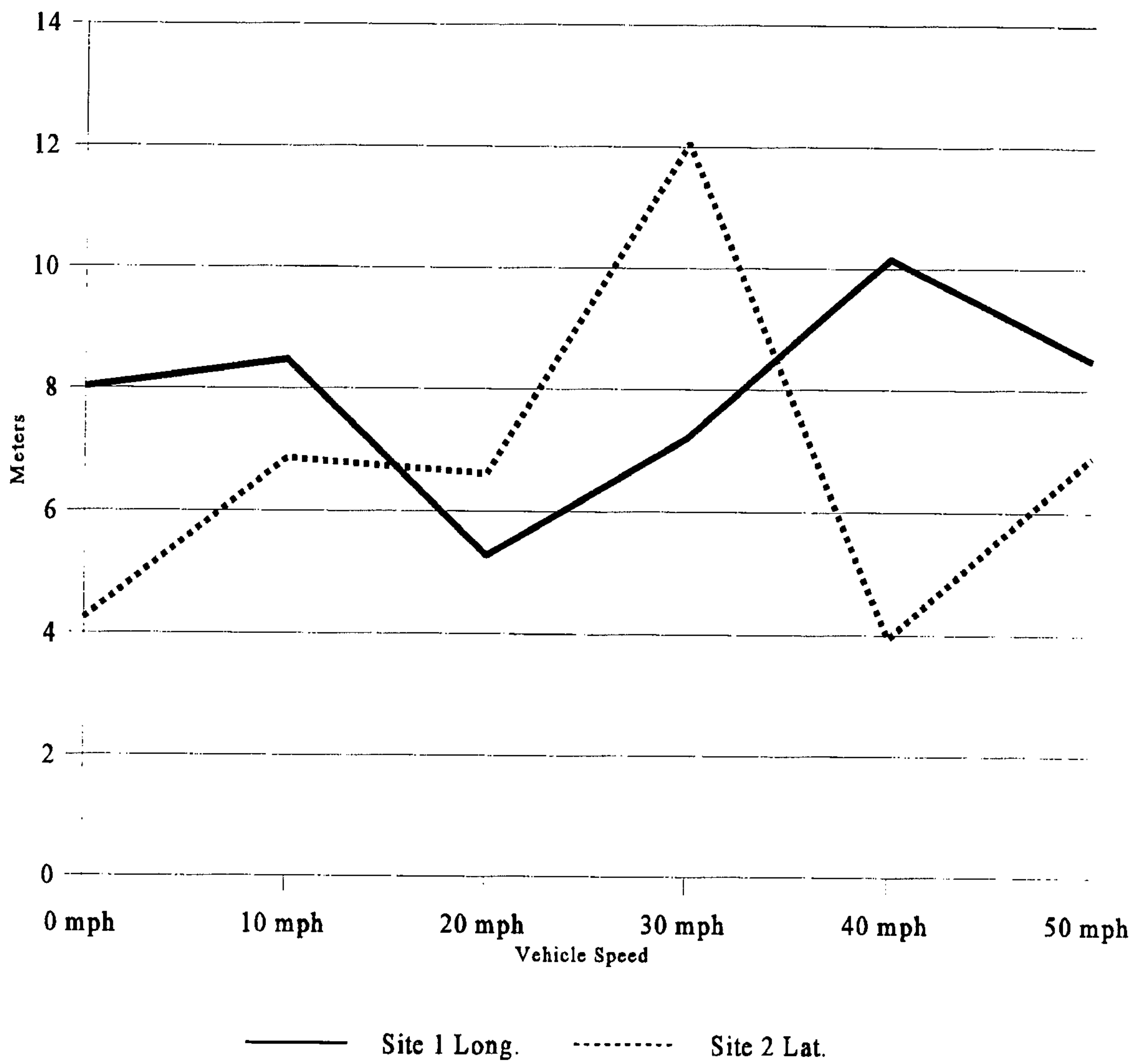

Figure 8. Error Perpendicular to Direction of Travel (Meters)

Data Throughput Assessment

In any system that includes communications, the speed at which communications and information travel depends on the system's data throughput capability. Data throughput is defined as the number of bits of information that can be processed per unit of time through a communications link. The AirTouch system depends on radio and computer communications to obtain and process vehicle location information from its vehicle location units and to convey that information to the user. The purpose of the data throughput evaluation of the AirTouch AVL system was to determine if the data throughput and, therefore, the communications speed, was high enough to provide necessary information to METROLift dispatchers without unreasonable delays. Further, the evaluation examined the potential for increasing the numbers of vehicles connected to the AirTouch system should METRO wish to expand vehicle location and communication capabilities to the METRO fixed-route fleet, METRO police, and other Houston-area vehicles.

The potential to expand the system to other METRO vehicles was discussed with Mr. Dennis McCain, AirTouch manager in May of 1995. Mr. McCain cautioned that the present AirTouch system is not equipped to handle extensive real-time data and communications for a large fleet such as METRO's, and that AirTouch was not currently interested in expanding to accommodate such a large customer base (8).

Although this response indicates that the AirTouch system does not have the throughput capabilities to handle regular polling of the full METRO fleet, an analysis was still conducted of the system. METRO staff identified a number of specifications for an AVL system, including those related to the Society for Automotive Engineers (SAE) standard J1708 (9). These specifications are outlined below, with a comparison to AirTouch operating characteristics.

- **The system must support 1-minute updates from 360 remote vehicle logic units including the following data items: vehicle identification, driver identification, current alarms, route assignment, current location, speed.** AirTouch's system limit is 36 vehicles per second (vps) for throughput. The current METROLift fleet, paged for vehicle identification and location only, utilizes approximately 5 percent of the AirTouch system's daily capacity. If the fleet were increased to 360 vehicles, with the additional data included, it would use 30 to 35 percent of AirTouch's capacity. At peak use times, when other AirTouch customers are also paging vehicles, the current capacity would be limiting.

- **The system must support at least 2500 field radio units without an identifiable degradation in performance**. At AirTouch's present throughput capacity, a request to locate a fleet of 2,500 vehicles would cause a delay of several minutes within the system. AirTouch, when asked about this capability, commented that they were not interested at this point in expanding to accommodate that volume of service (8).

- **The system must support emergency alarm delivery within 10 seconds.** The AirTouch system has the capability to provide an emergency alarm button that can be activated by an operator. This feature was initially provided but was removed due to liability concerns. At this time there is no provision for emergency alarms from METROLift vehicles other than verbal messages through a radio or cellular telephone. The dispatcher receiving the call would then need to identify the vehicle and page its location.

- **The system must support a minimum data modulation rate of 4800 bps**. AirTouch currently operates at 2400 bps, but can support 4800 bps.

Based on the above criteria, the AirTouch system has the data throughput capacity for the METROLift fleet. It does not have the data throughput capacity for regular polling of the full METRO fleet, however.

Evaluation of the ETAK Map

The ETAK map is currently used in conjunction with the AirTouch Fleet Director software to translate vehicle positions from latitudes and longitudes to street intersections and block numbers, both graphically and as text. The accuracy of the ETAK map's representation of the AirTouch AVL data is vital to the reliability of the system. A check of randomly selected locations and distances was conducted as part of this study to identify any potential concerns with the ETAK map.

Twenty street intersections were selected for this test and identified on the ETAK map. Intersections in low-traffic areas and narrow streets were used to minimize error due to vehicle position within the intersection. Aside from those considerations, the sites were randomly identified throughout the Houston metropolitan area. Measurements were taken at twelve sites selected from this list and at eight sites picked at random during the testing. A site not on the original list necessitated recording the street names and block numbers for subsequent location on the ETAK map. The two objectives of the site measurements were to compare the latitude and longitude measured at each site with the coordinates given on the ETAK map, and to note any discrepancies between the sites and their representation on the map.

One of the twenty sites could not be measured due to a recording failure with the DGPS data. The test results from the other nineteen sites are listed in Table 6. The measured coordinates for the nineteen sites differed from the ETAK coordinates by 4.03 to 27.66 meters. Several limitations to the study design may account for part of the discrepancies, however. First, while the ETAK map measures the location of an intersection at the center of both streets, the vehicle with the GPS antenna was parked to one side of each intersection due to traffic considerations. Second, the sites were measured using a DGPS system, not a physical survey instrument. The standard deviation for the differential DGPS system is approximately 2 meters.

Table 6. ETAK Map Assessment

Location	ETAK Map Coordinates	DGPS Coordinates	Difference (meters)	Notes
8650 Oakford @ 600 Bolton	29.77756 95.45709	29.77755 95.45705	4.03	
5450 Arbor Vitae @ 6100 Autumn Arbor	29.84335 95.48175	29.84346 95.48162	17.51	
800 Enterprise @ 8000 Lawn	29.87419 95.41716	29.87411 95.41718	9.08	
8200 Flatrock @ 11600 Knotty Pine	29.89382 95.26835	29.89381 95.26844	8.76	
1100 Akron @ 10700 Muscatine	29.77012 95.24029	29.77017 95.24012	17.35	
8100 Bendell @ 5300 Bliss	29.67472 95.26007	29.67490 95.26003	20.32	
2300 Redwood @ 6900 Palmetto	29.70514 95.29618	29.70519 95.29646	27.66	
4500 University Oaks @ 4400 Varsity	29.71549 95.34221	29.71544 95.34231	11.15	
5000 Doolittle @ 7300 Guadalcanal	29.67963 95.34545	29.67971 95.34547	9.08	
5600 Elm Spring @ 5550 Canterway	29.63927 95.33566	29.63945 95.33584	26.49	
2400 Bellefontaine @ 7100 Morningside	29.70323 95.41448	29.70333 95.41460	16.05	
900 16th Street @ 1600 Dian	29.79936 95.41379	29.79951 95.41384	17.32	Discontinuity on 16th St. between Dian and Beall does not appear on ETAK map.
8600 Norton @ 2600 Ojeman	29.81812 95.50263	29.81830 95.50255	21.40	
600 Dana @ 11200 Smithdale	29.76949 95.51280	29.76954 95.51274	8.02	
7700 Clarewood @ 6400 Lugary	29.70911 95.52177	29.70927 95.52179	17.84	
12300 Braesridge @ 7600 Secretariat		29.64229 95.50978		
13900 White Heather @ 4100 Ripplebrook	29.62588 95.43782	29.62597 95.43768	16.83	

Location	ETAK Map Coordinates	DGPS Coordinates	Difference (meters)	Notes
Bedford @ 2900 Norwich	29.57110 95.37549	29.57103 95.37559	12.41	Intersection shown between nearby Hughes Ranch Road and Highway 288 does not exist.
8400 Cannon @ 3200 Shelby Circle	29.67030 95.37686	29.67033 95.37681	5.87	

Notable discrepancies in the ETAK map's representation were recorded at two sites. First, the map shows 16th Street as being continuous throughout its length, while it actually contains a wide break due to a canal between Beall and Dian. The street, while appearing to be a direct route past these streets to the ETAK user, is actually impassable and requires a significant detour.

Second, Hughes Ranch Road is shown on the map to connect directly to Highway 288 south of the city. In actuality, that intersection does not exist. Some inconsistencies in street names were also noted. For example, what appears as Smith Ranch Road on a street sign is shown as County Road 93 on the ETAK map.

The second part of the assessment examined distances between points on the ETAK map. Odometer readings recorded while driving between test sites were compared to distance readings from the ETAK map for the same paths. Table 7 provides the results of this analysis.

As in the location-by-location review, the comparison of traveled paths to the path distances on the map did not demonstrate significant differences in mileage. Several differences did appear, however, in the representation of some street characteristics. As noted in Table 7, some of the vehicle's paths were impossible to duplicate on the ETAK map because the map incorrectly indicated discontinuities on some streets. For example, breaks were shown on Tidwell between Antoine and T. C. Jester, on Victory between Banjo and Shepherd, and on Smith Ranch Road between Hughes Ranch Road and McHard Road (FM 2234). Other discrepancies included a missing connection between Hammerly/Antoine and Hempstead Road, and no listed block numbers on Bedford Street.

Table 7. Comparison of ETAK Map Distance Measurements

Intersection	Odometer Reading (Miles)	ETAK Measurement
READING 1:		
Arbor Vitae @ Autumn Arbor Arbor Vitae @ Golden Forest; rt on Golden Forest Golden Forest @ Antoine; left on Antoine Antoine @ Tidwell; rt on Tidwell Tidwell @ T.C. Jester Tidwell @ Shepherd; left on Shepherd Shepherd @ Parker	0.00 0.05 0.50 1.00 1.90 4.70 5.50	Distance not measured; discontinuity on Tidwell on the map
READING 2:		
Enterprise @ Lawn Lawn @ Ringold; rt on Ringold Ringold @ Banjo; rt on Banjo Banjo @ Victory; left on Victory Victory @ Shepherd Little York (formerly Victory) @ I-45 Little York @ Northline Little York @ Nordling Little York @ Airline Little York @ W. Hardy Toll Road Little York @ Aldine Westfield Little York @ Eastex Fwy.	0.00 0.10 0.20 0.50 0.60 0.90 1.50 1.90 2.30 3.40 4.10 5.50	Distance not measured; discontinuity on Victory on the map
READING 3:		
Flatrock @ Knotty Pine Knotty Pine @ Mt. Houston; rt on W. Mt. Houston Mt. Houston @ Suburban Mt. Houston @ Hirsch Mt. Houston @ Hwy. 59; left on Hwy 59 Hwy. 59 @ Wedgewood Hwy. 59 @ Little York Hwy. 59 @ Tidwell Exit	0.00 0.20 1.30 2.40 3.10 3.70 4.50 5.80	5.64 miles. (29777 ft.)
READING 4:		
I-610 @ Market I-610 @ Clinton Exit I-610 @ Manchester Exit I-610 @ Broadway Exit I-610 @ I-45 Exit	0.00 1.90 3.40 4.70 5.30	5.32 miles (28086 ft)

Table 7. Comparison of ETAK Map Distance Measurements (continued)

Intersection	Odometer Reading (Miles)	ETAK Measurement
READING 5:		
Doolittle @ Guadalcanal	0.00	2.96 miles
Doolittle @ M.L. King; rt on M.L. King	0.60	
M.L. King @ Van Fleet	0.80	(15640 ft.)
MLK @ Bellfort	1.30	
MLK @ Reed	1.80	
MLK @ Lakefield	2.60	
MLK @ Airport	2.80	
READING 6:		
Kirby @ University	0.00	3.65 miles
Kirby @ Sunset	0.50	
Kirby @ Southwest Fwy.; left on SW Fwy	1.00	(19248 ft)
Southwest Fwy. @ Newcastle Exit	2.80	
Southwest Fwy. @ I-610	3.60	
READING 7:		
16th St. @ Dian;	0.00	6.70 miles
16th St. @ Shepherd; left on Shepherd	0.20	
Shepherd @ 19th St.; left on 19th	0.40	(35357 ft)
19th St. @ Durham; left on Durham	0.50	
Durham @ 18th St.; rt on 18th	0.60	
18th St. @ Bevis	1.20	
18th St. @ Ella	1.65	
18th St. @ Safford	2.60	
18th St @ Hempstead; rt on Hempstead	3.40	
Hempstead @ Kempwood; left on Kempwood	5.20	
Kempwood @ Bingle; left on Bingle	6.20	
Bingle @ Norton; rt on Norton	6.40	
Norton @ Ojeman	6.50	
READING 8:		
Norton @ Ojeman	0.00	2.57 miles
Norton @ Bingle; rt on Bingle	0.20	
Bingle @ Hammerly;	0.70	(13551 ft.)
Bingle @ Westview;	1.80	
Bingle @ I-10.	2.50	

Table 7. Comparison of ETAK Map Distance Measurements (continued)

Intersection	Odometer Reading (Miles)	ETAK Measurement
READING 9:		
Fondren @ Airport Fondren @ S. Main; left on S.Main S. Main @ S. Post Oak; rt on S.Post Oak S. Post Oak @ Orem; left on Orem Orem @ White Heather; rt on White Heather White Heather @ Ripplebrook	0.00 -- 3.70 -- -- 6.80	6.99 miles (36800 ft)
READING 10:		
White Heather @ Ripplebrook White Heather @ W. Fuqua; rt on W. Fuqua Almeda-Genoa (W. Fuqua) @ Hwy. 288; rt on 288 Hwy. 288 @ F.M. 518; left on FM 518 F.M. 518 @ C.R. 93; left on Cty Rd 93 C.R. 93 @ Hughes Ranch Road; left on Hughes R.Rd Hughes Ranch Road @ Bedford; rt on Bedford Bedford @ Norwich	0.00 0.90 3.90 -- -- -- -- 9.90	10.1 miles (52892 ft)
READING 11:		
Cannon @ Shelby Circle Cannon @ Belfort; rt on Belfort Belfort @ 288; rt on 288 288 @ 59; left on 59 59 @ Wesleyan; rt on Wesleyan Wesleyan @ Chevy Chase; rt on Chevy Chase Chevy Chase @ Timber	10.80	11.03 miles (58262 ft.)
READING 12:		
Bedford @ Norwich; Bedford @ Hughes Ranch; rt on Hughes Ranch Hugh. Ranch @ Smith Ranch; rt on Smith Ranch Smith Ranch @ McHard; left on McHard McHard @ SH 288		Distance could not be measured; map is discontinuous on Smith Ranch Road.
TTI DISTANCE STUDY OBSERVATIONS		
IH 10 @ Shepherd IH 10 @ Washington	1.20	1.19 miles (6267 ft)
IH 10 @ Washington IH 10 @ Loop 610 Loop 610 @ US 290 US 290 @ Mangum	3.67	3.68 miles (19395 ft)

Table 7. Comparison of ETAK Map Distance Measurements (continued)

Intersection	Odometer Reading (Miles)	ETAK Measurement
US 290 @ Mangum US 290 @ Pinemont	2.95 mi	2.91 miles (5398 ft)
US 290 @ Pinemont US 290 @ Little York	3.95	3.92 miles (20704 ft)
US 290 @ Little York US 290 @ Jones Rd.	2.62	2.59 miles (13691 ft)
IH 45 @ Memorial IH 45 @ North Main	2.1	1.95 miles (10280 ft)
IH 45 @ North Main IH 45 @ Airline	3.25	3.14 miles (16491 ft)
IH 45 @ Airline IH 45 @ North Shepherd	3.3	3.44 miles (18155 ft)
IH 45 @ North Shepherd IH 45 @ W.Mt.Houston	1.55	1.49 miles (7863 ft)
IH 45 @ W.Mt.Houston IH 45 @ North Belt 8	2.9	2.95 miles (15568 ft)

CHAPTER FOUR—IMPACT OF THE AirTouch AVL SYSTEM ON METROLift

The impact of the AVL system on METROLift services was examined from three different perspectives. First, a series of performance measures, including service efficiency, as measured by the ratio of passenger miles to vehicle revenue miles, the use of taxi backup service, and on-time performance were assessed. Second, the reaction from METROLift dispatchers and operators was examined through surveys and interviews. Finally, customer responses were noted through a review of changes in the number and types of complaints and a general telephone survey on METROLift services. The impact of the use of the AVL system on each of these three elements is discussed in this chapter.

As noted previously, during the study period, the AVL system was being used to assist an operator in locating an address and locating a vehicle if a customer called to inquire about the status of a ride. METROLift customers were not aware of the AVL system unless they specifically asked an operator, however.

Changes in Service Efficiency

Three general measures were examined to determine the impact of the METROLift AVL system on service efficiency. One of the objectives of the demonstration was to determine if vehicle efficiency would improve through the use of AVL technology. Knowing the location of METROLift vehicles should enhance the ability to maximize the efficiency of vehicle use, especially in responding to changes in passenger trip pick-up times. Changes in the ratio of passenger miles to vehicle revenue miles, the use of taxi backup services, and on-time performance helped assess the possible impacts of the AVL system.

Ratio of Passenger Miles to Vehicle Revenue Miles

The ratio of passengers to vehicle revenue miles provides an indication of the efficiency of a paratransit system. Higher ratios indicate that more passengers are being carried per mile. Monthly METROLift vehicle revenue miles and passenger miles for October 1992 to October 1994 were used to calculate the ratio of passenger miles. Both the monthly and the annual figures were examined.

The monthly ratio of passenger to revenue miles is shown in Figure 9. A number of factors—in addition to the AVL system—may have influenced the changes noted in the figure. For example, a computer-assisted scheduling program was implemented in May of 1993, just prior to the start of the AVL demonstration in October 1993. The decline in the ratio of passenger miles to revenue miles experienced from February to May 1993 may be partially attributable to the change to the new system. The increase from August through December of 1993 appears to be a result of the AVL system and the new computer scheduling system, however, as no other identifiable changes occurred during this period.

The results of this analysis indicate that the ratio of passenger miles to vehicle miles increased from the period before the demonstration to the present. The annual ratio of passenger miles to vehicle revenue miles for the two years before the demonstration were 1.11 and 1.04, while the ratio for Fiscal Year 1994, after the installation of the AVL system was 1.21. This change represents a significant improvement.

The increase in the ratio of passenger miles to vehicle revenue miles indicates that the AVL system has allowed METRO to better manage fleet requirements and dispatch functions. As a result, METRO is better meeting increased demand for service without significant increases in the fleet size.

Backup Taxicabs

The second efficiency measure examined was the use of backup taxi services. METROLift uses taxi service to help meet peak demands for service. When trip requests cannot be met by METROLift minivans, backup taxi services handle the excess. The use of taxis should decline if the AVL system increases the efficiency of METROLift vehicles, unless ridership continues to increase—placing more demands on the system.

Monthly records on taxi trips were examined for the period from August 1993 to November 1994. Records of taxis used as backup service to scheduled METROlift vehicles are kept separate from the records of other taxi use. All of the backup service was included in this analysis, regardless of the reason for the use of the replacement vehicle. Figure 10 illustrates the changes in the use of backup taxi services over the 14-month period.

On-Time Performance

The on-time performance of METROLift service was examined for the pre- and post-AVL time periods. METRO considers a trip late if the vehicle does not arrive within 15 minutes of the scheduled pick-up time. A log is kept of customers calling to report late trips. The percentage of monthly late trips was calculated from METROLift records.

As shown in Figure 11, the percent of reported late trips declined from approximately 4.5 percent in October of 1993 to 3.4 percent in September of 1995. The percent of late vehicles dropped to a low of around 1 percent during March and April of 1994. This corresponds to the time period when more taxis were also being utilized. Although the decrease in late calls during this time may be attributed to the deployment of additional taxis to meet demands, the AVL system allowed METRO to better manage the vehicle fleet helping to reduce the number of late trips.

Figure 9. Ratio of Passenger Miles to Vehicle Revenue Miles -- Month Averages

Figure 10. Percentage of Trips Made by Back-up Taxi Service

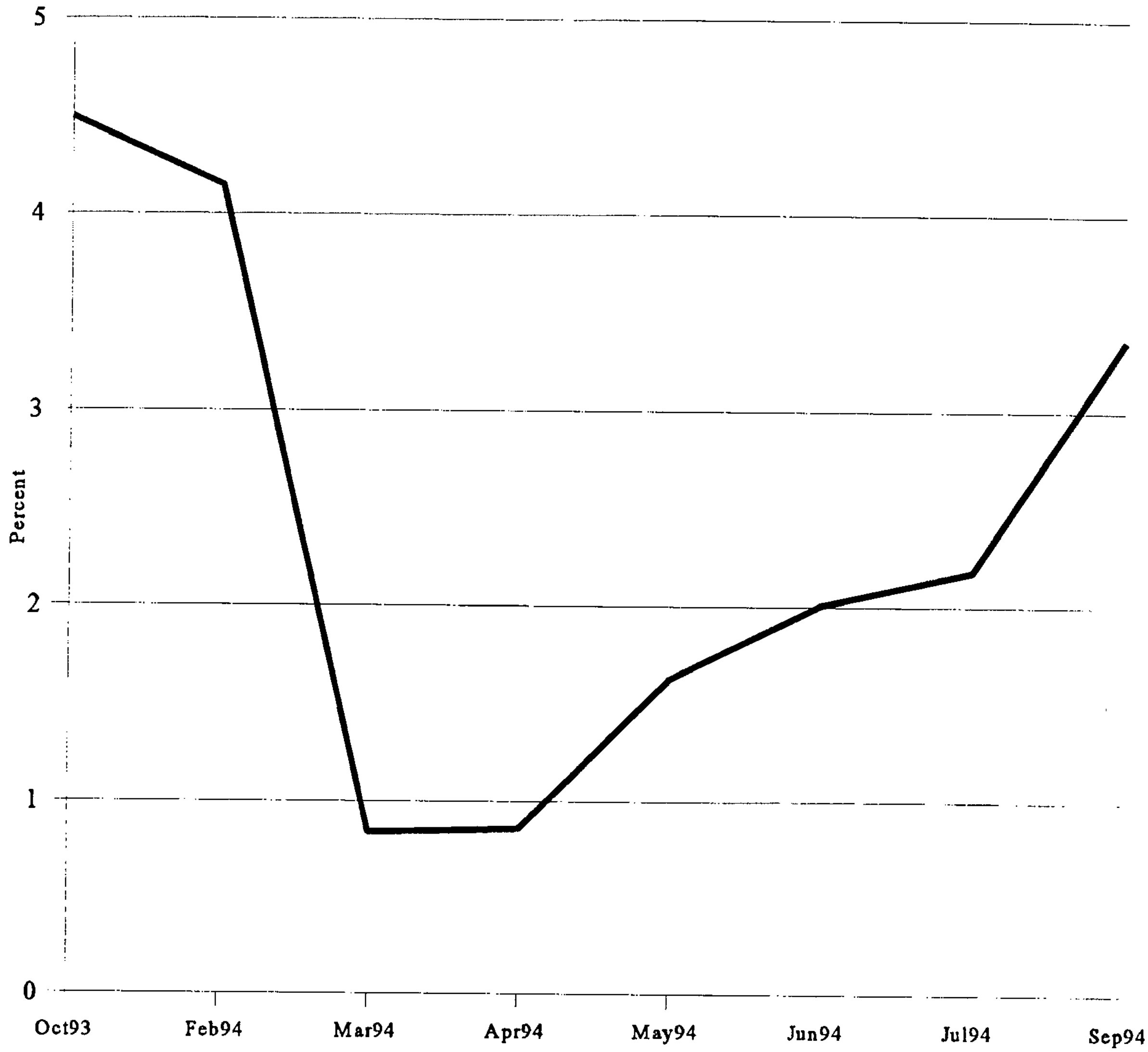

Figure 11. Percentage of Late Vehicles

Reaction of METROLift Dispatchers and Operators

Interviews with METROLift dispatchers and operators helped determine their reaction to the AVL system. Information was obtained on use of the system, ease of operation, problems or issues with the system, and recommendations for improvements or changes. Interviews were conducted with 12 of the 14 dispatchers and 30 of the approximately 220 METROLift operators. The overall response to the AVL system was very positive from both groups.

All of the dispatchers interviewed indicated that the AVL system is easy to use. Further, most noted that it had only taken a day or two to learn to use the system and to become comfortable with the different features. The eight dispatchers who had worked at METROLift before the system was implemented reported that their job is much easier now. Numerous benefits were noted related to the fast and reliable information about the location of vehicles provided by the AVL system. The key benefits identified included the enhanced ability to give operators directions to find addresses, the ability to provide customers with better information on the status of vehicles, and reduced telephone and radio time with both operators and customers. The dispatchers also indicated that paper work has been reduced, job stress has been lowered, and there is less worry about making mistakes.

METROLift dispatchers did indicate a few problems with the system, however. They noted some errors in the map, primarily with problems related to roadway construction, new developments, and changes in traffic flow. The need to update the map on a regular basis was the most frequently cited area for improvement by the dispatchers. Other suggested improvements to the AVL system included the following:

- Split screen for looking at two or more types of information at once.
- Update map.
- Clearer MDT screen.
- Support services to assist in identifying vehicle location units and equipment that is not locating properly.
- Include all vehicles on system; some of the cabs are not included yet.
- Confirmation/feedback that a message through the mobile data terminal has been received by the driver.
- Message added to mobile data terminal: "Passenger is ready for pickup now (earlier than Ready Time)."

All dispatchers felt that the information they give to both METROLift operators and to customers has improved greatly since the AVL system was implemented. Several commented that the improved level and accuracy of information had helped client relations and improved on-time pick-up performance. On the other hand, one dispatcher commented that the passengers' knowledge that vehicle location information was available led some of them to believe that vans should be fully demand-responsive, with no advance reservation.

The response from METROLift operators was also positive. Most of the operators found the system easy to use and indicated that it has simplified their job. The ability to get directions quickly was identified as one of the major benefits of the system. The majority of the operators interviewed also indicated they felt more secure with the system.

The operators suggested a number of improvements to the AVL system. The major issue raised by the operators concerned the location of the mobile data terminal (MDT) unit. Many of the operators noted the position of the MDT inside the vehicle was too high, making it difficult to read and send messages. Suggested changes included moving the unit closer to the dashboard or locating it on the engine boot. The small alphanumeric character size was also noted as a problem with the MDT.

Seventy-three percent of the operators stated that their jobs had been made easier by the addition of the AVL system. Only one operator said that the job had become more difficult. This comment related to the positioning of the MDT in the van, which "makes it difficult to use and watch the road at the same time." The operators indicating that their jobs became easier, most frequently cited the following reasons.

- Fewer radio transmissions.
- Don't have to stop and write extra information or key map code.
- Helps when you can't find your way.
- It saves time - instead of using the phone or radio.

Most operators also agreed that they felt more secure when driving, since the dispatcher could find them in case of emergency. Seventy percent felt that they are receiving better quality information from dispatchers, although 10 percent noted that improvement was still needed in this area. One operator commented that he still does not receive notice of canceled pick-ups, which he feels could and should be sent over the MDT by dispatchers.

While most operators feel that the system has improved their job in some ways, there are aspects of the system's operation and use that they feel could be improved. While some operators have seen a drop in the amount of time and writing it takes to receive and remember directions, others notice their writing time has increased. Seventy percent of the operators interviewed would like to see more use made of the MDTs for sending and receiving information, and 63 percent would like their daily manifests transmitted through the MDTs instead of using a printed manifest, particularly if changes to the manifest appeared on the screen. Seventy percent like the idea of their own computerized maps on board the vans, which would eliminate calling dispatchers for directions.

Other suggestions were as follows:

- Make MDTs a bit larger.
- Darker print would make it easier to read.
- Provide for responses to drivers' calls/messages.
- More training time on the system.

Reaction of METROLift Customers

METRO has conducted METROLift customer satisfaction surveys on a periodic basis. The most recent of these surveys occurred in 1994 and 1995. Since the AVL system has been used primarily as an internal management tool, METROLift customers have not been informed of its use. As a result, no questions in the customer surveys specifically addressed the AVL system. A number of questions did relate to general customer satisfaction, however.

The survey results do provide an indication of some improvements that may be attributed to the AVL system. For example, overall customer satisfaction was up slightly from the previous year. A 5 percent increase occurred in the number of respondents indicating that the service was much better than the previous year, and 3 percent more stated it was somewhat better. In addition, a 3 percent improvement was recorded in those reporting an excellent rating for METROLift on-time performance.

Changes in the number and the nature of customer complaints provides a second measure of rider satisfaction. METRO classifies complaints into the six general categories of service: driving safety, driver behavior, routing and scheduling, equipment, and miscellaneous. The number of complaints related to service and routing and scheduling declined in the months after the introduction of the AVL system.

Figure 12 shows the number of complaints received each month, normalized to reflect equal numbers of passengers. As noted, service complaints appear as a percentage of the total number of complaints received for each month. Both of these graphs show a drop in service-related complaints between September and October 1993, the month in which the AVL system was implemented. Complaints continued to decline until May 1994. In that month, METROLift changed its procedures for recording customer complaints and, as a result, achieved more complete reports of complaints and comments. This change increased the total number of complaints and comments reported, which can be seen in the figure. Since that time, however, customer complaints have continued to decline.

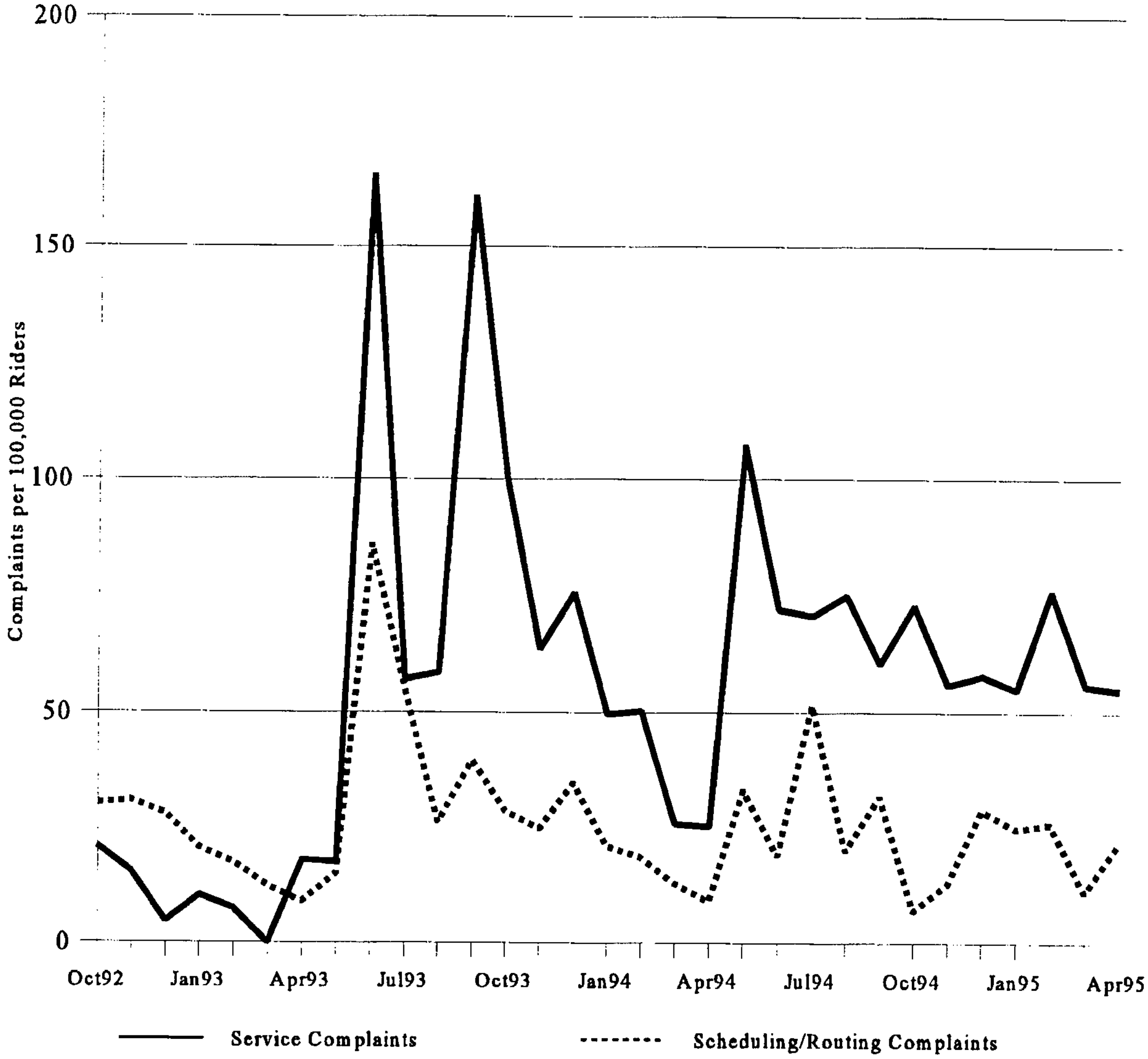

Figure 12. METROLift Service Complaints per 100,000 Riders

CHAPTER FIVE—USE OF AN AVL SYSTEM WITH THE FULL METRO FLEET

This study also considered the use of an AVL system with the full METRO fleet. This analysis was accomplished through the completion of a number of steps. First, the use of AVL systems by other transit agencies throughout the country was explored. Information was obtained on the types of AVL technologies being used and the experience to date with these systems. Second, possible applications for METRO's AVL system were explored. This assessment followed the initial steps outlined in a previous TTI report (3) for selecting and implementing an AVL system. The potential objectives for an AVL system were first defined for each type of METRO service, and the ability of different types of AVL technologies to meet these objectives was examined.

This chapter presents the results of both these elements. The use of AVL systems by other transit agencies and the experience to date is summarized first. A more detailed assessment of the possible application of an AVL system with the full METRO fleet are then described. The potential objectives and applications for an AVL system with different METRO services are identified first followed by a discussion of the advantages and disadvantages of different AVL technologies to meet these objectives.

The Use of AVL Systems by Other Transit Agencies

This section briefly summarizes the implementation and use of AVL systems by seven transit agencies. The first four applications—in San Antonio, Toronto, Ottawa, and Seattle—are utilizing ground-based systems. Satellite-based systems are in use in Baltimore, Denver, and Milwaukee. Information on these systems came from published literature, brochures and reports from the transit agencies, and telephone conversations with representatives from the agencies.

VIA Metropolitan Transit—San Antonio, Texas

VIA Metropolitan Transit in San Antonio was one of the first transit systems in the country to implement an AVL system. VIA first developed specifications for an AVL system in 1983 (10). The selected system, developed by General Railway Signal (GRS) Communications System, is a ground-based technology which uses signposts and odometer readings. Buses are tracked by transmitters mounted on streetlight poles. The transmitters send out coded identification signals that are picked up by location antennas mounted on VIA buses. As the bus passes a signpost, the transmitters read the bus code and transmit information on the status of the vehicle to the central control computer.

The transmitters, which act as low-powered radio transmitters, are located throughout VIA's service area. The signposts reflect coded messages to the on-board computer or vehicle logic unit. Information on all VIA routes, schedules, and the distances between signposts is stored in the central control computer. Bus locations are polled every minute. The actual performance data are then compared to the scheduled information to determine the status of vehicles (10).

The VIA AVL system provides for three types of two-way communication between the central dispatch center and the bus operator. First, routine messages can be sent in brief text format. The messages, which are typed using the operator and the dispatcher keypads, are sent by coded radio transmission and displayed on the in-vehicle and central control monitors. If voice communication is needed, a second option allows for direct radio contact between operators and dispatchers. Finally, the third option allows operators to activate a silent alarm in emergency situations. This alarm, which is unnoticeable to passengers, provides priority access to the central dispatch center (10).

The system polls vehicles at 60 second intervals and provides operators with feedback on schedule adherence every three minutes. If no vehicle movement is recorded in three consecutive one minute polls, the system alerts the dispatcher. This allows the dispatcher to identify potential problems early and to communicate with the operator to determine their exact nature. The dispatcher can then take appropriate corrective action. Depending on the problem, this might include notifying an on-street supervisor, a maintenance vehicle, or a replacement bus, or rerouting other buses. The frequent polling also helps prevent operators from making unauthorized stops. VIA uses the information provided by the AVL system in a number of ways including rerouting buses, making short term service adjustments, and in long-term planning.

Toronto Transit Commission—Toronto, Ontario

The Toronto Transit Commission (TTC), which is responsible for the bus, streetcar, subway, and light rail transit (LRT) systems serving the Toronto area, identified the need for some type of advanced communication and control system in the 1970s (11). The system, called the Communications and Information System (CIS), was developed by TTC and the Province of Ontario in the late 1970s and early 1980s (11,12). A signpost/odometer system, based on the same approach described with the VIA AVL system, is used. Buses are polled every six seconds and the information is reported to the central control facility (2). The CIS was initially tested between 1980 and 1984 with buses operating out of one garage. In 1986, a decision was made to equip the complete bus fleet (2).

The Toronto AVL system allows for communication between the operator and the central control center in a number of ways. First, messages can be typed and displayed on a small unit inside the vehicle. Second, direct communication between operators and dispatchers is possible. Buses are also equipped with internal and external boom microphones that allow control center personnel to talk directly to passengers. This approach is used in fare disputes. Finally, two safety alarms can be activated by the driver. One alarm is used for non-emergency situations, while the second silent alarm is used in emergency cases. In addition, some buses are equipped with automatic passenger counters. This system uses the same signposts as the CIS system to collect non-real time passenger boarding data but is not currently integrated with the CIS system (2,12).

Ottawa-Carleton Regional Transit Commission—Ottawa, Ontario

The Ottawa-Carleton Regional Transit Commission (O-C Transpo) has implemented a demonstration project to test the use of AVL technology on the Ottawa Transitway system. The demonstration focuses on two routes operating on the Transitway. Buses on these routes are equipped with AMTECH automatic vehicle identification (AVI) transponders. The transponders are read by signpost detectors located at strategic points along the Transitway. Information from the transponders is sent to the central computer system for storage, analysis, and dissemination (13).

The first phase of the demonstration tested the hardware, software, and information processing capabilities of the system. The second phase focuses on integrating the AVL system with the overall transit control system and the central control staff. This phase is focusing on staff training, developing the capabilities to model the progress of buses, and developing and evaluating different transit control strategies. A third phase will involve full implementation of an AVL system. This may involve the use of a GPS based system to complement the current ground-based approach (13).

The AVL system represents just one of the advanced technologies being implemented by the Ottawa-Carleton Regional Transit Authority. Other elements include the Automatic Passenger Counting System, the *560 Telephone Information System*, and the cross-based bus reference system. Each of these components is being coordinated or integrated with the AVL system. The Automatic Passenger Counting System includes 90 buses that are equipped with microprocessors and infrared light beam detectors to record the movement of passengers and buses. This is not a real-time system, but the information obtained is used for a variety of planning and scheduling activities. The *560 System* is an automated telephone passenger information system. It allows individuals to obtain information on the scheduled time for the next two buses that will arrive at a particular transit stop. The cross-based reference system is being developed by adding a second tag, or run plate, to the front of buses. These tags are read as a bus leaves a garage, and the resulting information will be used to match specific vehicles with actual run segments. O-C Transpo is also exploring future applications of transit priority treatments at traffic signals.

King County Metro—Seattle, Washington

The Municipality of Metropolitan Seattle (Metro) has implemented both a new data radio and an AVL system a little over a year ago. The AVL system uses a signpost-based technology. Metro's main objectives in designing the system were to improve bus communications, reduce emergency response time, and improve bus scheduling capabilities. The AVL system includes signpost transmitters, mobile odometers, and a central process unit. The radio system includes four 450-MHz channels for bus voice communication, two 450 MHz channels for supervisory vehicles, and two 800-MHz channels for maintenance vehicles (14).

Vehicle polling occurs every 30 to 90 seconds, depending on the number of buses in operation. The system also has an emergency alarm that can be activated by the driver. Vehicles are automatically polled more frequently—between 5 and 15 seconds—when the emergency alarm is activated. Control center personnel can also request more frequent polling at any time if they feel the need is warranted.

Metro is examining possible enhancements to the system and is coordinating the development of a CAD/AVL system with other activities. These include enhancing customer information through the provision of real-time bus status data and improving bus travel times through the use of priority treatments for buses at traffic signals (14). These activities are being coordinated as part of the SWIFT project. This effort includes a number of other ITS elements, all focused on enhancing the overall management of the transportation system in the Seattle area. The AVL system has been working well to date. One concern that has been raised, however, is the potential to lose track of buses between signposts.

Mass Transit Administration—Baltimore, Maryland

The Mass Transit Administration (MTA) in Baltimore has been developing an AVL system since 1988. An initial demonstration project used an AVL system based on LORAN-C, supplemented by bus odometer readings and map matching. This project was sponsored by the FTA to test the feasibility of using off route tracking systems. Westinghouse Electric Corporation developed the system for the MTA. Approximately 50 buses and 4 supervisory vehicles were equipped with AVL tags during this demonstration. Equipment used included a LORAN-C receiver, a vehicle logic unit, a transit control head, and a radio (2,15,16).

Buses were polled every 20 seconds, with the data transmitted over dedicated radio frequencies. A digital map displayed the real-time status of vehicles. Two screens were available to dispatchers. Using color coding, information relating to on-time performance, off-route location, vehicle maintenance needs, and emergencies were displayed graphically on one screen. The other screen provided a variety of information for operations management. The system also had recording and printing capabilities.

The current phase of the project includes equipping the remaining 850 MTA buses, 34 light rail vehicles, and commuter rail vehicles into an integrated CAD/AVL system. A GPS-based AVL system is being used in this phase to increase the accuracy of the vehicle location component. It is anticipated that the system will also include automatic passenger counting capabilities and scheduling software. In a related project, the MTA has also installed a customer information kiosk at the bus, LRT, and commuter rail stop at the new Camden Yards Ballpark in Baltimore. This kiosk provides transit and tourist information through a touch screen device (2).

Regional Transit District—Denver, Colorado

The Regional Transit District (RTD) in Denver has implemented a combined computer-aided dispatching (CAD) and AVL system. The RTD used an innovative approach involving a private sector consortium to develop and implement the CAD/AVL system. The RTD's major objective for the system included improving dispatching capabilities, improving scheduling, enhancing driver and passenger safety, and providing real-time information to transit riders (15,16).

The RTD initiated the development of its CAD/AVL system a few years ago in response to the need to upgrade the existing radio communication system. The RTD utilized a consultant to help examine the issues associated with the existing radio system and to identify the requirements for a new system. A request for proposal (RFP) was issued based on these requirements, soliciting innovative approaches to the development and implementation of a new system. Westinghouse Electric Corporation was selected by the RTD to provide the new CAD/AVL system (16).

The Westinghouse system includes a GPS-based communications and information package that performs a variety of functions. An operations center provides the focal point for the overall system. Other system components include an integrated CAD/AVL software package, the dispatcher and computer work stations, and the on-vehicle elements. Equipment on the RTD buses includes a mobile radio, an on-board processor, a driver console, handset, public address system, external microphone, and a GPS antenna. A vehicle odometer, connected to the on-board processor, provides a dead-reckoning feature to support the GPS in areas where satellite signals cannot be picked up (15).

The system polls the location of buses every two minutes on a normal basis, but more frequent communication can be made in response to incidents or emergencies. The system tracks the location of vehicles and compares the actual position with schedule information. In addition, the system allows the dispatchers to talk directly with the operators and to send text messages. The driver can also activate a silent alarm switch in the case of an emergency. This alerts the central dispatchers that a problem exists. Dispatchers can respond by monitoring the location of the vehicle more frequently and activating a microphone on the vehicle to monitor the situation (15,16).

Analysis capabilities are also being established to provide for the development of multiple databases and the ongoing use of information generated by the CAD/AVL system. It is anticipated that regular reports will be prepared to improve overall system management and evaluation. In addition, the RTD is developing a real-time public information system on the status of vehicles through the use of electronic screens in the two downtown transit stations and through the telephone information system (15,16).

Milwaukee County Transit System—Milwaukee, Wisconsin

The Milwaukee County Transit System is in the process of implementing a GPS-based AVL system. The system is being developed and implemented by a consortium that includes Westinghouse Electric Corporation, Trimble Navigation, and Motorola. The system components include 800 megahertz trunk radios, computer aided dispatch (CAD), and a GPS-based AVL system. The main objectives of the system are to enhance safety and schedule adherence of bus service in the Milwaukee area. Additionally, the information generated by the system will be used to enhance the overall management of the transit operations and to provide improved information to riders (15).

The AVL software and hardware are being developed so they can be integrated with many other systems in the future to greatly improve the overall efficiency of the Milwaukee transit service. For example, planned future enhancements focus on monitoring bus engines, wheelchair lift use, and passenger levels. Combining the system with enhanced vehicle scheduling software is also being explored. Further, the system can be coordinated with 3M Opticon traffic signal units to provide bus priority treatments at busy intersections (15,16).

The first implementation phase for the Milwaukee system, which was initiated in late 1993, included testing of the hardware and software on 15 buses. The system is currently being expanded to the full fleet, with further enhancements planned for the future (15,16).

Expansion of an AVL System to the Full METRO Fleet

The expansion of an AVL system to the full METRO fleet was examined as a part of this research study. This assessment followed the first three steps outlined in the AVL system selection and implementation process contained in a previous TTI report (3). Figure 13 illustrates the five steps in this process, which starts with the identification of the purpose and use of the system and ends with the issuance of a request for proposal and the selection of a vendor. The exact nature and complexity of the issues examined in each step will vary depending on the characteristics of the transit system and the area.

Step 1. Identify the Purpose and Use of AVL System. The development of an AVL system is not an end or objective in and of itself. Rather, AVL systems are used for specific purposes and to meet specific goals and objectives. As discussed previously, existing AVL systems are performing a variety of functions and the information is being used in numerous applications. The first step in the selection process should be a realistic assessment of the need for and use of an AVL system. This assessment should include a clear articulation of the problems or issues the AVL system will address, the purpose and use of the system, and the goals and objectives for its use. An initial listing of possible objectives for a METRO-wide AVL system are outlined later in this chapter. Ensuring that there is agreement on these among all METRO departments and staff is critical to both developing realistic expectations and to selecting the appropriate system.

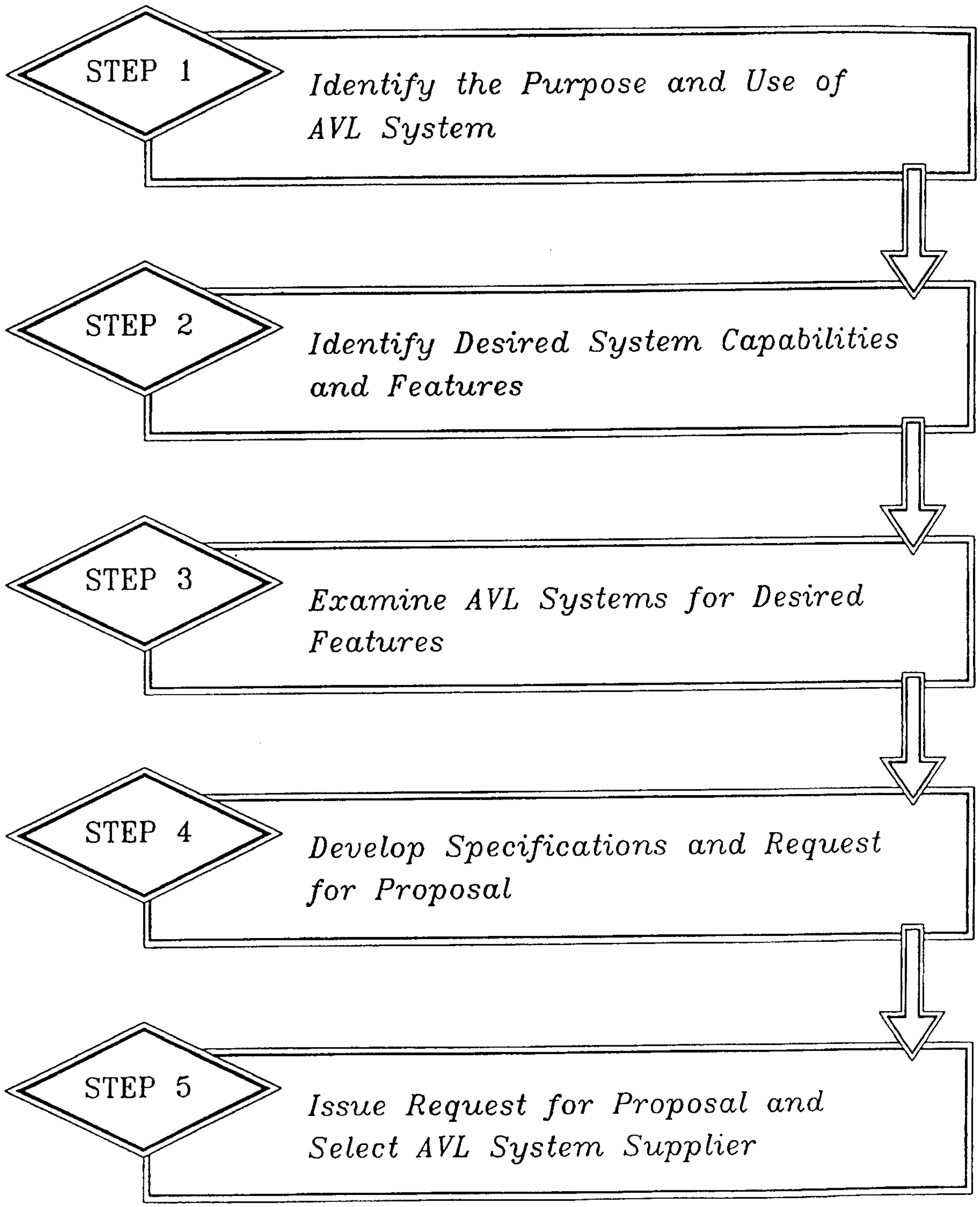

Figure 13. Key Steps to AVL System Selection

Step 2. Identify Desired System Capabilities and Features. Once the purpose and use or goals and objectives of the AVL system have been identified, the next step is to translate these into the specific features and capabilities desired in the technology. These will determine the types of AVL technologies that should be considered, which in turn will influence the cost of the system. For example, the need to locate vehicles anywhere within a service area—rather than just along a route—rules out the use of land-based or signpost technologies. Consideration of the desired system capabilities and features should include those associated directly with the AVL system, as well as additional elements. Elements basic to the AVL system include the desired level of accuracy and reliability,while additional features might include passenger counting, engine monitoring, and emergency notification capabilities.

Step 3. Examine AVL Systems for Desired Features. Once the desired system capabilities and features have been identified, the different types of AVL technologies available to meet these requirements can be examined. This step focuses on evaluating available AVL systems against the desired features. This process will assist in developing a realistic assessment of the types of technologies that may be used and the costs associated with each. The results of this analysis will provide a better indication of the nature, scope, and cost of the potential system.

Step 4. Develop Specifications and Request for Proposal. The detailed bid specifications and the request for proposal (RFP) or request for bid is completed in this step. The information analyzed in the previous step on the desired system features is used here to outline the specific elements vendors will be asked to bid on. A variety of approaches may be used in this process including either a one step process or a two step request for technical proposals (RFTP) process.

Step 5. Issue Request for Proposal and Select AVL System Supplier. The last step in the AVL selection process includes issuing the RFP or RFTP, evaluating the responses, and selecting the supplier or vendor. Specific activities in this step include notification and advertising, pre-proposal meetings, vendor contacts, schedule, and content of the response. The procedures may also address requirements to select the low bidder or may provide cost flexibility based on system specifications.

Currently, METRO provides a variety of services using a mix of vehicles. METRO services include METROLift, Park-and-Ride routes using the HOV lanes, park-and-ride and express routes, local fixed-route service, and the downtown circulator. To provide these services, METRO utilizes minivans and sedans, articulated buses, over-the-road coaches, standard 40-foot buses, and minibuses. In addition, the fleet also includes on-street supervisor vehicles, METRO police cars, tow trucks, and other support vehicles.

The characteristics of these services are different. As a result, the potential uses of an AVL system with these services may also be different. Table 8 outlines the general characteristics for the various major types of METRO services and possible objectives for the use of an AVL system. This information is presented to help focus discussion by METRO staff. It is realized that METRO may have further ideas on the objectives of an AVL system with the different services.

The ability of different types of AVL technologies to meet these objectives was also examined. Table 9 presents the result of this assessment. As shown, the technologies that appear most appropriate for further consideration are radio multilateration, DGPS, and some combination of multiple technologies. A number of other issues should be considered in this process. Some of the major issues for further consideration are outlined next.

- **Smart Vehicle or Smart Central**. Vehicle location information is available directly to the operator through a display or other interface. A Smart Vehicle system is particularly helpful for way-finding and would benefit paratransit, police, and other services which do not operate on fixed routes. The Smart Central approach reports all vehicle location information to a central office. An operator communicates with the central office to receive necessary information. Smart Central systems offer fleet monitoring capabilities and allow for instant notification of vehicle emergencies. For paratransit and other non-fixed operations, a combination of Smart Vehicle and Smart Central approaches may be the ideal AVL system.

- **Radio capabilities and compatibility**. For any Smart Central AVL system, vehicle location information must be communicated over radio frequencies to the central office. For radio multilateration systems such as AirTouch, location information must first be sent to the control center from the radio towers, then from the control center to the fleet dispatcher. In either case, data throughput capabilities and communication compatibility must be evaluated at each point through which information must travel. For a Smart Vehicle system, very little data is transmitted over communications lines. For a system using both Smart Vehicle and Smart Central functions, the communication of data can be reduced if the Smart Central component is limited to emergency and exception reporting. In these cases, radio compatibility will be less of an obstacle.

- **Cost**. The costs associated with the development and implementation of an AVL system will vary depending on the technology, the number of vehicles, and the other elements of the overall system. Cost may be an important factor in the decision making process.

- **Data throughput**. The number of vehicles, the desired paging frequency, and the system configuration will all influence the data throughput capabilities. For example, AirTouch personnel indicated that the AirTouch system did not have the throughput capacity to accommodate frequent polling of the full METRO fleet.

Table 8. Characteristics of METRO Services and Potential Objectives for Use of an AVL System

METRO Service	Service Characteristics	Potential Uses/Objectives of AVL System
METROLift	• Demand responsive.	• Help operators find addresses. • Help communicate status of vehicles to customers. • Real-time dispatching (with enhanced paratransit scheduling). • Enhance operator and passenger safety with emergency notification button. • Act as traffic probe. • Longer-term planning.
Park-and-ride with HOV lane	• Fixed route. • High speed travel in HOV lane.	• Bus stop annunciator in downtown area. • Real-time bus status to passengers. • Real-time corrections to improve on-time performance/schedule adherence. • Enhance operator and passenger safety with emergency notification button. • Act as traffic probe.
Park-and-ride, Express, and Local fixed-route services, and Downtown circulator	• Fixed-route. • With mixed-traffic.	• Bus stop annunciator in downtown area. • Real-time bus status to passengers. • Real-time corrections to improve on-time performance/schedule adherence. • Enhance operator and passenger safety with emergency notification button. • Long term route schedule planning. • Act as traffic probe.
METRO police	• Respond as requested, do not follow fixed route.	• Enhance ability to know where vehicles are. • Enhance response capabilities. • Enhance police officer safety with emergency notification.
Support vehicles	• Respond as requested, do not follow fixed route.	• Enhance ability to know where vehicles are located. • Enhance police officer safety with emergency notification.

Table 9. Suitability of AVL System Types to METRO Services

METRO Service	Type of AVL System				
	Signpost	Radio Multilateration	Dead Reckoning	DGPS	Multiple Technologies Combinations
METROLift	-	+	0	+	+
Park-and-ride with HOV lane	+	+	0	+	+
Park-and-ride, Express, and Local fixed route services, and Downtown circulator	+	+	0	+	+
METRO police	-	+	0	+	+
Support vehicles	-	+	0	+	+

Note: + = Meets objectives well
0 = Meets objectives marginally and/or with assistance
- = Not able to meet objectives

For block-by-block accuracy in the downtown area, or other areas with tall buildings, radio multilateration and DGPS will be more accurate when combined with another technology, such as dead reckoning or signposts.

- **Accuracy**. The level of accuracy desired may influence the technology selection process. The needed accuracy level will relate to the objectives and uses of the system. For example, greater accuracy is required for bus stop vehicle annunciation systems.

- **Emergency support**. The ability to summon help through the use of an emergency call button may be an important feature of an AVL system. Not all AVL systems may provide this.

- **Flexibility**. The flexibility of the AVL technology to increase the number of vehicles in the system or to make other modifications may be an important consideration.

- **Compatibility**. The compatibility of the AVL technology with other desired technologies may be a consideration. Other technologies might include vehicle stop annunciator systems, advanced passenger counting systems, and other features.

CHAPTER SIX—OTHER ITS TECHNOLOGIES TO ENHANCE SPECIALIZED PARATRANSIT SERVICE

This study also examined the potential application of addition ITS technologies to enhance paratransit services. The results of this assessment, which included a review of available literature and reports and telephone conversations with transit agency representatives from throughout the country, are documented in a separate report. A few projects and applications are highlighted in this chapter, however, to provide an indication of potential projects for consideration by METRO and other transit systems.

- **Dynamic or Real-Time Paratransit Scheduling**. Currently, the METROLift AVL system is being utilized primarily to assist operators find addresses and to communicate the status of vehicles to customers. The potential exists to expand the use of the system to provide dynamic or real-time scheduling of vehicles. A variety of approaches are appropriate—from simply enhancing the ability to respond to changes in trip requests to a real-time responsive system.

- **Real-Time Passenger Notification System**. The AVL system can be further enhanced to link into a passenger notification system. ITS or other advanced technologies can be used in combination with the AVL system to provide notification to a METROLift customer that a vehicle was approaching and they should be ready. Such a system might also notify the passenger's destination—such as a doctor's office—that they were approaching.

- **Advanced Paratransit Scheduling Package**. A number of enhancements have been made to computerized paratransit scheduling packages over the years. Paratransit scheduling and dispatching computer software include several features used to assign travelers to vehicles and vehicles to trips. Linking the AVL system with an advanced paratransit scheduling package would further enhance the ability to manage the METROLift fleet and maximize vehicle efficiency.

  Smart Cards. *Smart Cards* are a fare payment method utilizing pre-paid electronic cards. A number of different technologies are available for use with *Smart Cards*, and several transit systems have initiated demonstration projects using various approaches. For example, the Washington Metropolitan Area Transit Authority (WMATA) has implemented a Uniform Fare Technology Demonstration Program called the *Go-Card System*. The demonstration is using a proximity card technology for pre-paid fare transactions. Riders are able to use the *Go-Card* for fare payment on the Metrorail system, Metrobus service, and WMATA park-and-ride lots. Currently, the *Go Cards* are valid only at selected rail stations, park-and-ride lots, and bus routes. Go Transit in Toronto, Ontario, and Mississauga Transit are developing a contactless *Smart Card* system for deployment in the metropolitan Toronto area. The initial test of the *Combo Cards* started in the summer of 1995, with the pre-paid electronic fare cards used on multiple transit systems in the Toronto area.

Smart Cards are also appropriate for use with specialized paratransit services. *Smart Cards* would simplify the fare payment system for riders and operators, and would enhance the ability to track billings and use of the system.

- **Information Systems**. A variety of ITS and advanced technologies could be used to enhance information on paratransit services, as well as the status of vehicles or trip requests. Possible technologies and applications include interactive kiosks, interactive cable television, electronic maps, and the World Wide Web and Internet system.

These represent just a few examples of the potential use of additional ITS and other advanced technologies to enhance specialized paratransit services. Further application may also be appropriate with accessible fixed-route services. These include automatic stop annunciator systems, talking bus stops, and enhanced information services.

CHAPTER SEVEN—CONCLUSIONS

This research study has examined the use of the METROLift AVL system in Houston. It included an assessment of the performance of the AirTouch system and the impact on METROLift services. The study also examined the use of an AVL system with the full METRO fleet and the application of other ITS technologies to enhance specialized transportation services.

A number of conclusions can be drawn from the information presented in this report. This chapter summarizes the general findings related to the AirTouch AVL system performance, the impact of the AVL system on the METROLift fleet, and the potential use of an AVL system with the full METRO fleet. Also identified are potential demonstration projects and areas for additional research.

The results of the performance of the AirTouch AVL system indicate that the stated accuracy requirement of 46 meters at 2 sigma was met for most of the test. The instances where this criterium was not met were in areas with tall buildings, such as downtown Houston. Interference from buildings or other features appears to be the cause of less accurate readings in these areas. AirTouch notes that there is a potential for lower levels of accuracy in these environments and does not claim it can meet the stated accuracy levels in these instances (8).

The AirTouch data throughput capabilities are sufficient for the number of vehicles in the METROLift fleet. The AirTouch system does not have the capacity for substantially larger fleets such as all METRO fixed-route vehicles, however. Further, AirTouch does not currently have plans to expand to accommodate the frequent polling by large fleets.

The use of the AVL system has had a positive impact on METROLift service. Although not the sole reason, the AVL system has helped increase the ratio of passenger miles to vehicle revenue miles, reduce use of backup taxi services, and reduce late trips. Further, the response from METROLift dispatchers and operators has been very positive.

The results of this assessment indicate that the METROLift AVL system has allowed METRO to better manage fleet requirements and vehicle dispatch functions. As a result, METRO has been able to better meet the increasing demands for service in a time of limited resources. METROLift dispatchers and operators have also noted improved productivity and enhanced capabilities from the AVL system.

In terms of expanding an AVL system to the full fleet, METRO may wish to consider a number of options. As noted in this report, the different types of AVL technologies have different advantages and disadvantages. The lack of data throughput capabilities limits the use of the AirTouch AVL system with the full fleet. Further, METRO may desire to have enhanced emergency request features in an AVL system. A DGPS or a combination system may better meet METRO numbers needs.

As outlined in this report, other ITS and advanced technologies can be utilized to further enhance specialized paratransit services. Potential demonstration projects, operational tests, and areas for additional research should focus on the use of advanced paratransit scheduling packages, dynamic scheduling, *Smart Cards*, and enhanced passenger information systems.

ITS technologies can also be used to enhance the potential for individuals with special needs to utilize accessible fixed-route service. Bus stop annunciator systems, advanced in-home notification systems, and talking bus stops represent just a few possible applications. Additional research and demonstration projects focusing on these elements would also be appropriate.

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APPENDIX A—EFFECT OF POWER SOURCES AND ANTENNA GROUND PLANE

At most sites in the location accuracy tests, the AirTouch antenna was attached by its magnetized base to the top of the vehicle and powered through the vehicle's cigarette lighter. However, at a few sites along the Bellaire route, the absence of safe parking for the vehicle required that the antenna be removed from the vehicle and powered by a portable 12-volt battery. When the antenna is not attached to the vehicle, it loses some of its grounding, which may affect the accuracy of the signal it transmits to the towers. The difference in power source may also affect accuracy. These effects were tested using the NGS survey markers as a known point. Also tested were the effects of the vehicle operating conditions on the antenna; power levels to the antenna could change depending on whether the vehicle's engine was on or off, and whether or not other electrical systems were in use (air conditioning, radio, etc.).

Antenna strength was tested as an additional variable, to simulate different operating conditions that an AirTouch antenna may experience. Three antennas were used: one similar to the one used in the rest of the location accuracy tests, marked "0 dB;" one with a 3 dB gain to improve transmitting strength; and one with a -6 dB attenuation to simulate poor antenna placement, such as underneath or inside a vehicle.

The results of the tests are summarized below (Table 10). The two NGS markers used were on Main St. and Memorial Drive. The Main Street marker was at the edge of a highway overpass, with no trees or other obstructions overhead. The Memorial Drive marker was on a street median, in the middle of a grove of trees, which likely created some interference with signals.

Table 10. Location Error Under Power Sources and Antenna Variations

Location and Antenna Strength	Vehicle On, No Other Systems Running	Vehicle On, Other Systems Running	Vehicle Off	Antenna Not Attached to Vehicle; Battery Powered
Main - 3 dB Gain	6.72	5.70	7.51	13.44
Main St. Marker - 0 dB	6.60	5.72	7.08	15.94
Main - 6 dB Attn	6.90	6.98	7.63	11.79
Memorial - 3 dB Gain	19.67	----	----	18.55
Memorial Dr. Marker - 0 dB	22.53	----	----	20.34
Memorial - 6 dB Attn	27.20	----	----	33.02

From the results of these two sites, the greatest influence on locational accuracy appears to be the characteristics of the site. As stated above, the two sites differed markedly, with Memorial Drive shaded densely by trees in contrast to the open, "uncluttered" Main Street site. The worst case of error for the Main Street site (15.94 meters average error) is better than the best case for the Memorial Drive site (18.55 meters).

The absence of a "ground plane" for the AirTouch antenna also seems to affect the accuracy of readings, but the effect varies. The worst case for the 0 dB antenna was at the Main Street site, where removing the antenna from the vehicle led to an 8.88 meter increase in average error over that seen with the antenna attached to the "non-running" vehicle. At the Memorial Drive site, the error actually decreased for two out of the three antenna strengths when the antenna was removed from the vehicle. Under normal operating conditions, an AirTouch antenna will be attached magnetically to the vehicle; therefore, the only significance of these findings is in the results of the vehicle location tests along the Bellaire route where, in a few cases, the antenna had to be removed from the vehicle in order to take multiple readings over a period of time. Since most of those sites were downtown, interference from buildings and power lines were likely greater sources of error than the absence of a ground plane.

The operating condition of the vehicle (other than electrical systems on or off) did not appear to account for significant amounts of error. Voltage through the vehicle's cigarette lighter to the antenna was 12.5 volts (AC) with no other electrical systems on and 11.5 volts (AC) when all electrical systems were on. When the vehicle engine was off, the antenna was receiving 11 volts of DC power from the vehicle's cigarette lighter, equivalent to the 11 volts measured from the portable battery. There was a less than a 2 meter increase in average error when the vehicle was off.

APPENDIX B—TEST OF DGPS AND E-SYSTEMS ACCURACY

In order to verify the accuracy of the DGPS system that acted as a comparison for the AirTouch readings, the DGPS system was tested against two NGS survey markers. At each marker, the DGPS antenna was placed on top of the vehicle which was parked over the marker, and approximately 100 readings were recorded. The coordinates given by the DGPS system and the coordinates provided by NGS for the locations of the "Main St." and "Memorial Drive" markers are compared in Table 11. At the Main St. marker, GPS surveyed coordinates differed by approximately 2 meters. At Memorial Drive, the difference was approximately 4 meters; the larger error was likely due to the trees surrounding and covering the site.

Differential GPS readings were also compared to the coordinates provided by E-systems for the Wilcrest site on the Bellaire route. The difference recorded between the DGPS and E-systems coordinates was approximately 2 meters.

Table 11. Comparison of GPS, E-Systems, and Surveyed Coordinates

Site	Differential GPS Coordinates	NGS Survey Marker Coordinates	E-Systems Coordinates
Main St. NGS Marker	29.657178 95.441472	29.657174 95.441493	
Memorial Drive NGS Marker	29.764817 95.433338	29.764790 95.433311	
Bellaire@Wilcrest	29.703553 95.571353		29.703570 95.571361

APPENDIX C—SAMPLE OF SELECTED TEST PLOTS

This appendix contains sample plots of the data from the vehicle location accuracy tests. The plots appear in the following order. All of the plots are contained in a separate document, *Technical Appendix: METROLift AVL System Assessment.*

METRO 2 Bellaire Route-Dairy Ashford Branch:

- **Intersection of Bellaire and Wilcrest**

  AirTouch readings are clustered fairly closely around the known location.

- **Intersection of Main and Calhoun**
- **Intersection of Main and Clay**

  In these downtown locations, readings are more widely scattered.

- **Intersection of Bellaire and Cannock - Original Test**
- **Intersection of Bellaire and Cannock - Repeat Test**

  An extreme example of the variation that could occur between different days of testing.

Areawide Locations:

- **Mesa Transit Center**
- **Northwest Park-and-Ride**
- **Hillcroft Park-and-Ride**
- **Edgebrook Park-and-Ride**
- **Spring Park-and-Ride**

  The Park-and-Ride lots and Transit Centers tended to produce AirTouch readings which were more tightly clustered than the bus stop sites, probably due to the "open" locations offered by the parking lots. The exception was the Spring Park-and-Ride, the furthest north, which may have suffered from fewer towers in its vicinity.

Peripheral Locations:

- **Intersection of I-10 and Katy Road (West)**
- **North Park Park-and-Ride**

  For these sites at the edge of AirTouch's service area, scattering remained fairly low, but North Park and Katy Road readings were both offset slightly from the known point. Again, fewer towers in the area and the absence of towers on the "far side" of these points may account for the error.

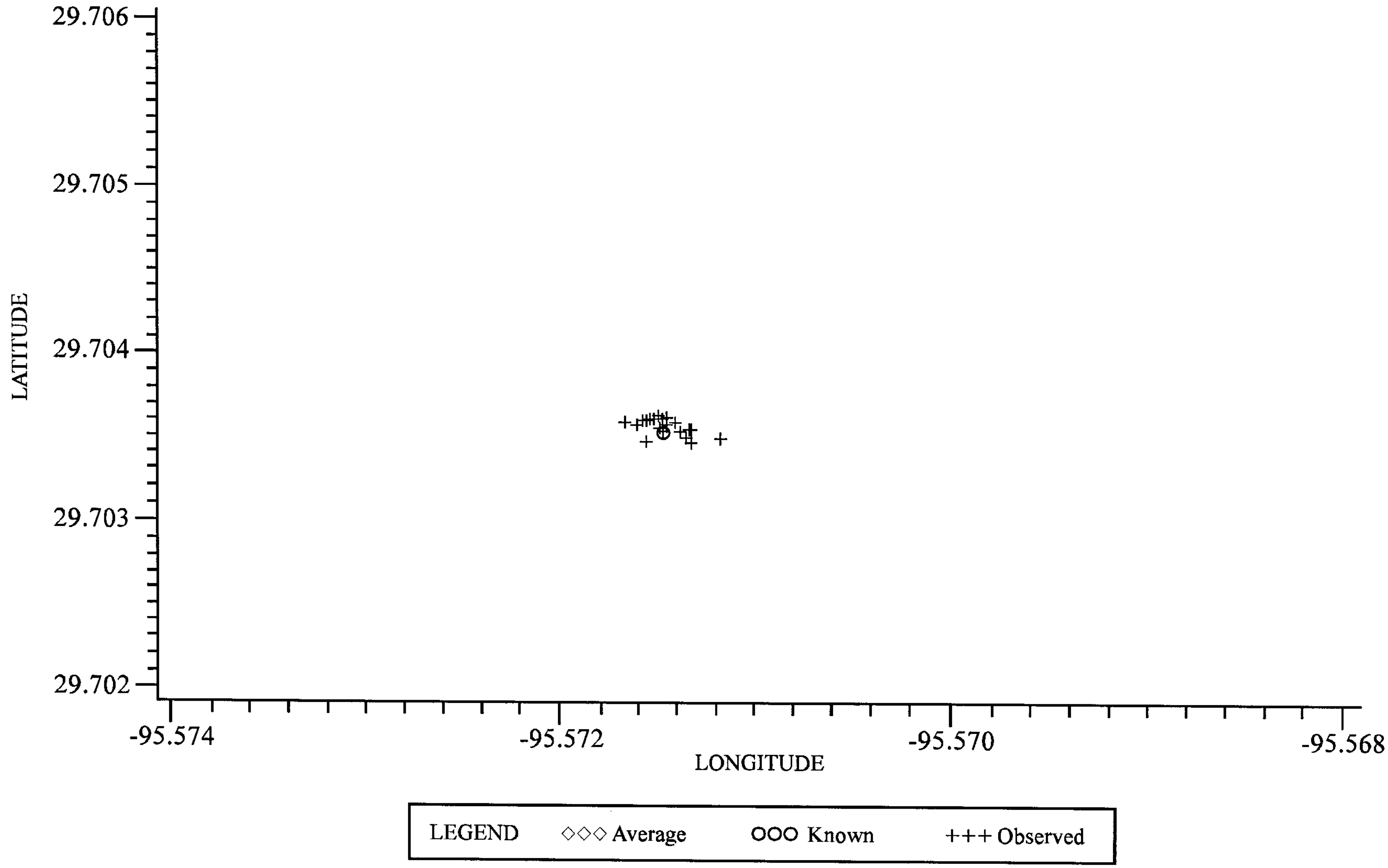
Underground Parking:

- **Galleria (Outside)**
- **Galleria Underground Parking**

  These two plots demonstrate the difference in scattering between above-ground and underground readings for the same approximate location.

BELLAIRE @ WILCREST (ORIGINAL - NAD27)

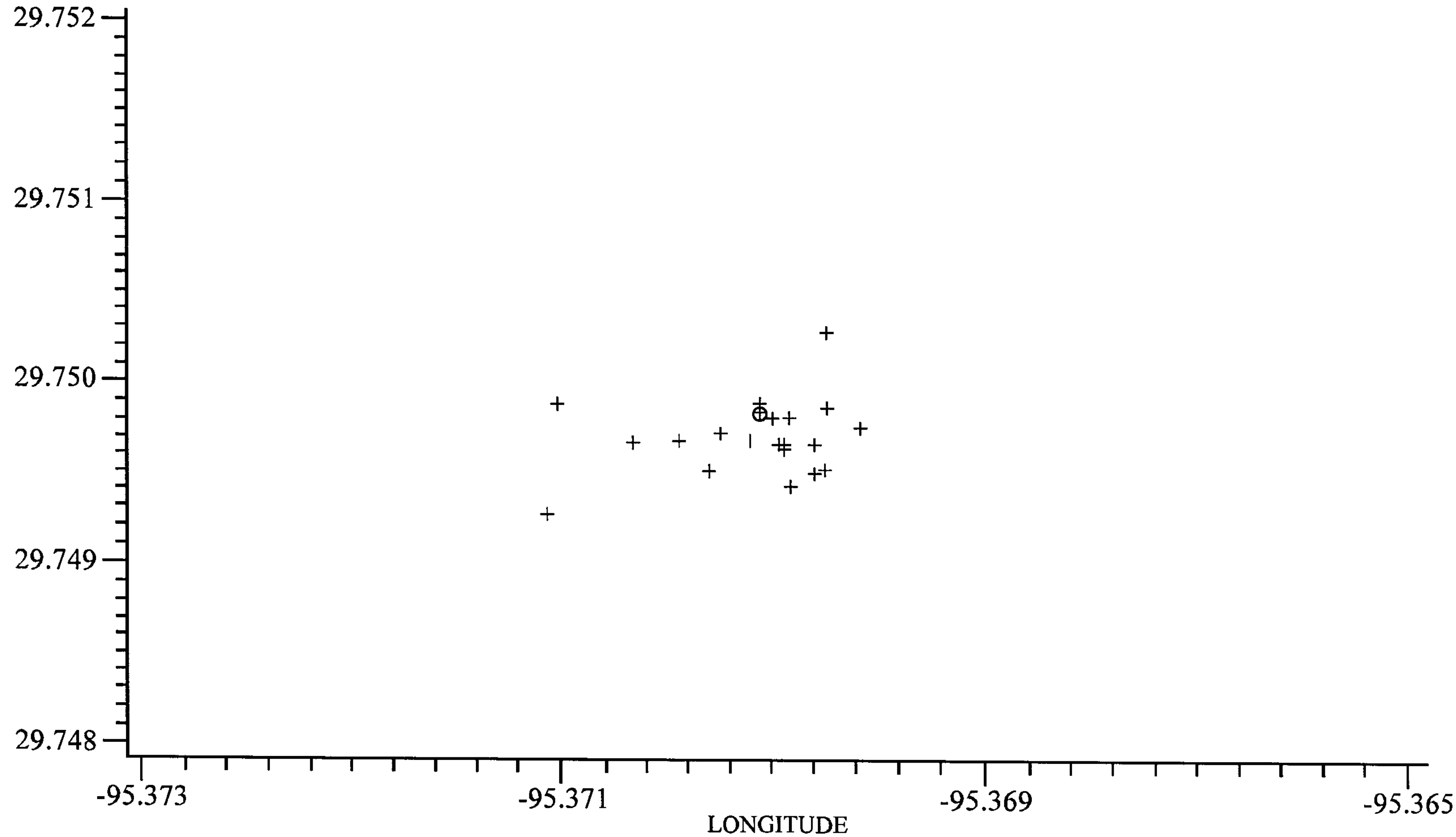
Latitude = 29.703570   Longitude = -95.571461



Average Distance from Known to Observed = 11.28 meters

MAIN @ CALHOUN (ORIGINAL - NAD27)

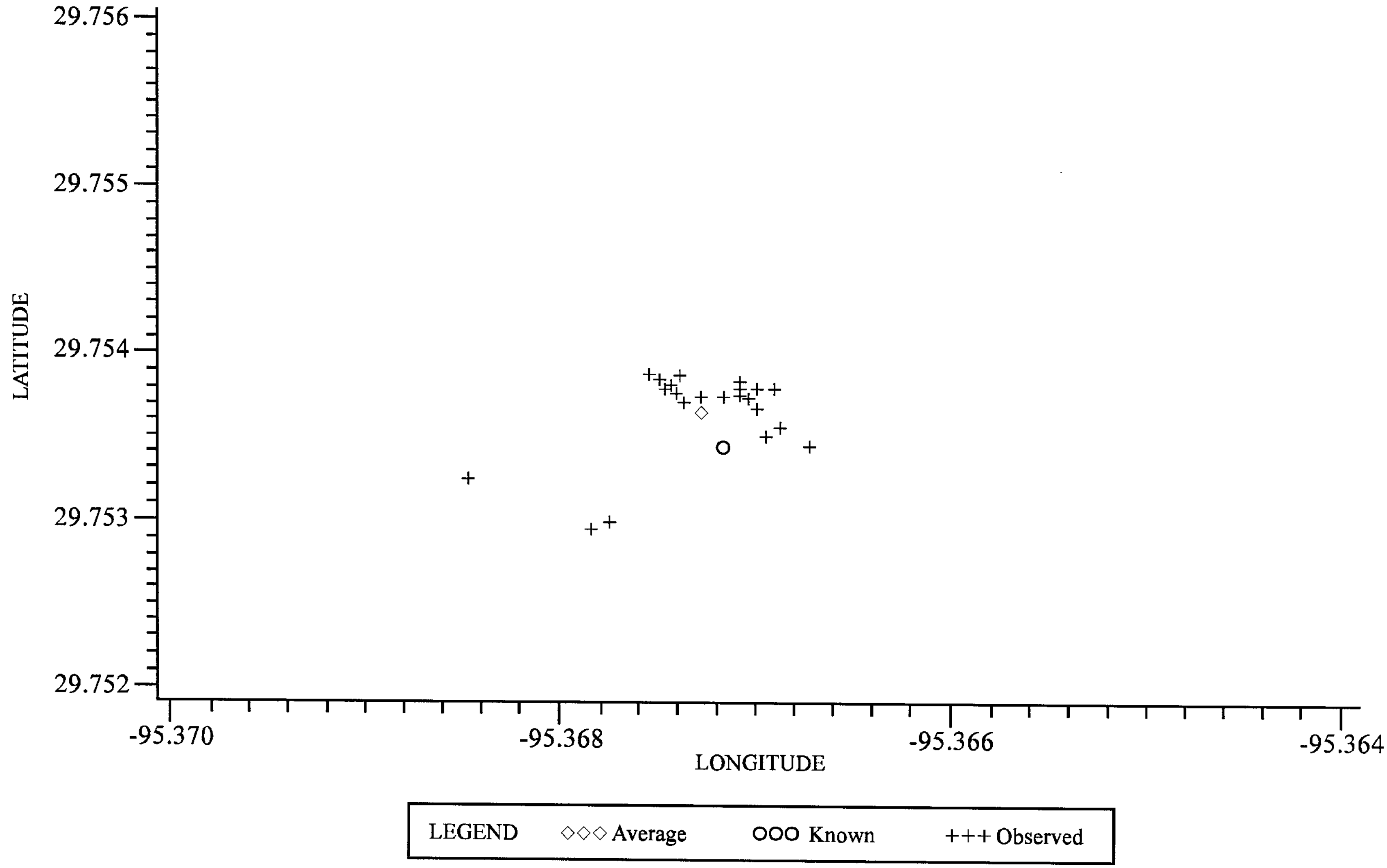
Latitude = 29.749839   Longitude = -95.370036



Average Distance from Known to Observed = 39.08 meters

MAIN @ CLAY (ORIGINAL - NAD27)

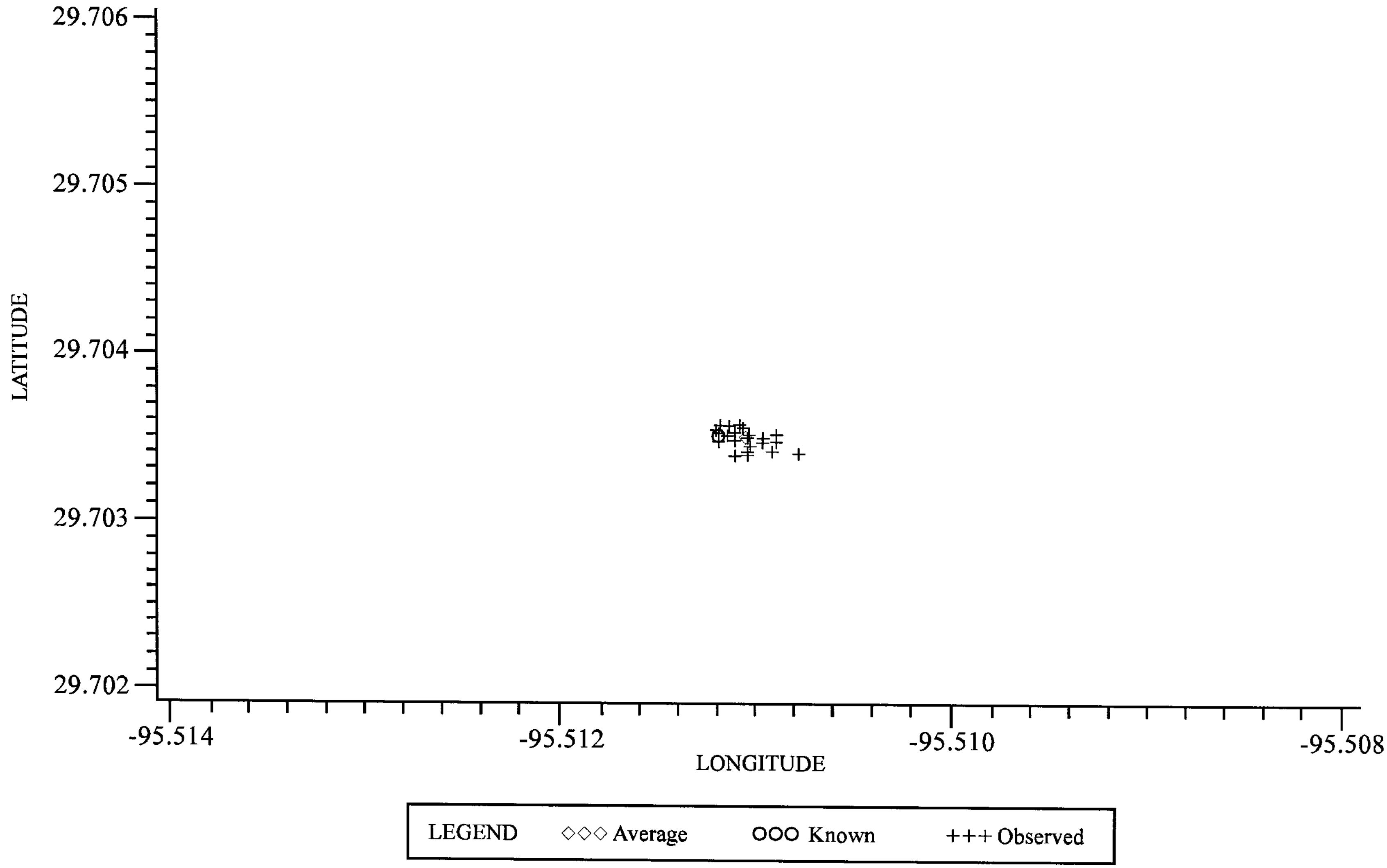
Latitude = 29.753486   Longitude = -95.367155



Average Distance from Known to Observed = 48.78 meters

BELLAIRE @ CANNOCK (ORIGINAL - NAD27)

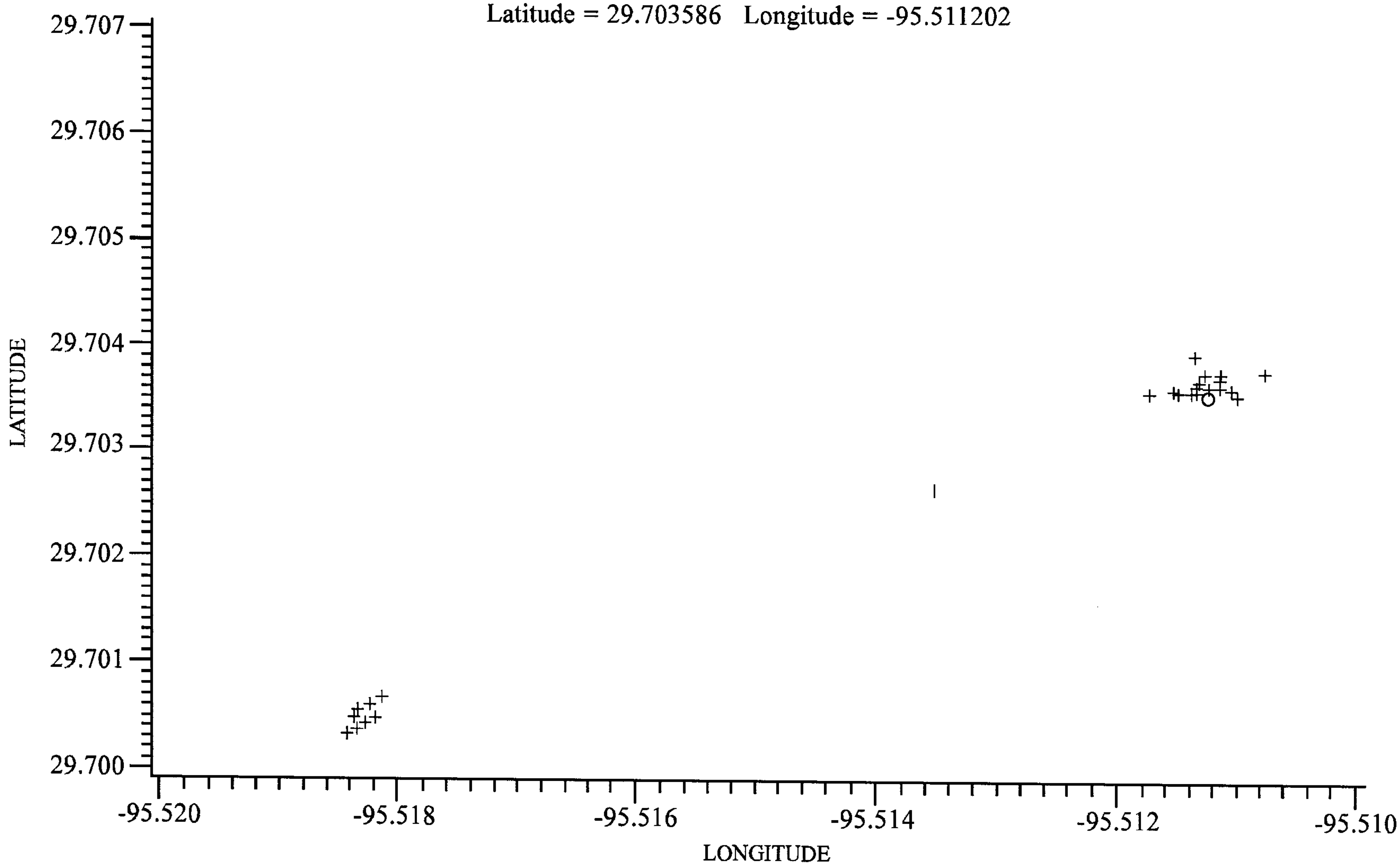
Latitude = 29.703586   Longitude = -95.511202



Average Distance from Known to Observed = 15.19 meters

BELLAIRE @ CANNOCK (REPEAT - NAD27)

Latitude = 29.703586   Longitude = -95.511202

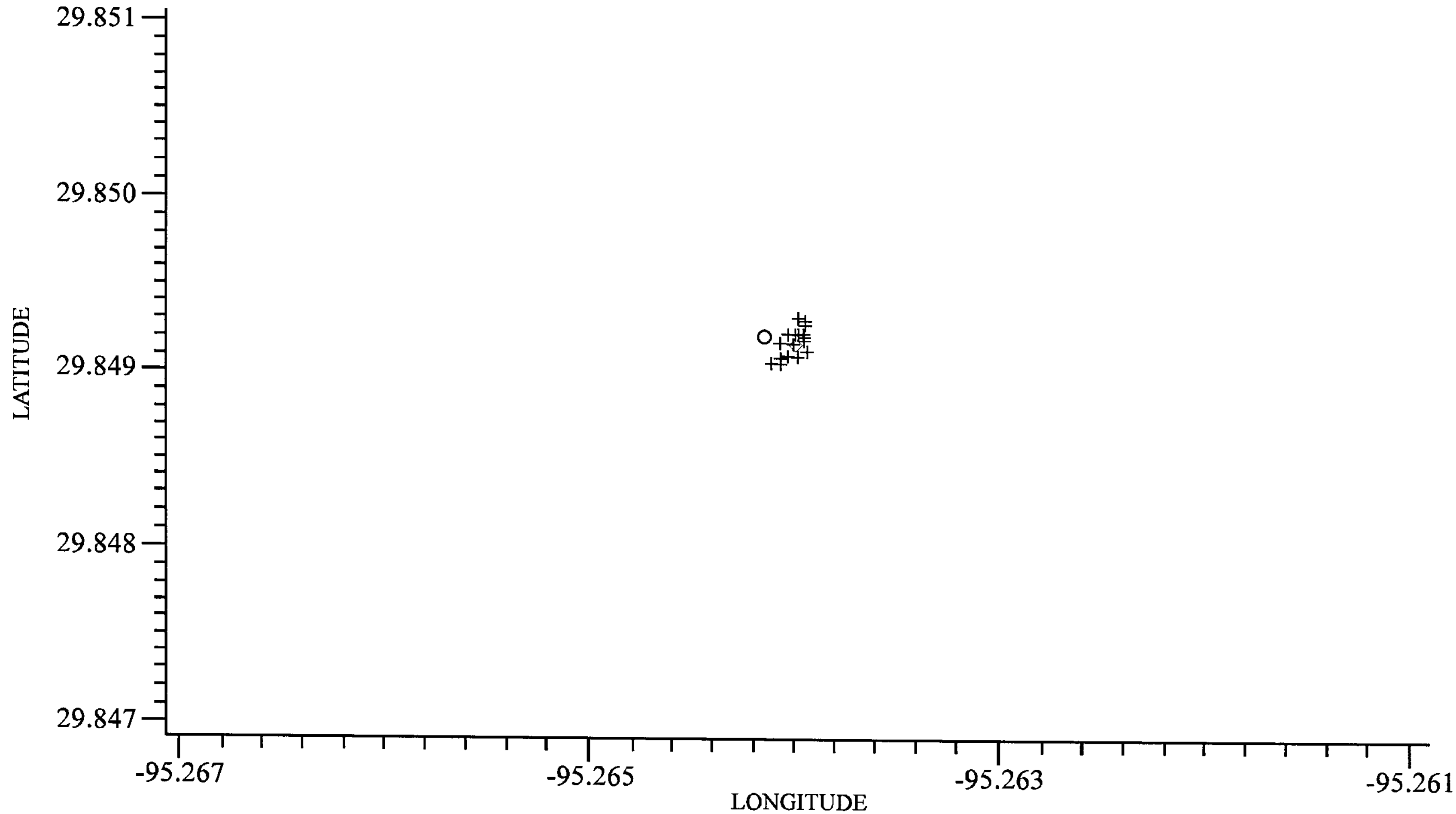


LEGEND ◇◇◇ Average OOO Known +++ Observed

Average Distance from Known to Observed = 260.67 meters

MESA TRANSIT CENTER (NAD27)

Latitude = 29.849235 Longitude = -95.264114

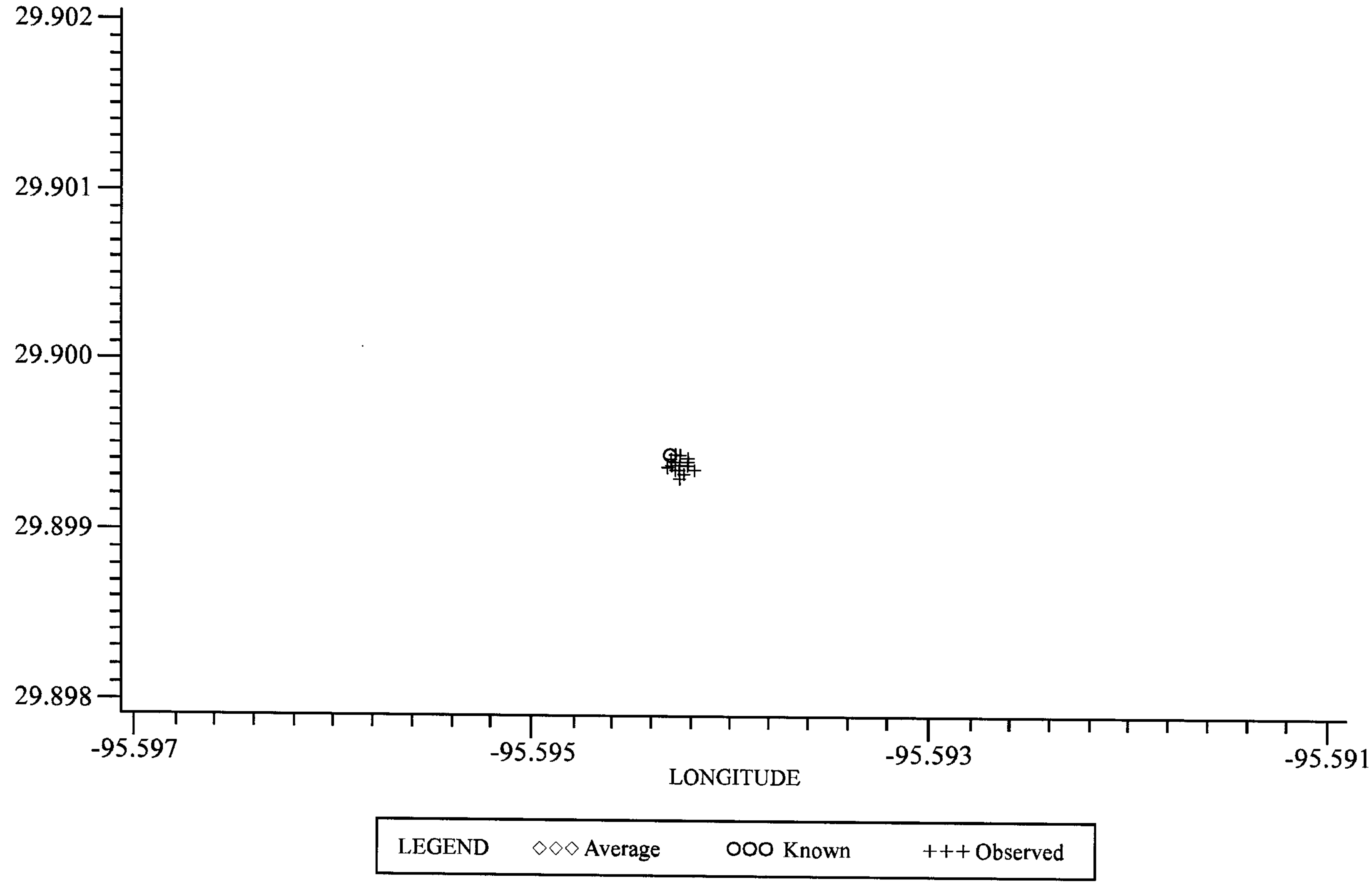


LEGEND ◇◇◇ Average OOO Known +++ Observed

Average Distance from Known to Observed = 17.25 meters

NORTHWEST P&R (NAD27)

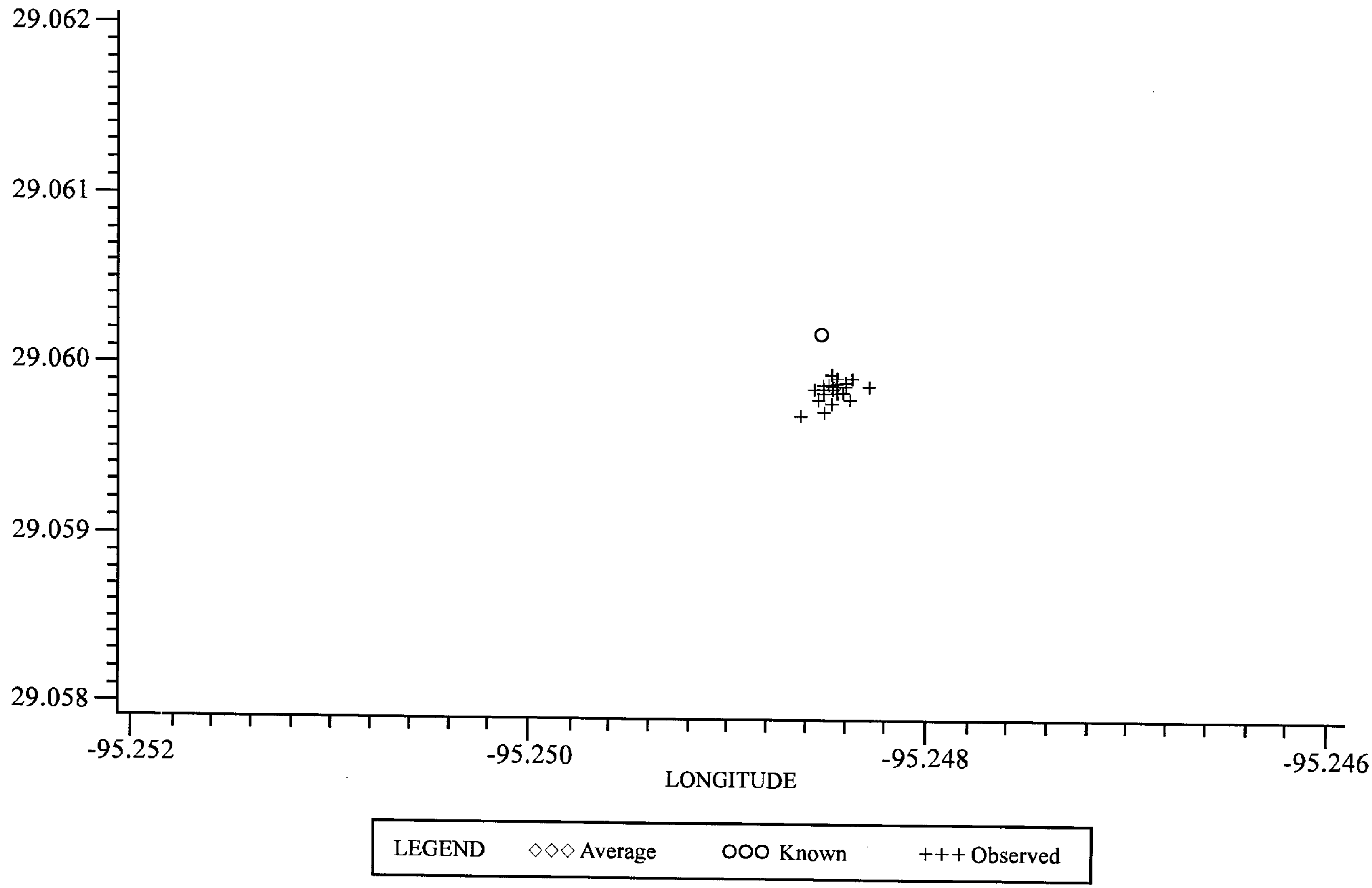
Latitude = 29.899443   Longitude = -95.594256



Average Distance from Known to Observed = 7.66 meters

NORTH PARK P&R (PERIPHERAL - NAD27)

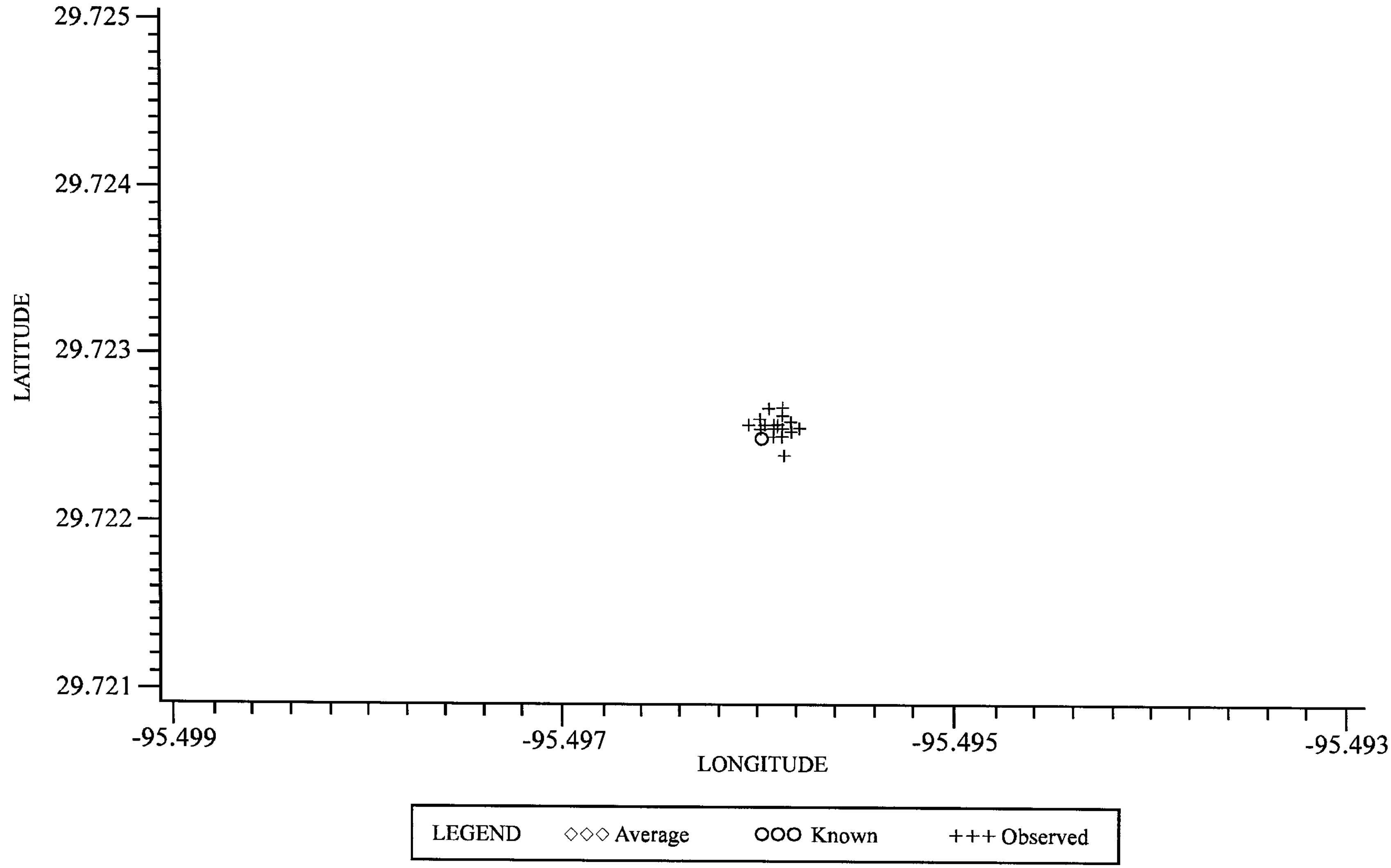
Latitude = 29.060208   Longitude = -95.248522



Average Distance from Known to Observed = 37.84 meters

HILLCROFT P&R (NAD27)

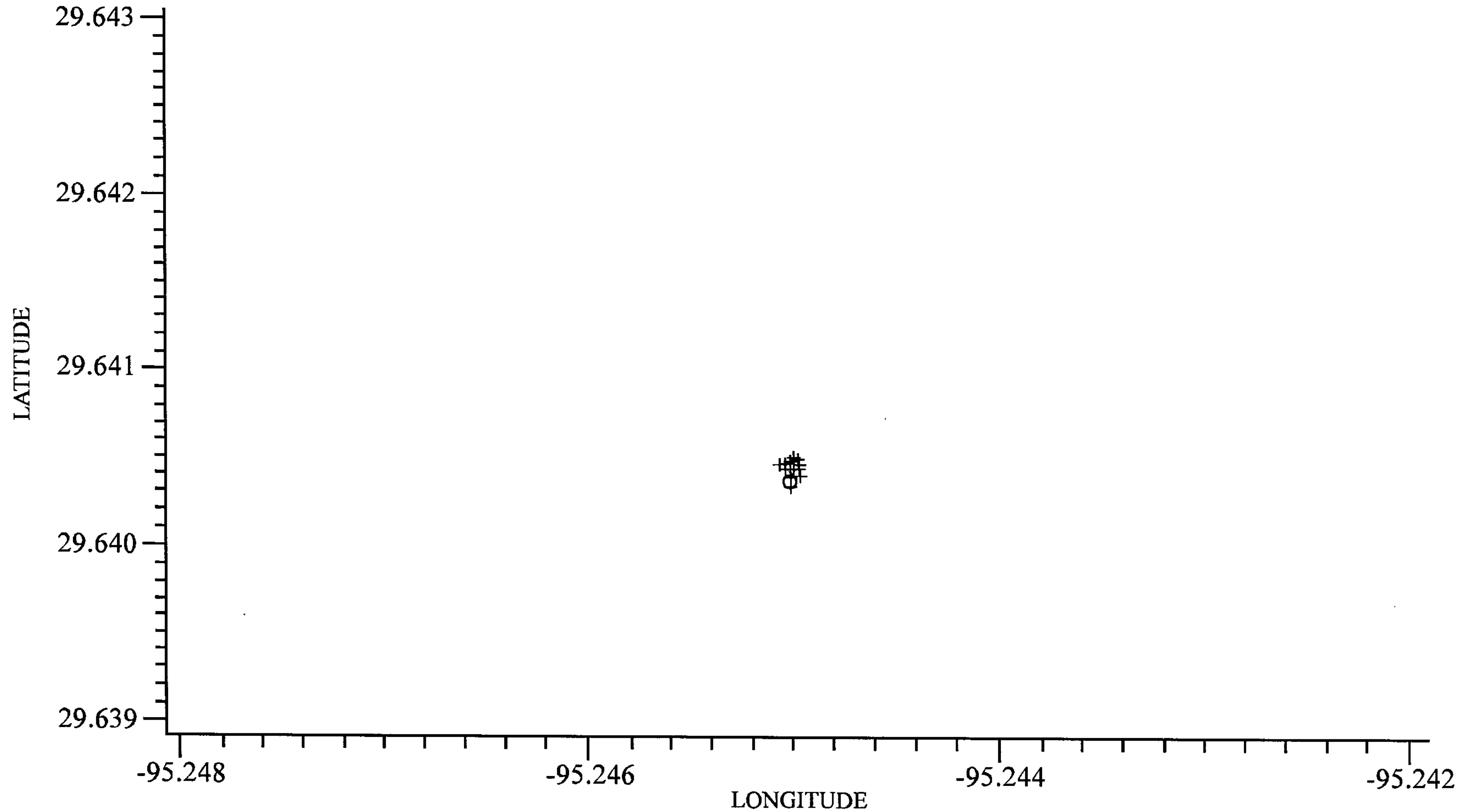
Latitude = 29.722518   Longitude = -95.496016



Average Distance from Known to Observed = 12.09 meters

EDGEBROOK P&R (NAD27)

Latitude = 29.640388   Longitude = -95.244966

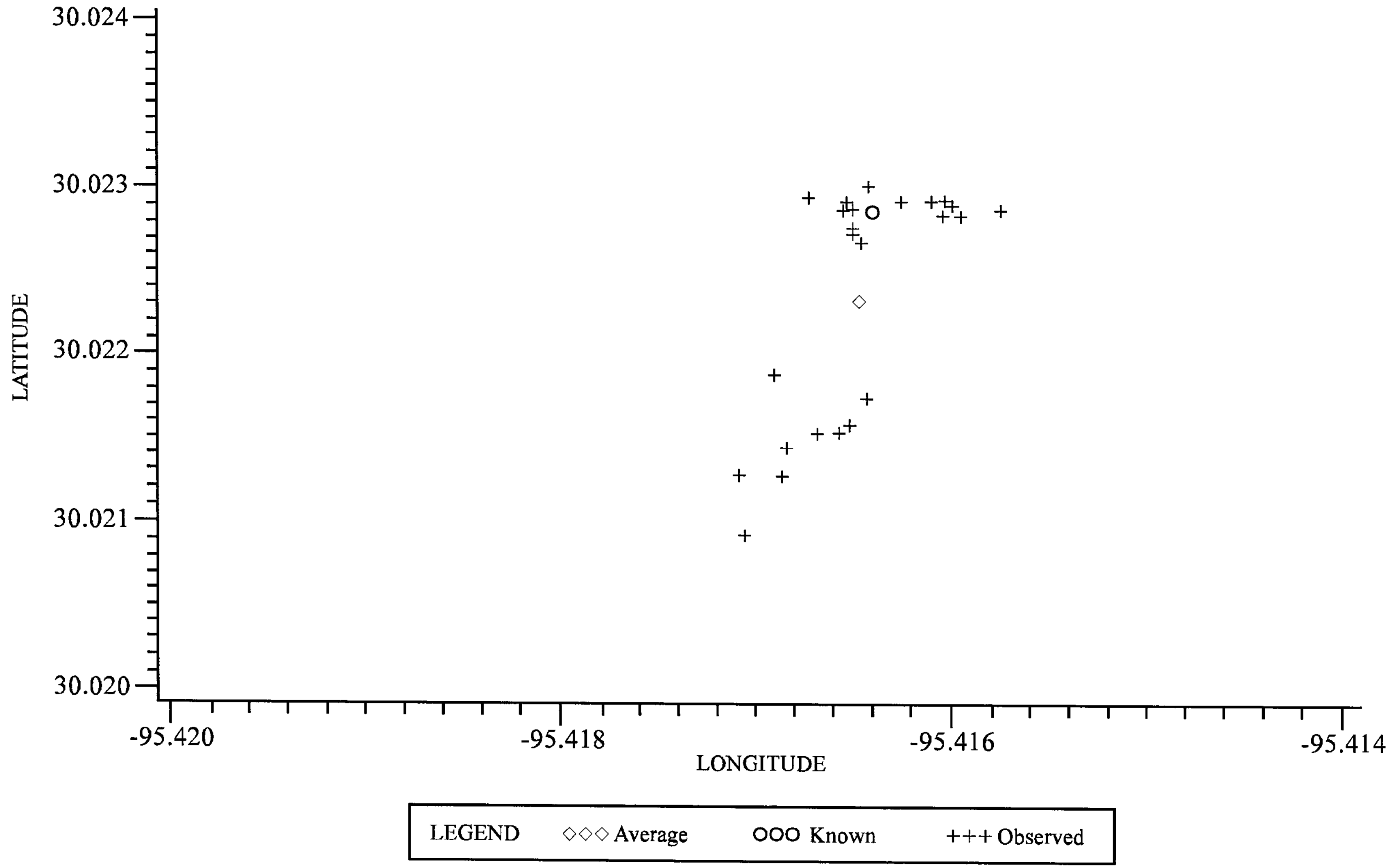


LEGEND ◇◇◇ Average OOO Known +++ Observed

Average Distance from Known to Observed = 7.81 meters

SPRING P&R (NAD27)

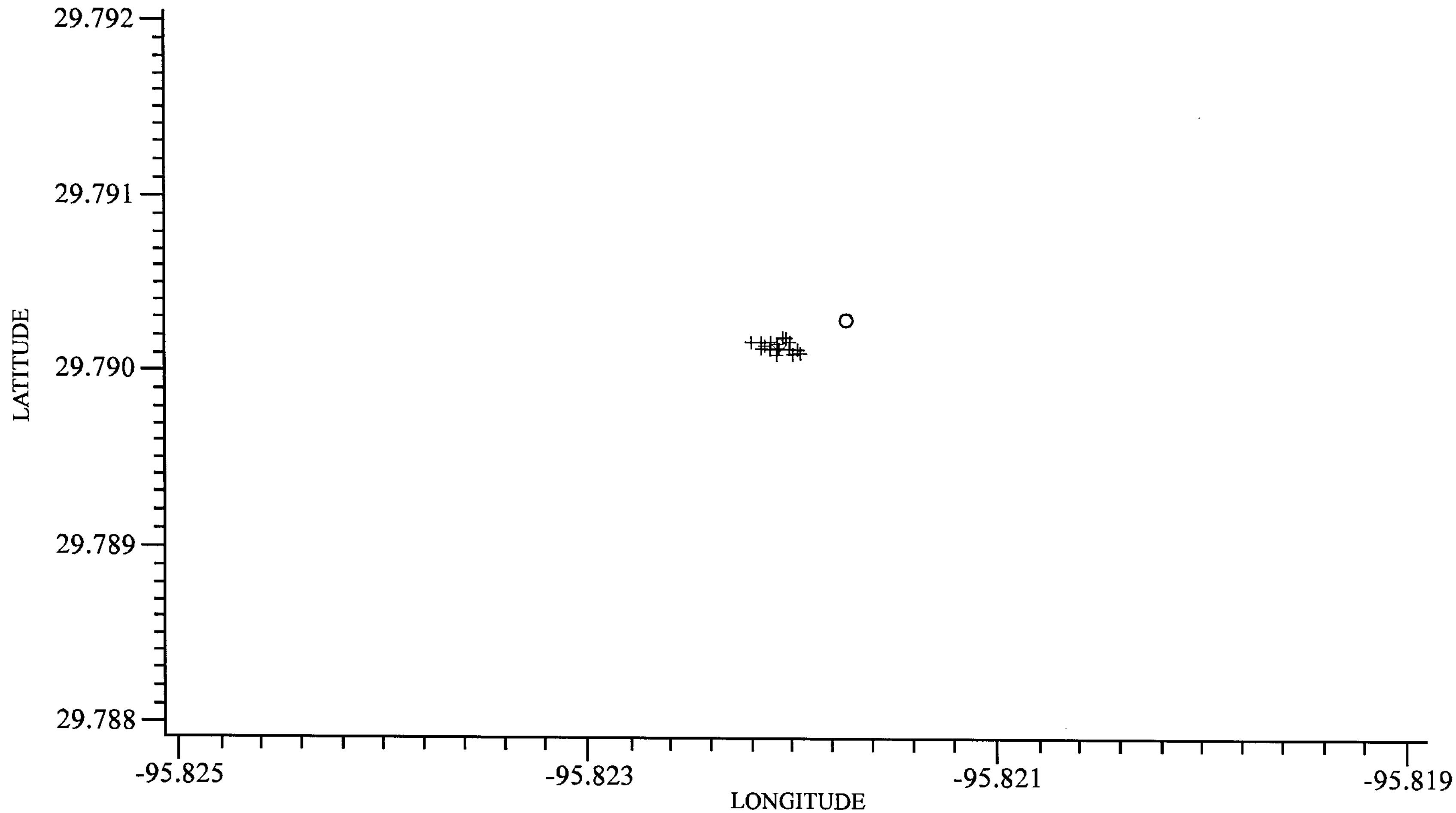
Latitude = 30.022890   Longitude = -95.416373



Average Distance from Known to Observed = 77.60 meters

I-10 @ KATY ROAD (PERIPHERAL - NAD27)

Latitude = 29.790383   Longitude = -95.821734

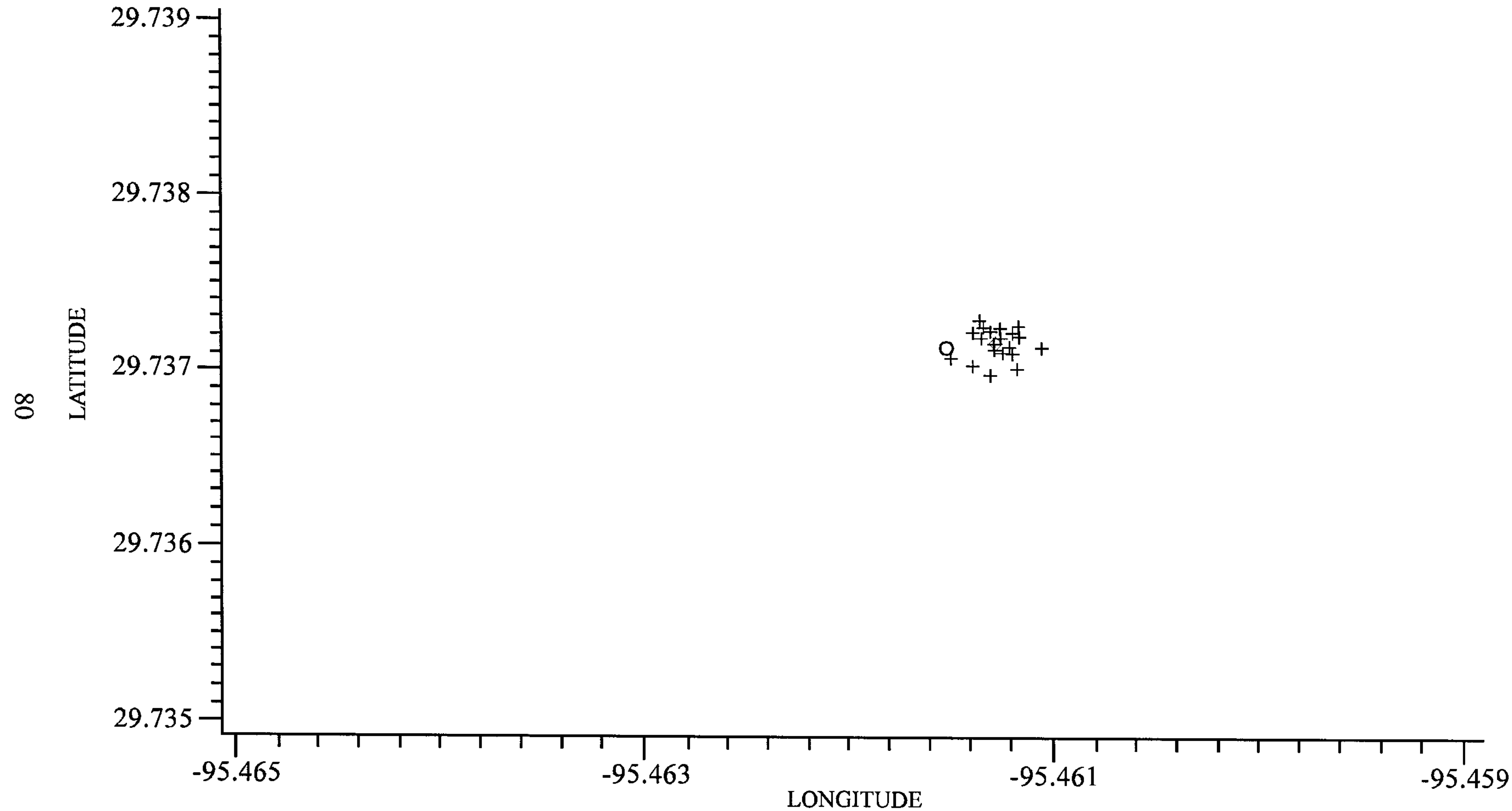


LEGEND	◇◇◇ Average	OOO Known	+++ Observed

Average Distance from Known to Observed = 37.22 meters

GALLERIA OUTSIDE PARKING (NAD27)

Latitude = 29.737180   Longitude = -95.461513



LEGEND	◇◇◇ Average	OOO Known	+++ Observed

Average Distance from Known to Observed = 25.55 meters

GALLERIA COVERED PARKING (NAD27)