5 ITS PROBE VEHICLE TECHNIQUES

The probe vehicle techniques discussed in this section are unique in that they are typically intelligent transportation system (ITS) applications designed primarily for collecting data in real-time. Their primary application is for a specific purpose other than travel time data collection, such as real-time traffic operations monitoring, incident detection, and route guidance applications. However, these systems can be used for the collection of travel time data. Since these probe vehicles are used for travel time data collection but are already in the traffic stream for a different purpose, they are sometimes referred to as "passive" probe vehicles. In contrast, the test vehicle techniques discussed in Chapter 3 are sometimes referred to as "active" test vehicles. Coordination is often necessary between the agency responsible for the system operation and the agency that would like to utilize the system for travel time data collection. This distinction removes these probe vehicle techniques from other techniques, such as tje test vehicle or license plate matching techniques.

This chapter presents guidelines for designing and maintaining ITS probe vehicle data collection systems to cost-effectively collect quality data that may be developed from existing ITS applications.

5.0.1 General Advantages and Disadvantages

ITS probe vehicle systems for travel time data collection have the following **advantages**:

- **Low cost per unit of data** - Once the necessary infrastructure and equipment are in place, data may be collected easily and at low cost. There is no need to routinely set up and disassemble equipment.

- **Continuous data collection** - Travel time data may be collected 24 hours per day with ITS probe vehicle systems. If the infrastructure is permanently installed, data are collected as long as probe vehicles continue to travel through the system. Note that the hours of data collection may depend upon transit schedules for some probe vehicle systems.

- **Automated data collection** - Data can be collected electronically. Probe vehicle systems are electronic, and data are automatically transmitted from the probe vehicle to the ITS control facility.

- **Data are in electronic format** - Once the data have been collected, they are already in an electronic format. This assists in the processing of raw travel time data into a useful format for analysis.

- **No disruption of traffic** - Since data are collected from probes within the traffic stream, the traffic is not influenced by the experimenter. Probe vehicles are often driven by persons not directly involved with the data collection effort, thus data are not biased towards test vehicle driving styles.

ITS probe vehicle systems for travel time data collection have the following **disadvantages**:

- **High implementation cost** - Probe vehicle systems typically have a high initial cost to purchase necessary equipment, install the equipment, and train personnel to operate the system and collect data.

- **Fixed infrastructure constraints** - Once the fixed infrastructure of receiving antennas is implemented, it is generally not financially feasible to make adjustments in the size and orientation of the system coverage area (GPS is the exception). The coverage area of a probe vehicle system, including locations of antenna sites, should be considered before implementation to ensure that data will be collected at strategic locations. Data cannot be collected outside of the coverage area of the probe vehicle system without expensive infrastructure additions.

- **Requires skilled software designers** - The software that performs the data collection tasks are complex programs and are typically designed in-house or by a consultant. The software is typically customized for a particular probe system.

- **Privacy issues** - Probe vehicle techniques involve tracking vehicles as they travel the freeway and arterial street system. This raises concerns that motorists may be more likely to receive traffic citations or have their travel habits monitored.

- **Not recommended for small scale data collection efforts** - Probe vehicle systems generally have large implementation costs, and they are most cost-effective for collecting data within a large study area.

Five types of ITS probe vehicle data collection systems are presented. These systems typically have a high implementation cost and are suited for large-scale data collection efforts. However, they allow for continuous data collection and for minimal human interaction. Table 5-1 provides a comparison of these probe vehicle data collection techniques. The ITS probe vehicle systems described are:

- **Signpost-Based Automatic Vehicle Location (AVL)** - This technique has mostly been used by transit agencies. Probe vehicles communicate with transmitters mounted on existing signpost structures.

Table 5-1. Comparison of ITS Probe Vehicle Systems/Techniques

Technique	Costs				Data Accuracy	Constraints	Driver Recruitment
	Capital	Installation	Data Collection [1]	Data Reduction			
Signpost-Based Automatic Vehicle Location (AVL)	High	High	Low	High	Low [2]	No. of signpost sites, transit routes, and probes	None - uses transit vehicles
Automatic Vehicle Identification (AVI)	High	High	Low	Low	High	No. of antenna sites and tag distribution	Required - but can use toll patrons
Ground-Based Radio Navigation	Low	Low	Low	Low	Moderate	No. of probes and size of service area	Required
Cellular Geolocation	High	High	Low	Moderate	Low	No. of cell users and cell towers	None - uses current cellular users
Global Positioning System (GPS)	Low	Low	Low	Moderate	High [2]	No. of probes	Required - but can also use currently instrumented vehicles

Notes: [1] Assumes that all data collection software development has been completed.
[2] Unless passenger vehicles are included in the study, samples are composed of transit or commercial vehicles.

- **Automatic Vehicle Identification (AVI)** - Probe vehicles are equipped with electronic tags. These tags communicate with roadside transceivers to identify unique vehicles and collect travel times between transceivers.

- **Ground-Based Radio Navigation** - Often used for transit or commercial fleet management, this system is similar to the global positioning system (GPS). Data are collected by communication between probe vehicles and a radio tower infrastructure.

- **Cellular Geo-location** - This experimental technology can collect travel time data by discretely tracking cellular telephone call transmissions.

- **Global Positioning System (GPS)** - Probe vehicles are equipped with GPS receivers and two-way communication to receive signals from earth-orbiting satellites. The positional information determined from the GPS signals is transmitted to a control center to display real-time position of the probe vehicles. Travel time information can be determined from the collected data.

5.0.2 Sample Size Criteria

Sample size requirements associated with probe vehicle applications are inherently different than sample size requirements for test vehicle or license plate matching techniques. In typical travel time studies, the sample sizes are established by the test conductors prior to data collection. Typically, these sample sizes are established based on desired levels of accuracy associated with the purpose of the travel time study and on budgetary constraints. Since probe vehicle systems are designed to collect data for real-time traffic monitoring, fleet monitoring, or electronic toll collection (ETC), the sample sizes are determined by availability of instrumented probe vehicles in the traffic stream. Probe vehicle samples sizes are considered in the following:

- Design of the probe vehicle system (e.g., distribution of AVI tags);
- Evaluation of probe vehicle system; and
- Analysis of data obtained from a probe vehicle system.

For example, a transit agency using signpost-based automatic vehicle location (AVL) will have equipped a certain number of buses with the necessary hardware, a traffic management system may collect data from an existing fleet of probe vehicles, or an ETC system may provide service to some fixed number of toll patrons. Therefore, the study supervisor has little to no control over the probe vehicle sample size if the data are collected from an existing probe vehicle system.

Practitioners using data collected from probe vehicle systems should consider the achievable sample size when designing their study and analyzing the data. While probe vehicle sample sizes may be fixed at a small number, it does not necessarily mean that the data are not useful. For planning studies that do not demand high statistical accuracy, a few probe vehicles per day can provide sufficient data for analysis (or at least as much as comparable test vehicle techniques). Small probe vehicle sample sizes may not provide sufficient representation for analyses that require high levels of accuracy.

Design of a Probe Vehicle System

In the initial stages of developing and implementing probe vehicle systems to collect travel time data for real-time and planning applications, it is necessary to estimate an effective probe vehicle sample size. This process may involve studying the practices of existing probe vehicle systems and comparing characteristics of respective transportation systems.

Probe vehicle systems are designed to generate a certain database on the purpose of their design. For example, signpost-based probe vehicle systems are designed to monitor the status of a transit agency's bus fleet. Thus, the buses function as probe vehicles within the traffic stream. The size of the transit agency's sample is most likely justified by the number of buses within the fleet and the available funding to equip the buses with the necessary tracking equipment.

A representative sample does not necessarily translate to a large sample size. The nature of some studies does not require large sample sizes to yield desirable results. For instance, a study by the Washington State Department of Transportation (WSDOT) suggested that sample sizes as low as 45 AVI-equipped probe vehicles per day, which averaged 30-minute headways, could yield useful data (1). These data were used to determine the occurrence, duration, severity, and frequency of congestion. The study recommended that the sample size was sufficient for facility performance monitoring, air quality planning and monitoring, and before-and-after studies.

A study by Boyce et al. (2) estimated necessary sample sizes for a dynamic route guidance model based on the results of a static, user-optimal route choice traffic assignment analysis. Their results suggested that about 4,000 probe vehicles were required for a 520 sq-km (200 sq-mi) suburban road network.

Srinivasan and Jovanis (3) developed an algorithm to estimate the number of probe vehicles needed to collect real-time travel time data for advanced traffic management and information systems. Their algorithm estimates the number of probe vehicles based on the time period of 5, 10, or 15 minutes, reliability criterion, the proportion of links to be covered, and the duration of the peak period. Their algorithm was tested on a simulation of the Sacramento, California 440 sq-km (170 sq-mi) network during the morning peak period. Results of the study indicated that the number of required probes increased non-linearly as reliability criterion grew more stringent, that more probes were required for shorter time periods, and that the number of required probes increased as the proportion of link coverage increased.

The Model Deployment Initiative (MDI) in San Antonio, Texas, is deploying an AVI probe vehicle system to collect real-time travel times for route guidance and traveler information purposes. The proposal originally called for the distribution of more than 200,000 AVI transponders. However, their tag distribution efforts were scaled back for several reasons, most notably budget shortages and a reluctance to distribute the AVI tags as part of the required vehicle registration stickers. Current plans in San Antonio are to distribute between 50,000 and 70,000 AVI tags to public volunteers and commuters. Another difficulty with tag distribution in San Antonio was the lack of any toll highways, especially any that could support electronic toll collection.

UNKNOWN ??

Probe vehicle sample sizes vary depending upon local road networks, traffic patterns, and many other variables. The limited research does not permit valid conclusions to be drawn for other urban areas without specific study.

An automatic vehicle identification (AVI) probe vehicle system designed as a traffic monitoring system may advertise for volunteers to serve as probe vehicle drivers. Motorists may be targeted by changeable message board advertising on specific roadways or by popular media. Probe vehicle drivers may be recruited by offering incentives, as well. For instance, a department of transportation may offer AVI tags to motorists free of charge. The free tags could then be used for an electronic toll collection service to conveniently pay toll charges while also participating as probe vehicle drivers in the local traffic monitoring system.

Evaluation of a Probe Vehicle System

The effectiveness of a probe vehicle system is dependent upon its purpose and the size of the probe vehicle sample, among other criteria. A probe vehicle sample size may be periodically reviewed to determine the system's ability to yield accurate real-time travel time information. The necessary sample size for providing accurate data depends on the level of accuracy that is established as a system goal. If the current sample size is equal to or greater than the calculated sample size, the results suggest that the system's current status provides adequate data. If the calculated necessary sample size is greater than the current sample size, the results suggest that additional probe vehicles may be needed.

IMPORTANT ☞

It is possible to evaluate the adequacy of a probe vehicle sample size by calculating a target sample size necessary for meeting specified accuracy criteria and comparing this value to the system's current sample size.

A study of AVI probe vehicles in Houston, Texas suggested that an average of two or three probe vehicles every 15 minutes could yield useful mean travel time data (4). The study found that the Houston traffic monitoring system was collecting real-time travel time data from between 1 and 7 probe vehicles every 5 minutes, or between 2 and 20 vehicles every 15 minutes, along instrumented freeway corridors. The highest number of probe vehicles were observed near major activity centers and the tollways. The study calculated required sample sizes through freeway links within 5-minute and 15-minute intervals based on the coefficients of variation from travel time data and suggested confidence and error constraints. A comparison between the actual probe vehicle sample size and the calculated necessary sample size (based on specified confidence and error constraints) suggested whether or not a sufficient number of probe vehicles were collecting data. Results showed that, for a 90 percent confidence level with 10 percent relative error, 2 or 3 probe vehicles every 15 minutes were sufficient to collect useful travel time data.

Sample Composition

An aspect that should be considered when collecting and analyzing probe vehicle data is the driver or vehicle composition of the sample. Composition refers to the type of vehicles or type of drivers that may compose the sample. It is important to understand the type of vehicles and drivers that are operating the probe vehicles. The sample may be biased if the data were collected by transit vehicles. The following traffic composition characteristics should be kept in mind when composing or evaluating probe vehicle samples:

- vehicle type - automobile, truck, transit vehicle, or other;
- driver type - depends on vehicle type; and
- travel lane representation - certain vehicles may primarily use certain travel lanes.

5.0.3 ITS Data Considerations

National ITS Architecture and Data Standards

Widespread implementation of intelligent transportation system (ITS) projects, including probe vehicle data collection systems, has created a pressing demand for standards and protocols to provide interoperability, compatibility, and interchangeability between various technologies. Interoperability can allow probe vehicles to travel throughout the country and still provide effective data collection or receive traveler information. Compatibility can allow different manufacturers' equipment to communicate without interference. Interchangeability allows one manufacturer's device to be replaced with a device from a separate manufacturer.

ITS applications are encapsulated within a compilation of interrelated user services. Standardization can allow the packaging of user services to form advanced traffic management systems (ATMSs), advanced traveler information systems (ATISs), advanced public transportation systems (APTSs), commercial vehicle operation (CVO) systems, advanced rural transportation systems (ARTSs), and advanced vehicle control systems (AVCSs), and ultimately, one unified national transportation system.

> **IMPORTANT** ☞ Practitioners designing or modifying probe vehicle systems should ensure that their local system is compatible with the National ITS Architecture standards.

Their designs and recommendations should reflect the proposed standards which are set forth by the various organizations and committees charged with that task. The framework for developing standards and protocols has been established by the U.S. DOT through the *National ITS Architecture* project. The project has developed a series of white papers that describe the need for standards, standards development process, example requirements, and an Architecture reference model (5). A standards requirement document (SRD) has been developed to provide definitions of interfaces and necessary priorities for standardization within the Architecture reference model. The project is working towards the development of a standards implementation plan (SIP), which will outline standards, time schedules, and critical milestones for the implementation phase.

The National ITS Architecture provides common structure for the design of ITS. The Architecture designs the functions, such as gathering traffic data, that are necessary to perform certain user services and to implement the vehicles and infrastructure of the system, the information flow between system components, and the communication requirements for the information flows (6). The National ITS Architecture defines how large scale ITS components, such as the ATMSs and ATISs, work together. At the ATMS or ATIS level, these systems will control how freeway systems communicate with traffic signal and control systems.

The National Transportation Communications for ITS Protocol (NTCIP) standards were developed for communications between traffic management centers and signal systems; however, the Federal Highway Administration (FHWA) broadened the protocol to include additional technologies. Simply stated, the NTCIP will define how traffic control systems communicate to their sub-components (7). More information on the current and developing NTCIP standards are available at ITS America's web site at "http://www.itsa.org".

Professional societies play a major role in the development of the National ITS Architecture. For example, the Institute of Transportation Engineers (ITE) is playing an active role in setting national standards and guidelines to simplify operations and maintenance of ITS networks, among other roles. The Institute is ensuring that traffic engineers are informed in the development, adoption, and review of ITS standards.

The Intelligent Transportation Society of America (ITS America) has a Standards and Protocols Committee to coordinate development of ITS standards. The Committee and the FHWA have jointly produced a standards and protocol catalog (Publication No: FHWA-JPO-95-005) which describes the current state and future direction of ITS standards development.

Recent discussion about the National ITS Architecture may result in the addition of a user service that relates to the retention or archival of ITS traffic data. This ITS traffic data, as pointed out in this chapter, could be useful for a wide range of planning, operations, and evaluation activities. The proceedings from the "ITS as a Data Resource" workshop held January 1998 in Washington, DC, is available on the web at "http://www.fhwa.dot.gov/ohim/".

5.1 Signpost-Based Automatic Vehicle Location

Transit agencies have utilized automatic vehicle location (AVL) or automatic vehicle monitoring systems to monitor the position and status of transit fleet vehicles. A variety of AVL systems exist based on such technologies as LORAN-C, ground-based radio navigation, and signpost-based technologies. These technologies are being replaced by the global positioning system (GPS), which is discussed later in this chapter. However, some transit agencies continue to use signpost-based systems successfully, whereas other agencies have reported limited success.

Signpost-based AVL systems are still operated, such as with the London Transport Bus (LTB) system, San Antonio VIA transit system, New Jersey Transit system, and the Seattle Metro system (8,9). This type of system is typically used by relatively large transit agencies in metropolitan areas. Only a few rural transit agencies have used this technology since it requires substantial capital investment and staff resources to develop, implement, and operate.

Signpost-based AVL systems are designed to track the location of fleet vehicles along their routes for real-time fleet monitoring, schedule adherence monitoring, computer-aided dispatching, and schedule evaluating. The system consists of seven main components to collect and store travel time data:

1. infrastructure of electronic transmitters;
2. in-vehicle receiver;
3. in-vehicle odometer sensor;
4. in-vehicle locating unit, or data microprocessor;
5. in-vehicle radio transmitter;
6. central control radio receiver; and
7. central control facility.

Figure 5-1 illustrates the communication processes between the electronic transmitter and transit vehicle and between the transit vehicle and the central computer. Electronic signposts emit unique identification codes. These unique codes are received by approaching fleet vehicles. The signpost identification is stored in the vehicle locating unit where it is assigned a time and date stamp, the corresponding differential odometer reading between sequential signposts, and the vehicle's identification. This data bundle is sent to a central control facility at periodic intervals or upon a controller's prompt. The data transmission to the central computer is mutually exclusive from the occurrence of the signpost transmission.

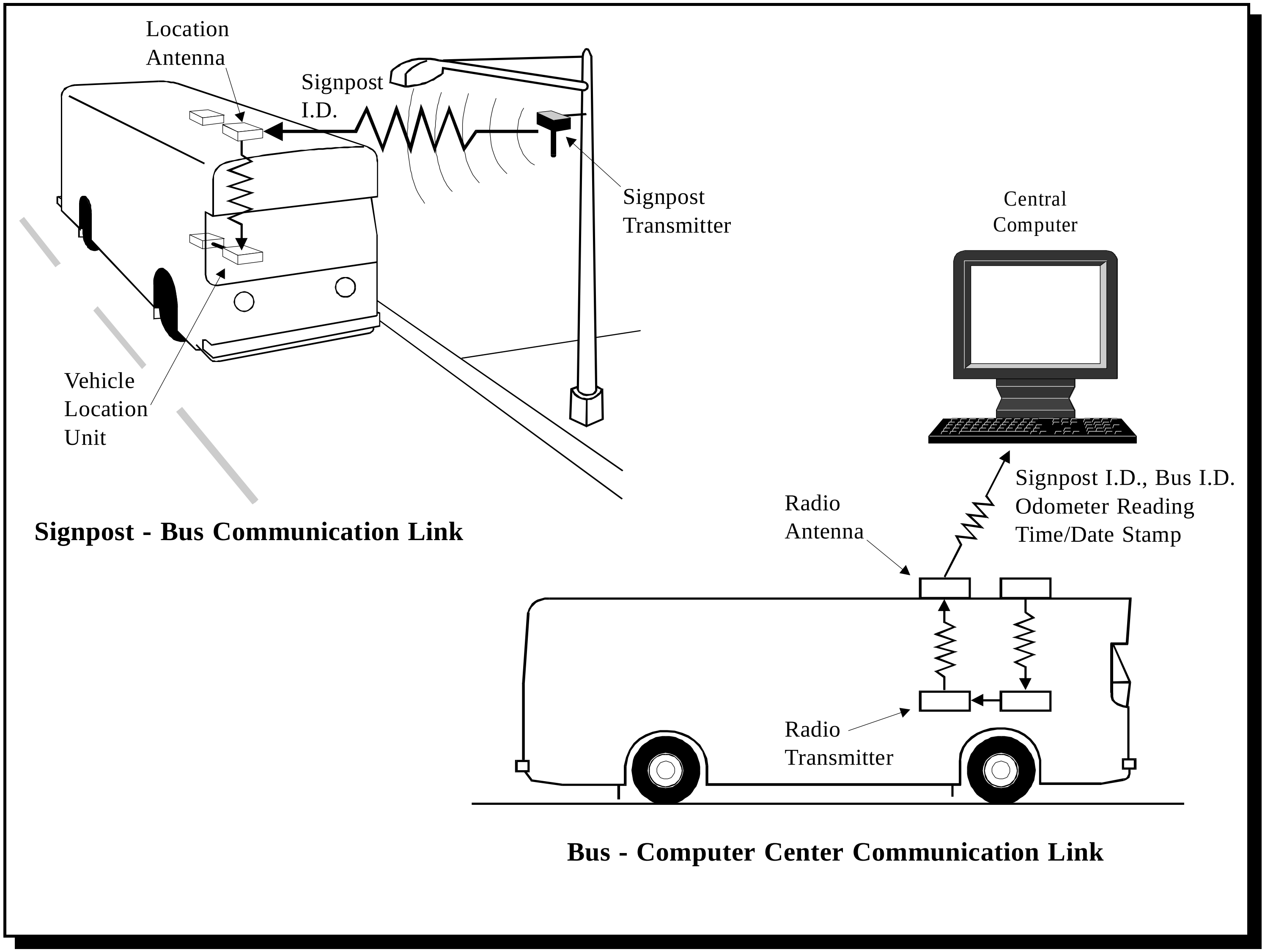


Figure 5-1. Signpost-Based AVL Communication Processes

5.1.1 Advantages and Disadvantages

The **advantages** of signpost-based AVL for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Simple infrastructure** - Signpost-based technology is relatively simple, straightforward and can be implemented quickly (9).

- **Vehicle performance data** - Some signpost-based AVL systems are designed to collect transit vehicle operational performance data, such as fuel consumption, oil pressure, or cooling temperature. These data may be useful for emissions or environmental modeling.

- **Passenger count data** - Some signpost-based AVL systems may be able to collect passenger counts as transit patrons enter and exit the vehicle. These data may be useful for production and attraction counts in trip generation or origin-destination studies.

The **disadvantages** of signpost-based AVL for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Non-representative data** - Since signpost-based AVL systems are typically designed to monitor transit fleet operations, their travel time data reflect the travel habits of transit vehicles and transit drivers. This representation may not be acceptable for travel time studies that wish to target automobile traffic.

- **Limited coverage area** - Since the signpost-based system collects data from transit probe vehicles, the data are limited to roadways that are traveled by transit vehicles.

- **Equipment maintenance** - Transit agencies have reported that odometers and signpost transmitters require routine calibration to prevent erroneous data collection.

- **Outdated technology** - Many transit agencies are upgrading to GPS technology (see Section 5.5). The signpost-based AVL technology has been out-performed by the more accurate and robust global positioning satellites. Signpost-based AVL equipment is also difficult to obtain in the event that equipment needs upgrading or replacement. Vendors of signpost-based equipment are focusing on the more lucrative GPS technology.

- **Complex data reduction** - Although data are in electronic format and can be imported into a spreadsheet or statistical analysis package, the data require extensive editing and quality control. For example, data must be edited to adjust for bus layovers or else link travel times will appear larger than they actually were. Gross data collection errors, from poorly placed or malfunctioning signpost transmitters, will need spot editing.

5.1.2 Costs and Equipment Requirements

A signpost-based AVL system requires an infrastructure of electronic transmitters, several in-vehicle components, and control facility equipment. These components are necessary for data collection tasks. Additional equipment is needed for data reduction after completion of the data collection tasks. This section provides a brief description of both data collection and data reduction equipment. Table 5-2 summarizes the necessary equipment and related costs. Much of the cost information is not available since development of this technology stagnated.

Table 5-2. Estimated Costs for the Signpost-Based AVL Probe Vehicle System

Equipment	Unit Cost (1998 dollars)
Hardware	
Electronic Signpost Transmitters	~ $2,000
In-vehicle Radio Receivers	n.a.
In-vehicle Radio Transmitters	n.a.
In-vehicle Data Processor	n.a.
In-vehicle Odometer Sensor	~ $100
Control Facility Radio Receiver	n.a.
Personal Computer	Varies
Software	
Specialized Software	n.a.
Analysis Software	$150 to $300
Personnel	
Data Reduction Personnel	Varies

Note: n.a. - not available.

Data Collection Requirements

Electronic Transmitters - Electronic transmitters are installed at the side of the roadway. They are typically installed on existing signpost structures. Installation time is typically about two hours.

In-Vehicle Radio Receivers - This device receives the electronic transmitters' signals. It is typically installed on the top or front of the vehicle.

In-Vehicle Data Processor - This collects and stores data (odometer mileage) until the signpost transmission is received and then transmits data to the control facility.

In-Vehicle Odometer Sensor - This device records the distance between signpost transmission receptions. Installation time typically requires about two hours.

Control Facility Radio Receiver - This device receives data transmissions from the probe vehicle fleet.

Personal Computer - Traditionally, agencies have collected and processed data with mainframe computers. Desktop computers can be used to perform the necessary tasks.

Specialized Software - Special software is needed to poll vehicles and collect and process data. Software is typically created in-house or by a consultant. The software also generates reports and data archives which can be analyzed by other software.

Data Reduction Personnel - Individuals who will reduce the data that is being received by the AVL system for use in travel time determination.

Data Reduction Requirements

Personal Computer - Electronic data from the signpost-based system can be analyzed using typical desktop computers. Disk storage requirements depend upon the size of the transit agency's signpost-based AVL system (e.g. link coverage, sample size, number of routes).

Analysis Software - Raw data can be imported into typical spreadsheet or statistical analysis software packages for personal computers. With the necessary understanding of the data to code the software, the data can be analyzed.

5.1.3 System Design Considerations

This section describes several considerations that can facilitate the data collection and reduction process. These recommendations can help ensure that the most useful data are collected to meet the demands of the study.

Select strategic routes - It may not be feasible to include all transit routes in the system coverage area. Selecting strategic links along the transit route to include in the system can ensure that travel time data are collected along critical links (e.g., most congested, greatest demand) in the system.

Identify signpost locations - It is important to consider which locations within the system are the most appropriate for detecting the probe vehicles. This can be done by installing signposts at the beginning, end, and major points throughout the route. Signpost transmitter locations are typically spaced several miles apart.

Obtain signpost use agreement - Once a signpost location has been selected, a post or pole to attach the electronic signpost transmitter must be identified. A pole attachment agreement must be obtained from the owner of the post or pole (e.g., telephone company, electric company, municipality, or private owner).

Attach transmitters to signposts - Transmitter installations on signposts should comply with utilities specifications for attachment method, height, and other criteria. The transmitter power should be appropriately adjusted.

Maintain map-matching database - The map-matching database is necessary to track the probe vehicles throughout the system. Each signpost must have an identification number and its location must be entered into the map-matching database. This database should be continuously updated as changes in the system, such as relocated signposts and route adjustments, are implemented. Verify the mileage of each route by driving it in the field.

Certify working condition of in-vehicle equipment - Odometer sensors should be properly calibrated. All in-vehicle equipment and cables and probe vehicle electrical system should be in proper operating condition.

Provide on-call equipment maintenance staff - On-board equipment and signpost transmitters require constant calibration and routine maintenance. Transit agencies have full-time personnel to maintain the functionality of their equipment.

5.1.4 Data Reduction and Quality Control

Once the raw data have been collected, it is necessary to process the data into a useful format. This section describes several measures that are necessary to develop a useful data set and several measures that assist in performing an efficient analysis.

Data files are typically in an ASCII text format. These data may be imported into a spreadsheet software package or into statistical analysis software for analysis.

IMPORTANT ☞ It is important to consider that the raw data are difficult to interpret without some understanding of the transit agency's bus operations and location of electronic signposts within the roadway network.

This section presents several issues to consider when reducing and inspecting the quality of signpost-based AVL travel time data.

Identify scheduled layover points - The raw data file includes the bus identification number, time that the bus passed an electronic signpost, the location of the signpost, and the physical length of roadway traveled among other data. These data are essential to determine travel times through roadway segments. It is also important to keep in mind that bus schedules include layovers. Layovers detain a bus at a stop along its route. These layover durations should be figured into the travel times by obtaining information on pre-scheduled layovers from the transit agency.

Maintain signpost transmitter locations with map - Additionally, it is necessary to maintain the locations of the electronic signpost transmitters so that a physical roadway reference may be used to interpret the location of time points. Ensure that transmitter locations are updated on the system map when changes are implemented in the field. Signpost transmitters are often relocated in the field, however, the map remains unchanged thereafter.

Interpret physical location of time points - Data are sent from the vehicle to the control center not upon passage of the signpost transmitter, but upon passage of a scheduled point in time (time point). The data describe the distance traveled between sequential time points. Thus, a travel time for a section of roadway is known. However, the physical location of that roadway section can only be inferred. It is possible to approximate the location of a time point since it is known when the vehicle passes a signpost transmitter. The exact location of the transmitter is known, and the location of the vehicle passing within range of the transmitter can be estimated to within about 30 m (100 ft). Based on the difference in time between transmitter passage and time point passage, the approximate roadway location of a time point can be interpreted.

5.1.5 Previous Experiences

Several agencies in the U.S. and Europe have operated signpost-based AVL probe vehicle systems. Their experiences are useful for designing and managing your system. VIA Transit in San Antonio, Texas has operated a signpost-based AVL system to monitor its fleet of buses. The New Jersey Transit agency has used signpost-based AVL technology since 1993 to provide bus operations control centers with accurate real-time information on schedule performance adherence and fleet management. Their system is used to alert and predict service delays. Seattle Metro uses the technology to monitor its bus operations, and data are archived for "next day" access by transit analysts (10). London Transport aims to equip 6,500 vehicles and 700 bus routes with signpost-based AVL technology by the year 2000 (11).

San Antonio VIA Metropolitan Transit

VIA Transit first developed specifications for the signpost-based AVL system in 1983, and this system was developed by the General Railway Signal Communications System. The design of San Antonio's system is similar to that described in the preceding section with only slight modifications. The total system cost of $3.7 million included the development and installation of equipment on 537 buses, all central computer hardware and software, 200 electronic signposts, two un-interruptible power supplies, and all training and documentation (9).

The San Antonio system covers about 3,100 sq-km (1,200 sq-mi). The odometer readings are compared to programmed readings for schedule adherence monitoring. The system can generate a variety of reports, including daily schedule adherence reports by route, time, or location. The schedule adherence reports may illustrate data by route across a range of dates. The software also allows minute-by-minute tracking of individual buses. VIA's experience with the software is that it is a highly specialized code to learn (12).

Data reports can be formatted as text documents. These documents can be imported into a spreadsheet or statistical analysis software package. Figure 5-2 shows a sample of raw data from VIA's signpost-based AVL system. These data correspond to one bus (# 532) traveling along its route.

Several rows of data in Figure 5-2 have missing data. However, beginning in the seventh row of data, bus #532 can be observed traveling along its route. At time point 0005 at 06:11:22, the bus transmits its odometer reading to the control facility. It is determined that it traveled along segment #3686 in a southern direction for a distance of 1.56 km (0.97 mi). On the eighth row of data, bus #532 passes time point 0504 at 06:17:25 after traveling a distance of 3.78 km (2.35 mi). These time points are not synonymous with signpost locations, and there is no way of knowing the precise location of a bus when it reaches a time point. The bus location can only be inferred.

RTE LGRP	BLK	SCHED TIME	LAY OVER	ACTUAL ROUTE RIL	SEG#	TIME PT	TIMEPOINT LOCATION	Dir Cmp	I/O	SEG MILE .01	Bus #	SCHD ADH	TIME OF PASSAGE
034	004	0513	00	034	2856	9999	GARAGE	N	O	0927			
034	004	0538	00	034	2855	1703	NWDR-INGR	S	I	0278	532	033E	05:34:42
034	004	0547	00	034	3189	0808	BDVW-INGR	S	I	0167			
034	004	0553	00	034	3190	0806	WOOD-BAND	S	I	0187			
034	004	0559	00	034	3191	0805	WOOD-ZARZ	S	I	0155			
034	004	0605	00	034	3685	0106	FRED-FLOR	S	I	0128			
034	004	0610	00	034	3686	0005	ST.M-MART	S	O	0097	532	014L	06:11:22
034	004	0617	00	034	3192	0504	ST.M-ALAM	S	O	0235	532	004L	06:17:25
034	004	0624	00	034	3193	0506	ROOS-EADS	S	O	0174	532	017L	06:25:40
034	004	0630	00	034	3194	0418	MCCR-ELES	S	O	0200	532	027L	06:32:43
034	004	0638	00	034	3195	1912	GOLD-VLLY	S	O	0265	532	021L	06:40:04
034	004	0647	10	034	3196	0522	N.BR-HOSP	N	I	0257	532	012L	06:48:14
034	004	0708	00	034	3197	1912	GOLD-VLLY	N	I	0205	532	001L	07:08:04
034	004	0717	00	034	3205	0418	MCCR-ELES	N	I	0174	532	019E	07:15:04
034	004	0727	00	034	3200	0506	ROOS-EADS	N	I	0231	532	001L	07:27:05
034	004	0737	00	034	3183	0504	ST.M-ALAM	N	I	0051	532	006E	07:36:23
034	004	0740	00	034	3184	0013	NAVA-VILL	N	O	0175	532	007E	07:39:16
034	004	0752	00	034	3201	0106	FRED-FLOR	N	O	0157	532	001E	07:51:55
034	004	0800	00	034	3202	0805	WOOD-ZARZ	N	O	0182	532	014E	07:58:36
034	004	0806	00	034	3203	0806	WOOD-BEND	N	O	0171	532	010E	08:05:00
034	004	0813	00	034	2837	0808	BDVW-INGR	N	O	0330	532	017E	08:11:15
034	004	0824	00	034	2855	1703	NWDR-INGR	S	I	0278	532	119L	08:35:56
034	004	0842	00	034	3189	0808	BDVW-INGR	S	I	0167			
034	004	0848	00	034	3190	0806	WOOD-BAND	S	I	0187			
034	004	0855	00	034	3191	0805	WOOD-ZARZ	S	I	0155			
034	004	0902	00	034	3685	0106	FRED-FLOR	S	I	0128			
034	004	0908	00	034	3686	0005	ST.M-MART	S	O	0097			
034	004	0916	00	034	3192	0504	ST.M-ALAM	S	O	0235			
034	004	0925	00	034	3193	0506	ROOS-EADS	S	O	0174	532	016E	09:23:21
034	004	0934	00	034	3194	0418	MCCR-ELES	S	O	0200	532	0353	09:30:31
034	004	0941	00	034	3195	1912	GOLD-VLLY	S	O	0265	532	002L	09:41:15
034	004	0950	04	034	3196	0S22	N.BR-HOSP	N	I	0257	532	019L	09:51:54
034	004	1003	00	034	3197	1912	GOLD-VLLY	N	I	0205	532	017L	10:04:45
034	004	1012	00	034	3205	0418	MCCR-ELES	N	I	0174	532	027L	10:14:43
034	004	1020	00	034	3200	0506	ROOS-EADS	N	I	0231	532	012L	10:21:11

Figure 5-2. Data from San Antonio VIA Transit's Signpost-Based AVL System

VIA's signpost-based AVL system has several important design characteristics and noteworthy operational aspects:

- **Signpost transmitter spacings** are approximately 8 km (5 mi) along the bus routes.
- **Buses polled** every 60 seconds for an odometer reading by the control facility.
- **Difficulty maintaining route/schedule database** since field changes are often implemented to bus routes or schedules. A lag often occurs between the field implementations and the update of the route/schedule database and short-term changes in the bus routes go unnoticed.

- **1 to 2 persons required** to maintain route/schedule database.

- **Aging hardware** and signpost-based technology is difficult to replace.

- **Quality of data** is suspect since data are often erroneous or missing for report generation because vehicles often have malfunctioning equipment, odometers are not calibrated for vehicle's tire size or inflation level, or route/schedule reference database are not updated. Erroneous data are also obtained when a bus passes through a layover point (e.g., transit center or bus stop) since there is no distinction between arrival or departure; however, data between layover points is reliable.

- **Signpost maintenance** requires checking signposts periodically for proper signal transmission. Signpost maintenance is a large expense. Sensitivity of signposts on low-speed facilities should be set at a shorter range than for signposts on freeways. Sensitivity refers to the transmission range of the signpost transmitter.

- **Odometer maintenance** requires odometers that are properly calibrated for each bus.

VIA uses its signpost-based AVL system for real-time location tracking, schedule adherence monitoring, and computer-aided dispatching. They reported that the data have never been requested for use in any other applications other than for their personal fleet management.

New Jersey Transit Agency

The New Jersey Transit agency has used signpost-based AVL technology since 1993 to provide bus operations control centers with accurate real-time information, on schedule performance adherence, and fleet management. Their system is used to alert and predict service delays. Data are also maintained to report on-schedule performance for more effective transit scheduling. An example of raw data from trace files is shown in Figure 5-3. These trace files contain data transaction between the bus radio and control facility. The files are stored at the central control facility.

To the casual observer, the data in Figure 5-3 are difficult to interpret. At 12:54:06.19, vehicle 2675 passes timepoint 1 and transmits its odometer reading to the control facility. The vehicle's last location of 0036 and current location of 0038 are determined by the system. These locations are associated with a link on a map database. Based on the elapsed time to travel between a previous location and the current location, the travel time for a particular link can be estimated.

```
12:31:42.82   LOC_MSG Veh:  2675        Last Loc 005A       Curr Loc 005A       Odm 0     TID 00004813     Trip Id
00002661
12:33:50.98   LOC~MSG Veh:  2675        Last Loc 005A       Curr Loc 0036       Odm 0     TID 00004813     Trip Id
00002661 12:33:51.01   TIMEPT     Veh:  2675      EOT Trip Msg TID 00004813     Trip Id 00002661
12:33:51.01   TIMEPT     Veh:          2675      Timepoint 6 completed by Signpost TID 00004813
12:43:52.06   LOC_MSG Veh:   2675       Last Loc 005A       Curr Loc 0036       Odm 0     TID 00004813     Trip Id
006E117F
12:53:51.91   LOC_MSG Veh:   2675       Last Loc 005A       Curr Loc 005A       Odm 0     TID 00004813     Trip Id
006E117F
12:54:06.17   LOC_MSG Veh:   2675       Last Loc 0036       Curr Loc 0036       Odm 0     TID 00004813     Trip Id
006E117F
12:54:06.19  TIMEPT       Veh:          2675      Immediate Trip Msg TID 00004813         Trip Id 006E117F
12:54:06.19  TIMEPT       Veh:          2675      Timepoint 1 completed by Signpost TID 00004813
12:54:52.25   LOC_MSG  Veh:  2615       SOT Msg TID 00004813 Trip Id 006E117F
12:54:52.29  TIMEPT       Veh:          2675      Immediate Trip Msg TID 00004813         Trip Id 006E117F
13:00:34.06   LOC_MSG  Veh:  2675       Last Loc 0036       Curr Loc 0038       Odm 0     TID 00004813      Trip Id
006E117F 13:00:34.09   TIMEPT      Veh: 2675      Immediate Trip Msg TID 00004813         Trip Id 006E117F
13:00:34.09   TIMEPT      Veh:          2675      Timepoint 2 completed by Signpost TID 00004813
13:02:54.62   SPM$EMPNO_MSG   -   EmpNo    26758 Msg TID 00001134
13:10:34.56   LOC_MSG  Veh:  2675       Last Loc 0038       Curr Loc 0038       Odm 0     TID 00004813     Trip Id
006E117F
13:11:53.29   LOC_MSG  Veh:  2675       Last Loc 0038       Curr Loc 005A       Odm 0     TID 00004813     Trip Id
006E117F
13:11:53.32   TIMEPT       Veh: 2675           Immediate Trip MsgTID 00004813  Trip Id 006E117F
```

Figure 5-3. Data from New Jersey Transit's Signpost-Based AVL System

Seattle Metro Transit System

The Seattle Metro system was designed to provide a method of collecting, storing, and analyzing performance data to improve service analysis and scheduling modifications for its bus fleet (10). Some specific characteristics about Metro's system are:

- **Probe vehicle polling** rate of 30 to 90 seconds;
- **Fast polling rate** of 5 to 15 seconds for individual vehicles;
- **Location accuracy** to within ± 76 m (± 250 ft).

Location accuracy discrepancies were attributed to bus odometer malfunction, in-vehicle receiver failure, in-vehicle processor failure, and the bus being off-route.

London Transport Bus System

The London Transport Bus (LTB) system uses signpost-AVL technology in which in-vehicle transponders communicate with roadside microwave beacons (13). Nine hundred and fifty buses, out of a 6,500 bus fleet, are equipped with AVL tags. The system is used to estimate arrival times for buses and display the information at bus stop variable message signs.

Current operations generate 40 megabytes of data every day. The data are archived for seven days to include the time at which buses pass certain points and the length of time to complete routes. These data can be used to compute journey times. The data set does not include raw location data, thus the layover time at bus stops are included.

5.2 Automatic Vehicle Identification

Automatic vehicle identification (AVI) technologies are in widespread use throughout the United States for a variety of purposes: electronic toll collection (ETC), real-time traffic monitoring, incident management, traveler information, and performance measure data collection. A few large metropolitan areas monitor traffic operations in real-time with AVI technology; however, its primary application is for electronic toll collection. Currently, about 18 U.S. toll collection agencies use AVI to electronically collect tolls (14). An additional 10 toll agencies are planning to use AVI for electronic toll collection by the end of 1998. In Houston, Texas, AVI technology is used for both electronic toll collection and traffic monitoring.

Figure 5-4 illustrates the AVI components and the data collection process. An AVI system collects travel time data by using four primary components:

- ITS probe vehicles equipped with electronic transponders;
- roadside antenna that detects the presence of electronic transponders;
- roadside readers which bundle data; and
- a central computer facility to collect all data.

Tags, also known as transponders, are electronically encoded with unique identification (ID) numbers. Since these tags are often used for electronic toll collection, the tag ID number can be synonymous with the electronic registration number used to determine vehicle ownership in electronic toll collection (15,16). Roadside antennas are located on roadside or overhead structures (e.g., bridge, guide sign), or as a part of an electronic toll collection booth.

The antennas emit radio frequency signals within a capture range across one or more freeway lanes. The radio frequency (RF) capture range may be constantly emitted, or it may be triggered by an upstream loop detector (i.e., as in toll plazas). When the probe vehicle enters the antenna's capture range, the radio signal is reflected off of the electronic transponder. This reflected signal is slightly modified by the tag's unique ID number. The captured ID number is sent to a roadside reader unit via coaxial cable and is assigned a time and date stamp and antenna ID stamp. These bundled data are then transmitted to a central computer facility via telephone line where they are processed and stored. Unique probe vehicle ID numbers are tracked along the freeway system, and the probe vehicles' travel times are calculated as the difference between time stamps at sequential antenna locations.

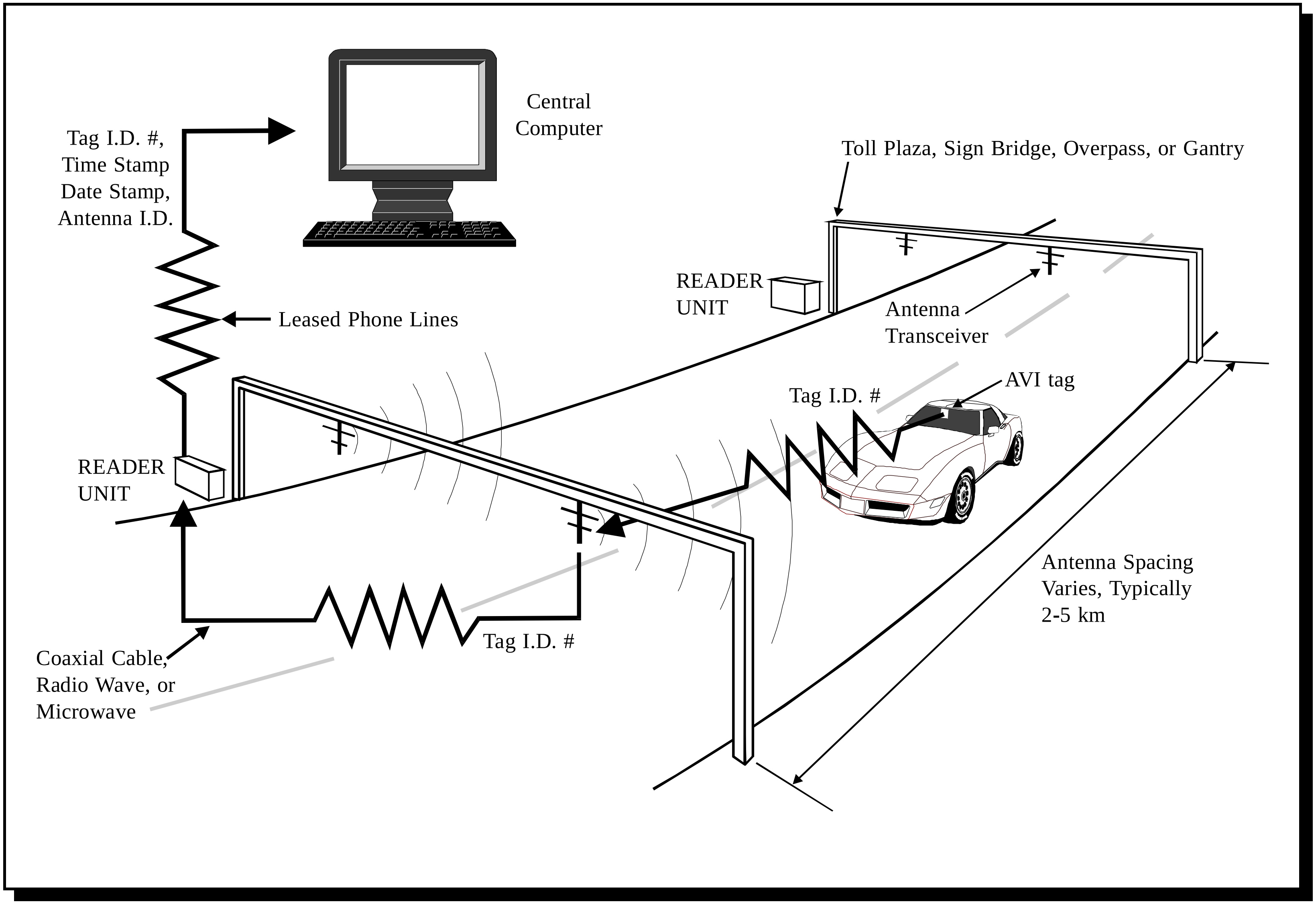


Figure 5-4. AVI Vehicle-to-Roadside Communication Process

The roadside readers have the capability of initiating the dial-up process to the central facility or they may answer dial-in requests for data. The data collection process may slightly differ for some electronic toll collection systems. An ETC plaza may store data for lengthy periods before the data are sent to a central facility.

AVI systems have the ability to continuously collect large amounts of data with minimal human resource requirements. The data collection process is constrained primarily by sample size characteristics and the coverage area of the AVI infrastructure (i.e., antenna readers or ETC booths). AVI technology has demonstrated itself as highly accurate. Since AVI tags are commonly used for toll collection, it is important to have a high detection rate. The Electronic Toll and Traffic Management (ETTM) User Requirements for Future National Interoperability, published by the Standards and Protocols Committee of the Intelligent Transportation Society of America (ITS America), suggests detection rates of greater than 99.5 percent. Agencies using AVI technology have experienced detection rates of between 85 to 99 percent.

Electronic Toll Collection

Many toll agencies in the U.S. are using AVI technology for electronic toll collection. The combination of an electronic toll collection system and a traffic information and management system can be referred to as an electronic toll and traffic management (ETTM) system. This combination offers an expanded utility for vehicles equipped with electronic tags to not only process tolls, but also service ITS applications (17). Electronic toll collection systems can provide useful travel time data, particularly on systems with a large percentage of motorists using ETC. Some system adjustments will most likely be necessary to provide an effective data collection effort. For example, toll plazas are typically spaced further apart than recommended for AVI data collection, and computer systems may not be prepared to archive travel time data.

While most ETC systems are not set up to simultaneously collect and manage travel time data, some existing ETC agencies, such as the Illinois State Toll Highway Authority have begun to utilize AVI technology for travel time data collection in addition to toll processing. Some ETC systems experience between 25 percent to 100 percent of all tollway vehicles having electronic tags. This provides a large sample to collect representative travel time data.

Some modifications may be necessary for ETC systems to collect accurate travel time data. For example, antenna spacings may be too far apart. Also, some ETC systems have open-ended designs in which tolls are transacted at only one antenna per direction. Recall that two sequential antennas are needed to collect travel time data. These and other modifications are feasible, and ETC systems can provide an abundant source of travel time data.

5.2.1 Advantages and Disadvantages

Inherent within the AVI data collection methodology are certain advantages and disadvantages which can affect the quality of travel time data. The AVI technology presents characteristics which can affect the integrity of travel time data. These technological characteristics are presented and briefly discussed in this section.

The **advantages** of AVI probe vehicles for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Continuous data collection** - Travel time data may be collected for entire 24-hour periods for each day of the year since personnel are not required for field data collection. Data may be collected during weekends and holidays, as well. AVI allows data collection during all types of weather and environmental conditions as long as probe vehicles are detected.

- **Minimal personnel requirements** - The AVI data collection process is completely automated. Personnel are not necessary to collect data from the field. Very few personnel are needed to maintain the system and process data (18).

- **Safe data collection** - Since personnel are not required in the field, the risk of injury is eliminated.

- **Minimal human error** - The elimination of manual data collection virtually removes potential of human error from the actual data collection process.

- **Accuracy of data collection** - For small sample sizes, 100 percent of AVI tags can be captured by the antenna (15). The Washington State Transportation Center (TRAC) experienced an 83 percent detection rate. Travel time observations have been validated by simultaneous floating car travel times. AVI tags have been detected at speeds of 180 km/h (110 mph) and when multiple probe vehicles simultaneously pass the same reader site. AVI technology has demonstrated itself as immune from interference from cellular telephones, citizen band radios, and electric generators (1).

- **Lane specific** - Can collect travel time data corresponding to particular lanes.

- **Vast amounts of data** - Since data can be collected continuously and since the system has the potential to collect data from many probe vehicle drivers, the potential exists for vast amounts of travel time data. Data can be collected over an entire year and through all types of environmental conditions.

The **disadvantages** of AVI probe vehicles for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Infrastructure dependent** - The system can collect travel time data only along freeway or arterial street segments that are within the coverage area of AVI infrastructure (i.e., segments equipped with antennas or ETC booths).

- **Electronic tag dependent** - Data collection is limited to the number of tags in use within the study area.

- **Clock drift problems** - Several agencies have reported that maintaining the antennas or ETC booths is expensive and may affect data quality. A common maintenance problem is keeping the clocks, which place the time stamp on each transponder read, in synchronization (1,15).

- **Privacy issues** - The technology requires that unique tag IDs are tracked between sequential antennas to determine travel times. The IDs correspond to individual drivers of probe vehicles, as the drivers are often registered to use an ETC system. The technology may allow individual vehicles to be tracked along the system.

- **Large data storage requirement** - In AVI systems, especially systems with many antenna locations and probe vehicles, a large amount of data storage space is needed.

5.2.2 Costs and Equipment Resources

This section will describe the essential components for collecting travel time data using the AVI probe vehicle technique. The quantity of certain components depends on the application of the technology. Equipment are presented by field hardware requirements and by central facility hardware requirements. Table 5-3 summarizes the needed AVI equipment and costs. As with most probe vehicle systems, they may be installed initially for reasons other than travel time data collection. Therefore, some of the costs presented in Table 5-3 may be subsidized by different agencies benefitting from the system.

Data Collection Requirements

Electronic Tags - These devices are attached to the probe vehicles. They are usually placed on the inside windshield and are about the size of a credit card. Three different tag types (types I, II, and III) are commercially available. The primary difference between transponder types is the ability to write onto the transponder, and these distinctions are relevant primarily for electronic toll collection purposes. Different transponder types allow toll account data to be stored on the transponder instead of in a centralized database. The tag type does not affect the ability to collect travel time data. Individual tag costs have been reported to range from $25 to $100, depending on the quantity of tags purchased (1). If tags are purchased in bulk, a substantial discount is achieved. Tags can be installed easily within five minutes with adhesive tape.

Roadside Antennas - The antennas function as transceivers which receive tag ID numbers and send the tag ID numbers to a roadside reader unit. The antennas are typically mounted over the travel lanes on existing structures. Minimal disruption to traffic is necessary for installation or repair.

Table 5-3. Estimated Costs for AVI Probe Vehicle System

Equipment/Personnel	Unit Cost (1998 dollars)
Hardware	
Electronic Tags	$20 to $50 each
Roadside Antennas	$1,500
Roadside Readers	$10,000 - $30,000
Cable Connections	$100/meter
Telephone Connection	$25 to $40
Telephone Communications	Varies
Control Facility Computer	$2,000 - $5,000
Computer Data Storage	$100 - $200/gigabyte
Software	
Specialized Software	Varies
Analysis Software	$150 to $300
Personnel	
Data Reduction Personnel	Varies

Roadside Readers - These units receive the tag ID numbers from antennas and assign the time, date, and antenna location ID stamps. These bundled data are stored and transmitted to a central control facility. The storage durations and update frequencies may be established by the system operators. Readers can cost about $31,000 on average. Readers require frequent maintenance, which has been reported as costly as $256 per lane per site per month.

Cables - Antennas and readers are typically connected by coaxial cables.

Telephone Line - Reader units are often tied into the central computer facility by leased telephone lines. The cost of leasing telephone lines may be a major operational cost. One telephone line is necessary for each reader unit in the field. Fiber optic cable or microwave transmission offers a much quicker by costlier alternative to telephone lines.

Data Management and Reduction Requirements

Specialized Software - Specialized software is required to collect and process incoming tag reads and match them to calculate travel times. Software is often designed in-house, by a consultant, or is a proprietary-based application.

Archive Capacity - Sufficient archival capacity is needed to store historic travel time data. The size of archival depends on the size of the AVI system (i.e., sample size, antennas, tag reads).

Analysis Software - Archived data can typically be analyzed using a common spreadsheet or statistical analysis package.

Data Reduction Personnel - Individuals who will reduce the data that is being received by the AVL system for use in travel time determination.

5.2.3 System Design Considerations

This section will discuss how to design the AVI system to generate data which are most useful for the readers' travel time data needs. Certain hardware configurations, such as antenna spacing, mounting, or capture zone area, may be more appropriate for certain analysis methods or may be more inclusive for a variety of analysis methods. Certain hardware specifications/types may require additional attention than others, and this should be considered.

Electronic Tag Types

Several vendors develop AVI technologies, and a variety of transponders and antennas are commercially available. Currently, three different transponder technologies have been used. These transponder technologies are referred to as types I, II, and III (19). The primary difference between transponder types is the ability to write onto the transponder, and these distinctions are relevant primarily for electronic toll collection purposes. Different transponder types allow toll account data to be stored on the transponder instead of in a centralized database. The technological differences between tag types do not affect their abilities to collect travel time data since the necessary data (i.e., unique ID numbers) are transmitted from the transponders to the roadside units regardless of transponder type.

Maximizing Tag Distribution

It is desirable to distribute as many electronic tags as possible to collect travel time data. A greater number of probe vehicles can provide a more representative sample of the traffic population's travel time characteristics. In order to achieve a desirable level of probe vehicles, it is necessary to attract probe vehicle drivers and distribute the electronic tags. Participation in an AVI system can be achieved by offering probe drivers various incentives. Potential incentives may include the following:

- priority passage through toll facilities;
- priority passage through weigh/inspection stations (for trucks);
- ability to receive in-vehicle travel information;
- free electronic tag;
- voucher for merchandise or fuel;
- registration for roadside maintenance service; or
- some type of payment.

It is also important to ensure participants that their privacy will not be violated. Public concerns have been raised about various privacy issues. A privacy policy should be drafted, perhaps in accordance with the Intelligent Transportation Society of America Privacy Principles, to ensure that individually identifiable data are not improperly managed and personal privacy is not compromised (20). Some common privacy concerns include:

- vehicle/driver tracking;
- automated traffic law enforcement;
- distribution of personal travel history; and
- distribution of personal information.

Vehicle-to-Roadside Communication Media

Other technological differences exist between vehicle-to-roadside communication signals and between roadside antenna types. These differences may affect the accuracy and performance of the AVI system and should be considered when installing or upgrading AVI technologies or when collecting travel time data. The most common vehicle-to-roadside communication signal is radio frequency (RF). However, laser signals have been used. RF signal AVI technologies have been demonstrated to be more reliable than laser technologies, and RF technology is the choice of new ETC systems (21).

Antenna Spacing and Installation Specifications

Antennas are usually mounted on existing overpass or sign structures and antenna spacing often varies as mounting structure spacing varies. More expensive options include constructing a gantry over the roadway for exclusive use of AVI antennas. The level of congestion is often considered in the placement of antennas; antennas are spaced more frequently in areas with greater congestion levels. In addition, antenna spacing is set according to anticipated benefits from incident detection. Incident detection requires more frequent spacings than does simple travel time monitoring. One AVI system designer recommends that antennas are spaced no greater than two minutes apart in sections where speeds are less than 48 km/h (30 mph) during recurring congestion for the purposes of future incident detection (22).

Typical antenna spacings range between about 2 km (1.2 mi) to 5 km (3.1 mi). It is important to consider that adequate antenna spacing varies with variations in mean travel time data. Larger antenna spacings result in decreased sensitivity to variations in mean travel time within the segment. It is important to consider that antennas must be connected to roadside readers. Roadside readers must be connected to the control facility via telephone cable or other transmission medium, and power must be supplied to the readers and antennas. Antenna and reader placement must accommodate these connections.

Roadside Reader Clock Synchronization

AVI roadside reader clocks place a time stamp on the tag read prior to transmitting the data to the control facility. The clocks on readers must be synchronized to ensure that accurate travel times are collected throughout the entire system. It is imperative that sequential reader clocks are synchronized. It is necessary to periodically synchronize clocks. It is also possible to control reader clocks from the control facility by synchronizing all system clocks simultaneously.

Antenna Capture Range Adjustment

Reports suggest that one antenna can cover 18 lanes of traffic; however, practical application limits one antenna to 8 or 9 bi-directional lanes of traffic. Typical installations allow for separate antennas for directional lanes of traffic. The capture range for the RF signal can be adjusted to detect one lane or multiple lanes, thus allowing for detection of specific lanes. Different antenna types allow for different capture range dimensions and are more conducive to monitoring multiple traffic lanes.

Telephone Connection to Reader Units

Analog telephone lines are often used. However, the recurring costs of analog lines presents ISDN lines as an alternative. ISDN lines can be multiplexed into a single channel into the control facility and have smaller long-term costs. However, in the event that power is lost to the ISDN modem, manual re-connection may be required by the telephone company.

5.2.4 Data Reduction and Quality Control

An AVI system requires special software applications to perform the necessary data processing. Software is typically developed by the vendor of AVI equipment, a consultant, or agency operating the AVI system.

Roadside reader units are equipped with computers running software to recognize each tag ID read, bundle the reads with corresponding time and date stamps and antenna ID stamp, and transmit the bundled data to a central computer. The central computer operates software which solicits data from the multiple roadside reader units, typically at some preset time interval.

Once data have been received by the central computer facility, several steps are taken to reduce data into a useful format. This section describes the basic steps in the AVI data reduction process after the data have been transmitted from the field to the central computer.

1. **Store tag read data**. As data enters the central computer, the data must be stored within a local database. For real-time data processing, it is necessary to store data on a shared disk drive to allow for a second computer to compute travel times. The stored data are tag records which are generated each time a probe vehicle passes an antenna. A tag record contains the tag ID, antenna ID, and time and date of tag detection. Figure 5-5 is an example of raw data from the Houston, Texas AVI system tag records. These data entered the computer center from multiple reader units and are in an ASCII text format. This file is accessible through spreadsheet or word processing programs.

2. **Match sequential tag reads**. A software application matches tag records between sequential antennas and then calculates the travel time between the antennas. Travel time is calculated as the difference between two tag record time stamps of the same tag ID.

3. **Filter erroneous data**. The travel time data should be reviewed with a screening algorithm to identify erroneous data. An erroneous data point may result in a tag read from a vehicle which stalled, stopped, or detoured off the route between sequential antennas.

4. **Archive travel time data**. The valid travel time data are then stored within a database management system, such as a relational database. This can be done automatically by system software. Commonly, all travel time data are sent into an archive file which is renamed based on the date. Data can be transferred to an historical database, often consisting of daily binary files containing individual travel time observations on each link within the system. AVI systems have reported daily file sizes of 15 to 20 megabytes for a system collecting 450,000 tag reads, or about 225,000 matched tag reads, per week.

Tag ID	Antenna ID	Checkpt. ID	Read Time	Read Date
123456789	4054	56	0:16:14	3/31/97
234567900	4063	57	0:16:25	3/31/97
345679011	4000	50	0:16:17	3/31/97
456790122	4114	112	0:16:19	3/31/97
567901233	1054	6	0:16:22	3/31/97
679012344	4096	107	0:16:30	3/31/97
790123455	5107	159	0:16:31	3/31/97
901234566	5000	72	0:16:32	3/31/97
1012345677	5155	162	0:15:41	3/31/97
1123456788	5000	72	0:16:34	3/31/97
1234567899	5155	162	0:16:00	3/31/97
1345679010	5138	161	0:16:35	3/31/97
1456790121	4029	54	0:16:34	3/31/97
1567901232	7011	101	0:16:40	3/31/97
1679012343	5070	157	0:16:47	3/31/97
1790123454	5078	173	0:16:52	3/31/97
1901234565	6043	131	0:16:56	3/31/97
2012345676	4042	55	0:16:55	3/31/97
2123456787	4048	58	0:17:06	3/31/97

Figure 5-5. Typical AVI Tag Reads in ASCII Text File

5. **Access archived travel time data**. Travel time data files can be accessed from the archives for specific days. Files may be archived in a binary format. If you are using a spreadsheet package or statistical analysis software, it may be necessary to run a conversion process on the files to transform them into a text format or accessible format.

6. **Consider creating anonymous data file**. The tag read matching process is based on matching unique tag ID numbers which correspond to individually identifiable persons. These ID numbers often remain in the data files and they can be useful for tracking vehicles for origin/destination studies. However, problems can arise due to the sensitivity of privacy issues. It is possible to assign an anonymous ID number

to each original tag ID number. This reassigned anonymous ID does not correspond to an individually identifiable account, yet it retains the ability to track vehicles for origin/destination studies. Once the anonymous file is created, the original tag ID numbers can be discarded.

5.2.5 Previous Experience

This section describes several AVI systems in the U.S. and describes actual experiences and practices of the operating agencies. The Texas Department of Transportation (TxDOT) has helped to develop the TranStar system in Houston which operates an AVI system in order to monitor traffic conditions, detect incidents, distribute travel information, and archive travel time data. TxDOT is currently developing an AVI system in San Antonio to monitor traffic conditions and detect incidents. The Washington State Transportation Center (TRAC) studied AVI use in Seattle's Puget Sound region in 1994. The TRANSCOM agency operates the TRANSMIT system in New York and New Jersey to monitor traffic conditions with AVI technology. In addition, several AVI systems are operated abroad, and system design criteria from these systems are useful for U.S. applications. The experiences of these agencies can provide useful support for designing and managing AVI systems and effectively collecting quality travel time data.

TranStar Traffic Monitoring System, Houston, Texas

Antenna installation specifications - Antennas are mounted above traffic on existing roadway overpasses, overhead sign structures, or side-mount sign structures. Antenna spacing depends on the availability of existing structures, and spacings are typically 2 km (1.2 mi). The actual range of spacings is between 1.4 km (0.9 mi) and 10.8 km (6.7 mi) with an average of about 4.6 km (2.85 mi).

Antenna capture range setting - The Houston system uses two general antenna types. One antenna type emits a directional, narrow, and long RF capture range. These narrow band projecting antennas are mounted over high-occupancy vehicle (HOV) lanes and inside freeway main lanes to prevent false reads from adjacent lanes. The second antenna type emits a broader and shorter RF capture range, and these types are mounted over outside freeway main lanes. A typical installation configuration of these two antenna types is shown in Figure 5-6.

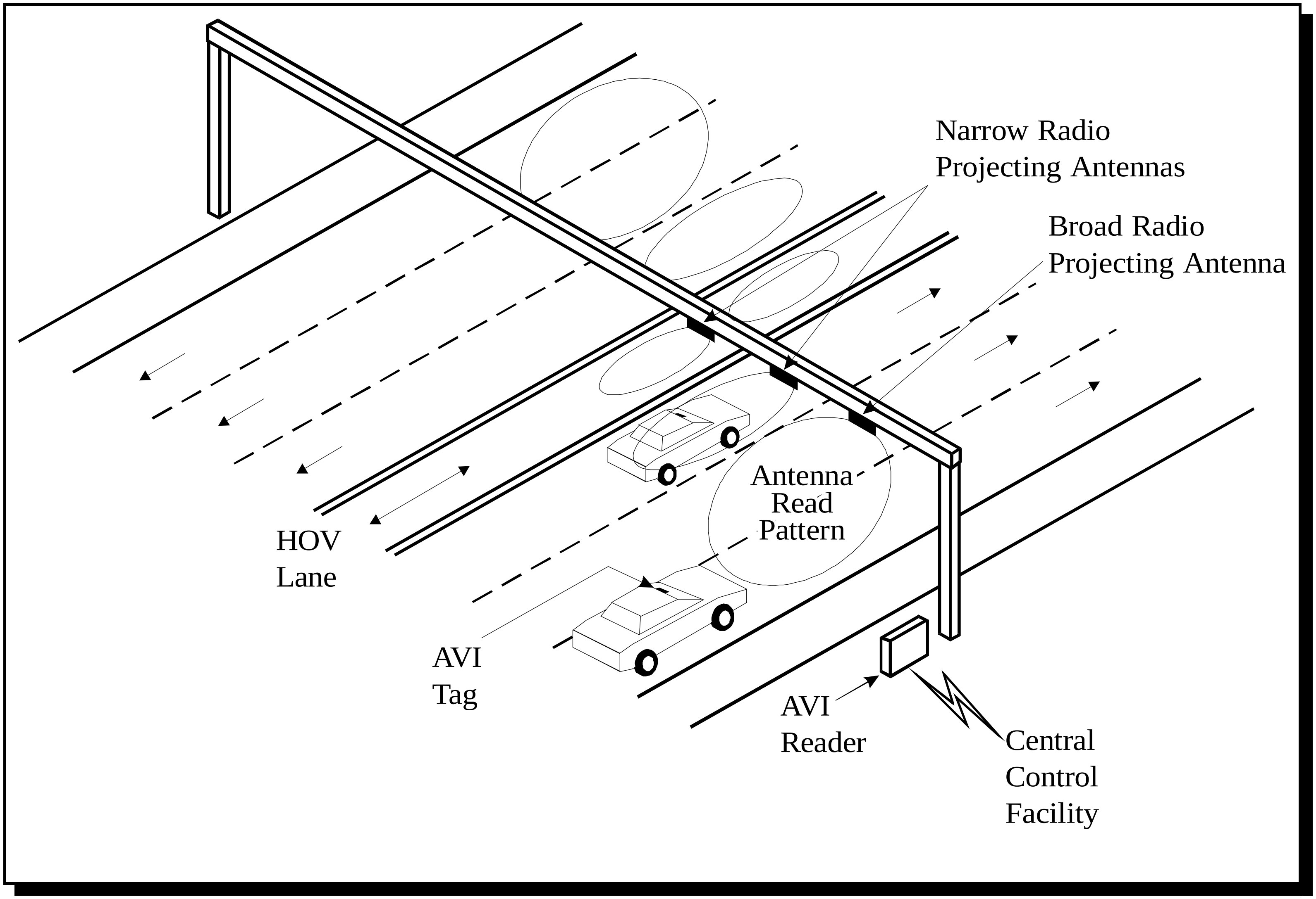


Figure 5-6. Typical AVI Antenna Mounting in Houston, Texas

AVI tag distribution - Motorists traveling during the peak period were targeted to receive electronic tags from the Texas Department of Transportation (TxDOT) through a recruitment process. The system also relied upon vehicles equipped with ETC tags from the local toll authority to supplement peak period coverage and provide for off-peak period coverage. Over 200,000 tags have been distributed through the local automated toll collection system (23) to date.

Probe vehicle driver recruitment - Citizens were reluctant to place an electronic tracking device in their vehicles. Volunteer drivers were sought through correspondence with large employers, advertising over news media, advertising on changeable message signs and trailer message signs, and advertising on the Internet. The most effective method of driver recruitment was through changeable message signs and trailer message signs along the freeways. Signs identified an appropriate telephone number to seek an explanation of the AVI system.

Probe vehicle density/tag read frequency - When planning for the system, the target rate was one probe vehicle or one tag read per antenna location per one minute. This target rate was set because it required one minute to process field data to the central facility. Approximately five percent of the total volume passing antenna locations yield tag reads. This corresponds to approximately four tag reads per minute during peak periods and about three tag reads per minute during off-peak periods. About 60 percent of the tag reads were correctly matched with tag reads at sequential antenna locations to yield a travel time data point.

Data archival - In the Houston AVI system, the travel time data are stored in an Oracle relational database. Travel time data are stored in binary files, and one binary file is created for each 24-hour period (24). Daily files can be extracted from the archive in order to analyze one day of data at a time.

Automatic Vehicle Identification System, San Antonio, Texas

The Texas Department of Transportation and the City of San Antonio are planning the development of a real-time traffic monitoring system using AVI technology.

Antenna spacing - Site selection for antennas was based partly on an analysis of volume to capacity (v/c) ratios to determine the most congested areas of the freeway system. These congested areas were ranked by congestion priority, and care was taken to ensure that antenna distribution was balanced throughout the system.

Antennas were spaced at 1.6 km (1 mi) to 3.2 km (2 mi) intervals. Travel patterns were considered to determine where the greatest number of tag reads would occur. Field evaluations were necessary to determine if antennas could be mounted on existing structures. Mounting on existing structures can significantly reduce the installation costs.

AVI tag distribution - Initially, it was decided to distribute AVI tags through the vehicle registration process. However, the process of distributing tags through the registration system and to motorists required one year which was beyond the system's schedule. Approximately 80,000 tags will be distributed. This quantity was established based upon budgetary constraints.

Tags were to be randomly distributed to large employers in the area. The system designers were attempting to target motorists who traveled the corridors within the AVI coverage area during the peak hours. No record was to exist of any particular tag placed in any particular vehicle. Tag ID numbers were to be scrambled to prevent the ability to track individuals.

Data management and reduction equipment specifications included provisions for a 167 MHZ computer, two 2.1 gigabyte hard drives, and 128 megabytes of random access memory (RAM) desktop memory.

New York/New Jersey TRANSMIT System

The TRANSCOM System for Managing Incidents and Traffic (TRANSMIT) system operates on 29 km (18 mi) of the New York State Thruway and Garden State Parkway in New York and New Jersey. About 23 antenna locations are a part of the $1.4 million system.

The TRANSMIT system follows these guidelines:

- **Antenna spacing** of 2.4 km (1.5 mi) for maximum incident detection time of five minutes;
- **Probe vehicle density specifications** of 0.9 percent of total volume for two-lane highways and 2.1 percent for three- and four-lane highways;
- **One antenna** used to cover all lanes in one direction; and
- **Antenna mounting** utilized existing overhead structures.

Puget Sound Region Study

The Washington State Transportation Center (TRAC) studied AVI use in Seattle's Puget Sound region in 1994. A combination of 50 electronic transmitters and 10 antenna units made up the infrastructure. This system used an AVI loop detection type system with the 50 in-vehicle transmitters installed underneath the vehicle.

Sequential antenna spacing was between 1 and 4 km (0.62 to 2.5 mi) with an average distance of 2.6 km (1.61 mi) (23).

European AVI Systems

Several AVI systems are operated abroad, and system design criteria from these systems are useful for U.S. applications. The Automatic Debiting Electronic Payment in Transport (ADEPT) project is an electronic toll collection (ETC) system using two-way communications between in-vehicle tags and roadside beacons (13). Type III tags, or "smart" tags contain vehicle identification, driver, financial, and other data. Toll transactions are processed within the in-vehicle tag. Since the system was designed to collect tolls, the accuracy and quality of data are very good with only one tag in 1,000,000 tags missed or incorrectly detected. Speeds as high as 140 km/h (87 mph) have been detected by the system. The main technical problem was ensuring that the system could distinguish between vehicles across multiple traffic lanes.

One estimation of AVI technology costs offered cost data based on two unique installations (13). The first installation technique requires that a single AVI antenna is required for each lane of traffic with a cost of $8,200 for site installation. It was estimated that the cost of one antenna per lane was $1,600. The second installation technique assumes that one antenna covers an entire direction of travel. For a two-directional roadway, two antennas are required per site at a cost of $3,200 in addition to the $8,200 site installation charge. Communications costs were estimated based on a theoretical AVI system (13). The theoretical system's infrastructure covered 450 directional links of multi-lane roadways carrying 75,000 vehicle per day, 750 directional links of four-lane roadways carrying 50,000 vehicles per day, and 750 directional lanes of two-lane roadways carrying 25,000 vehicles per day.

The most cost-effective method to provide communication links to antenna sites was ISDN lines. It was estimated that the annual costs of ISDN communications for the theoretical AVI system would be $1,100,000 in addition to installation fees. Annual leased-line costs for the same system were estimated at $5,400,000 plus $2,800,000 for installation. Annual radio data communications costs for the same system were estimated at $9,500,000.

An AVI system on the Oslo toll ring in Norway collects data from 400,000 probe vehicles (25). The system has been especially sensitive to Norwegian privacy legislation, such as the Personal Data Register Act of 1978. Under this law, a record of AVI tag identity is defined as a personal data register, and the unique seven digit tag ID was truncated to the last three digits. This truncation allowed the vehicles to remain anonymous and records were no longer defined as personal data files.

The Oslo toll ring AVI system tracks vehicles, calculates travel times between antennas, and averages travel times every five minutes for each section within the field reader units. The averaged travel time data are transmitted every five minutes to a traffic control center. Maximum volumes at test sites are about 1,200 to 1,400 vehicles per lane per hour, or about 100 to 120 vehicles per five-minute interval. Since one-third of the total traffic population is equipped with AVI tags, about 30 to 35 probe vehicles are recorded every five minutes during maximum volume at test sites. However, about 20 vehicles pass test sites every five minutes on average (25).

5.3 Ground-Based Radio Navigation

Ground-based radio navigation is also referred to as terrestrial radio navigation and as radio triangulation. This method involves the use of a receiving antenna network and probe vehicles which are equipped with electronic transponders. Ground-based radio navigation is commonly used by transit agencies and private companies to manage fleet operations. The ground-based radio navigation communication process is illustrated in Figure 5-7. A central computer facility solicits the location of a probe vehicle according to either a controller's request or a prescheduled location interval. Once the probe vehicle receives the location request, it transmits its unique ID code and the transmission time via a radio frequency (RF) signal. The ID code and time stamp are received by multiple antenna towers which then relay the data to the central computer facility.

These RF signals travel linearly between the probe vehicle and radio tower and at a constant known velocity. Thus, the system can calculate the linear distance of the probe vehicle from an individual tower based on the product of the signal's velocity and travel time. The probe vehicle's location is estimated by a triangulation technique. A probe vehicle's mathematically unique position may be determined if four tower sites receive transmissions from the probe vehicle (26).

Ground-Based Radio Navigation Market

Ground-based radio navigation systems are typically subscriber-based. A small number of private companies provide ground-based navigational services to primarily private companies that want to monitor their drivers or fleet vehicles. The majority of fleet management and navigational services utilize GPS technology, however, some ground-based services continue to prosper. Ground-based radio navigation infrastructure is established in several major U.S. cities including Chicago, Dallas/Forth Worth, Detroit, Houston, Los Angeles, and Miami. The ground-based navigation market is expanding into other major U.S. cities (27).

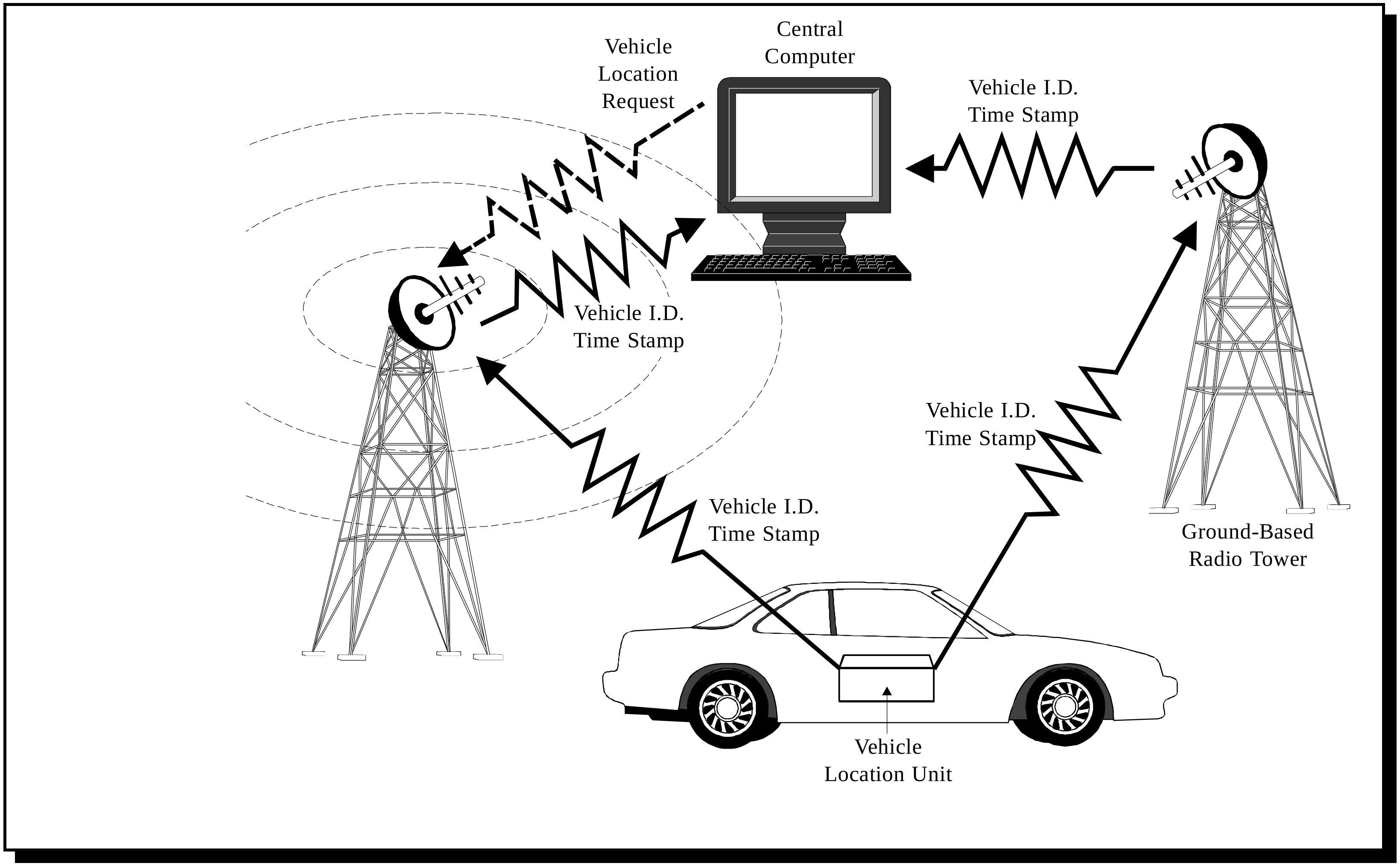


Figure 5-7. Ground-Based Radio Navigation Communication Process

5.3.1 Advantages and Disadvantages

The **advantages** of ground-based radio navigation for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Low start-up cost** data collection approach compared to other probe vehicle methods if ground-based radio navigation service is available in your area.

- **Expanding market** means more widespread use of technology.

- **Relatively simple** data collection if a ground-based location service provider is available in your area.

The **disadvantages** of ground-based radio navigation for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Low precision** - The accuracy of the locating system is between 15 to 46 m (50 to 150 ft), and errors as high as several hundred meters have been reported. Accuracy is affected by the topography of the land and mounting and power setting of the in-vehicle equipment.

- **Antiquated technology** - Ground-based radio navigation technology is less sophisticated and less precise than GPS technologies.

- **Dense urban areas** - RF signals can have difficulty penetrating in urban areas. Radio tower infrastructure can be difficult to mount in dense urban areas.

- **Non-representative data** - Technology is typically used by commercial vehicles or transit agencies. Thus, travel time data collected from these agencies may be biased towards transit or commercial drivers or vehicles and may not represent the driving population.

- **Privately-owned data** - Ground-based navigation systems are mainly operated by private companies. If you wish to utilize data collected from an outside party, the company must agree to provide data access.

- **Small market** - Ground-based radio navigation is currently available in only select cities, and is feasible in only dense urban areas with large market potential.

- **Driver recruitment** - May need to recruit volunteers to drive probe vehicles depending on the size and scope of the study.

5.3.2 Cost and Equipment Requirements

The ground-based radio navigation data collection process requires the equipment listed below. As described previously, since probe vehicle systems are often installed initially for uses unrelated to travel time data collection, other agencies interested in the system may aid in subsidizing the costs of the system.

- **In-Vehicle Transponders** - Transponders may be installed within approximately 30 minutes, depending upon the installer. The entire in-vehicle AVL unit consists of a control unit (about the size of a video cassette) and a pancake-shaped antenna. The control unit must be connected to the vehicle's ignition and is typically mounted underneath the steering column. The unit detects when a trip has begun or ended based on when the ignition has been triggered or terminated.

- **Personal Computer Workstation** - A 386 microprocessor has proven sufficient to run the proprietary software package. The personal computer must have a high-speed (14,400 bps) modem connection to the service provider.

- **Proprietary Software** - Since the service is provided by a private company, software is typically proprietary and is provided upon subscription to the service. Software requires a DOS operating system and the map database files for the coverage area. The software is typically configured to request the locations of vehicles every 30 seconds when ignition is on and every 5 minutes when ignition is off. The software can write data to an ASCII text file, and location data can be in a longitude/latitude format or in a street/nearest cross street format (26).

- **Software Training** - Relatively simple and can be done within one day.

- **Service Start-Up Costs** - A fee must be paid to the service provider to initiate service. This fee can cost as much as several thousand dollars depending upon the size of the study. However, public institutions have been given discounts.

- **Monthly Service Costs** - A monthly fee is charged in addition to the start-up costs. This fee typically runs about several hundred dollars for in-vehicle equipment rental and services.

- **Supervision and Management** - Required to obtain and reduce the data.

5.3.3 Data Collection Instructions

The ground-based navigation technique is commonly used by private agencies, such as couriers. It may be possible to obtain an agreement with an agency to utilize data collected from their fleet vehicles. However, these data will most likely be biased towards transit or commercial vehicles' atypical travel patterns. It will also be difficult to negotiate an agreement to access their data. The alternative is to establish an agreement with a service provider in your area and use probe vehicles similar to a test vehicle method. In this case, the following steps should be taken:

1. **Determine if service is available** in your area. Recall that this service is currently available in several U.S. cities, including Chicago, Dallas/Forth Worth, Detroit, Houston, Los Angeles, and Miami, and service is expanding to other cities.

2. **Obtain a service agreement** with ground-based radio navigation service provider.

3. **Establish study links** - Make sure that desired links in the study are within the provider's service area.

4. **Determine sample size** - You can select the number of probe vehicles that you wish to use for data collection. The vehicles will be instrumented with the necessary navigation equipment.

5. **Identify reliable drivers** - Determine who will be driving the probe vehicles. This may involve recruiting drivers and offering them incentives for participating.

6. **Install in-vehicle navigation equipment** in the probe vehicle fleet.

7. **Determine the polling interval** at which you wish to poll the probe vehicles for data.

8. **Archive data and process** for necessary analysis application. Depending on the size of the system (number of probe vehicles, number of link, number of trips) a typical day of data may consume several megabytes of storage space. Typically, proprietary software can automatically save daily data to a new file at the end of a day.

9. **Develop electronic report -** The proprietary software typically generates a raw data file in a useful file format, such as an ASCII text file. If this is not the case, it is necessary to configure the software to generate the report electronically.

10. **Analyze data** with a common spreadsheet or statistical analysis package.

5.3.4 Data Reduction and Quality Control

Several steps should be taken to reduce the raw data into useful travel time data. This section describes these steps which facilitate the processing of quality travel time data.

Calculate difference in sequential data points to determine the link travel time. The output contains the vehicle ID, location, and time. In order to determine the distance traveled between two locations, you must calculate the hypotenuse between sequential latitude/longitude data using Equation 5-1 or the difference between sequential cross street locations. Next, it is necessary to take the difference in time stamps from the sequential data points. Table 5-4 and Table 5-5 show replications of a typical ground-based radio navigation system software output. Table 5-4 shows the location of the probe vehicle to the nearest cross street along the traveled link. Table 5-5 shows the probe vehicle's latitude and longitude. The ASCII file report can be configured to report location data in a similar layout to the reports shown in these tables. Notice that the output contains speed data for the previously traveled link. The travel time for the previously traveled link can be determined by taking the inverse of the speed data. However, it is still necessary to calculate the distance of the link.

Table 5-4. Replication of Ground-Based Radio Navigation Vehicle Location Output Showing Nearest Cross Street

Vehicle ID	Speed/Direction	Time	Date	Route	Nearest Cross St.
1234	35 North	07:36:33 am	08/23/95	Texas Ave.	G. Bush Dr.

Table 5-5. Replication of Ground-Based Radio Navigation Vehicle Location Output Showing Latitude/Longitude

Vehicle ID	Speed/Direction	Time	Date	Latitude	Longitude
1234	35 North	07:36:33 am	08/23/95	25.74728	80.21642

$$z = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (5\text{-}1)$$

where: z = hypotenuse, or traveled distance;
x_1 = latitude at location 1;
x_2 = latitude at location 2;
y_1 = longitude at location 1; and
y_1 = longitude at location 2.

A minimum link length of less than 0.000224 geographic units, or about 24 m (80 ft), is often the limit for which a travel time can be determined. Software typically assumes that the difference in vehicle location readings less than this length is due to inaccuracies with the positioning technology and will default the distance to zero.

Avoid short link lengths when measuring travel times. Research suggests that the location accuracy of ground-based radio navigation can vary several hundred meters. For short distances, this error could skew the travel time measurement significantly. For example, for a link of 1,000 m (3,281 ft), an error of plus of minus 30 m (100 ft) could skew the travel time measurement by 20 percent.

Validate the accuracy of your data by performing simultaneous floating vehicle runs while collecting data with a probe vehicle. This can indicate whether or not the system is estimating travel times accurately. This can also verify that the system is tracking the probe vehicle on the intended link and not on an adjacent roadway.

Ensure proper installation of in-vehicle equipment. The power setting of the in-vehicle transmitter and the mounting of the in-vehicle antenna can affect the system's ability to accurately locate a vehicle. Equipment is typically installed by the service provider.

5.3.5 Previous Experience

Ground-based radio navigation technology is typically used in the commercial sector for commercial fleet management services. Two studies by public research institutions have investigated the ability of ground-based radio navigation technologies to collect accurate travel time data. The Center for Urban Transportation Research (CUTR) of the University of South Florida and the Texas Transportation Institute investigated the accuracy of the technology. Their findings are presented in this section.

Center for Urban Transportation Research Study

A study by the Center for Urban Transportation Research (CUTR) at the University of South Florida conducted 30 validation runs during a 113-day period with test vehicles. The study tested differences in speed output from the ground-based radio navigation system and the test vehicles. Study results suggested a mean difference of 1.72 km/h ± 1.38 mph (1.07 km/h ± 0.86 mph) with 95 percent level of confidence (28). Differences between the ground-based navigation speed values and the manually collected speed values followed a normal distribution.

The CUTR staff configured the proprietary software to generate an electronic report of vehicle location, time, date, and speed data in an ASCII text format. They also developed software to analyze the data and report on average speeds. The proprietary software saved the day's vehicle location data in a new file for that particular day. For a four-month period, the system logged over 4,400 trips which required about 150 megabytes of computer storage space (26).

Drivers were recruited for the study and were given an incentive of a vehicle maintenance service. This service is offered to all qualifying south Florida motorists vehicle breakdown service and stolen vehicle recovery for $300 per month, however, it was offered free-of-charge to study participants.

Texas Transportation Institute Study, Houston, Texas

A Texas Transportation Institute (TTI) study in Houston evaluated ground-based radio navigation accuracy based on its ability to locate a stationary probe vehicle in a high-density urban environment, locate a stationary probe vehicle along the periphery of the service area, and locate a moving probe vehicle (29). The location measurements were referenced to a point of known latitude and longitude.

Outside the central business district (CBD), the ground-based navigation technique located probe vehicles to within 30 m (98 ft) in 61 percent of all attempts. This satisfies the nominal global positioning system (GPS) accuracy of 30 m (98 ft). In the CBD, 26 percent of measurements were within 30 m (98 ft), as validated by differential GPS. Ninety-three percent of all measurements in the CBD and non-CBD areas were within 100 m (330 ft), and 43 percent of all measurements were within 30 m (98 ft). The range of vehicle location measurements was between one and 785 m (2,580 ft) from the reference point.

The average difference between the ground-based measurement and differential GPS measurement in CBD areas was about 56 m (180 ft) with a standard deviation of about 70 m (230 ft). In non-CBD areas, the difference was about 34 m (110 ft) with a standard deviation of about 90 m (295 ft). The test results suggested that little difference existed in the accuracy of ground-based navigation location measurements within the service area and near the periphery of the service area. In testing the accuracy of ground-based radio navigation at locating moving probe vehicles, the study suggested that accuracy remained relatively constant at speeds between zero and 80 km/h (50 mph).

5.4 Cellular Phone Tracking

Cellular telephones have been used to collect travel time data in several major U.S. cities. Two data collection techniques have been applied using cellular technology: cellular telephone reporting and cellular geolocating. The cellular reporting method has been utilized in the Boston, Massachusetts Smart Route System and as a pilot study to the Houston, Texas AVI traffic monitoring system. Cellular geolocating has been tested only once through an operational test in the Washington, D.C. area. Both methods are described, although this section emphasizes the cellular geolocation technique.

Cellular Telephone Reporting

Cellular reporting requires volunteer drivers to call a central facility when they pass checkpoints along the freeway. An operator at the central control facility records each driver's identification, location, and time (15). By monitoring the time between successive telephone calls, the travel time or travel speed between reporting locations may be determined (30).

The technique is useful for reporting a qualitative assessment of current traffic conditions (e.g., stop-and-go, bumper-to-bumper, free flow) and for collecting travel time data during delays or accidents since the incident can be visually confirmed. However, probe vehicle drivers often miss checkpoints or fail to report locations at the proper times. Further, travel times can be skewed by one or two minutes and can vary between individual probe vehicle reports. The cellular telephone reporting method is recommended for short-term studies with low accuracy requirements.

Cellular Geolocation

The cellular geolocating methodology discreetly tracks cellular telephone calls to collect travel time data and monitor freeway conditions. Use of cellular geolocating is limited to one operational test conducted in the Washington, D.C. area. This operational test was sponsored by private and public organizations under the project name Cellular APplied to ITS Tracking And Location (CAPITAL). The technique utilizes an existing cellular telephone network, vehicle locating devices, and a central control facility to collect travel time data. All vehicles equipped with cellular telephones are potential probe vehicles. The system automatically detects cellular telephone call initiations and locates the respective probe vehicle within a few seconds. Vehicles are not actively sought by the system, but vehicles initiating cellular phone calls are monitored by the system.

An illustration of cellular geolocation communications are shown in Figure 5-8. The system searches for vehicles initiating cellular telephone calls by processing the cellular reverse control channels (phone-to-tower) and identifying when a mobile telephone transmits a message. Simultaneously, the forward control channel (tower-to-phone) is examined for the assignment of communication channels to mobile telephones. The geolocating component of the system identifies when a cellular telephone transmits a call initiation message. Direction finding equipment located at multiple sites in the area determine the origin of the telephone call.

The probe vehicles' locations are determined by a combination of lines of bearing and time difference of arrival calculations by the direction finding system to geolocate a vehicle (31). Intersecting lines of bearing are used to triangulate probe vehicles' locations. Time-difference-of-arrival method calculates the location based on signal propagation times between the vehicle and nearby cellular towers. The system has the capability of tracking the cellular activity of probe vehicles even as the vehicle passes through multiple cell sites and when the telephone call switches cellular channels.

The probe vehicle's location is passed to a traffic information module. By repeating the process every five to seven seconds, sufficient data are generated in 30 to 50 seconds to provide an accurate estimate of the probe vehicle's velocity (32).

Future Direction of Cellular Technology

The Federal Communications Commission (FCC) has adopted a Report and Order which develops rules to govern the implementation of Enhanced 911 (E911) calls for wireless, or cellular, services (33). The ruling requires cellular providers to be capable of relaying the location of the base station or cell site receiving a 911 call to an appropriate Public Safety Answering Point (PSAP). They will also be required to provide the location of the mobile station, or cellular telephone, to the PSAP in two dimensions with an accuracy within a 125 m (410 ft) radius in 67 percent of all instances. These changes are to be implemented over the next several years.

The locations of the cellular telephones will be determined by time difference of arrival techniques (34). These are the techniques used in cellular geolocating methods to collect travel time data. These changes in the cellular industry can affect the feasibility of collecting travel time data cost-effectively since similar service can be used for other codes, such as 555.

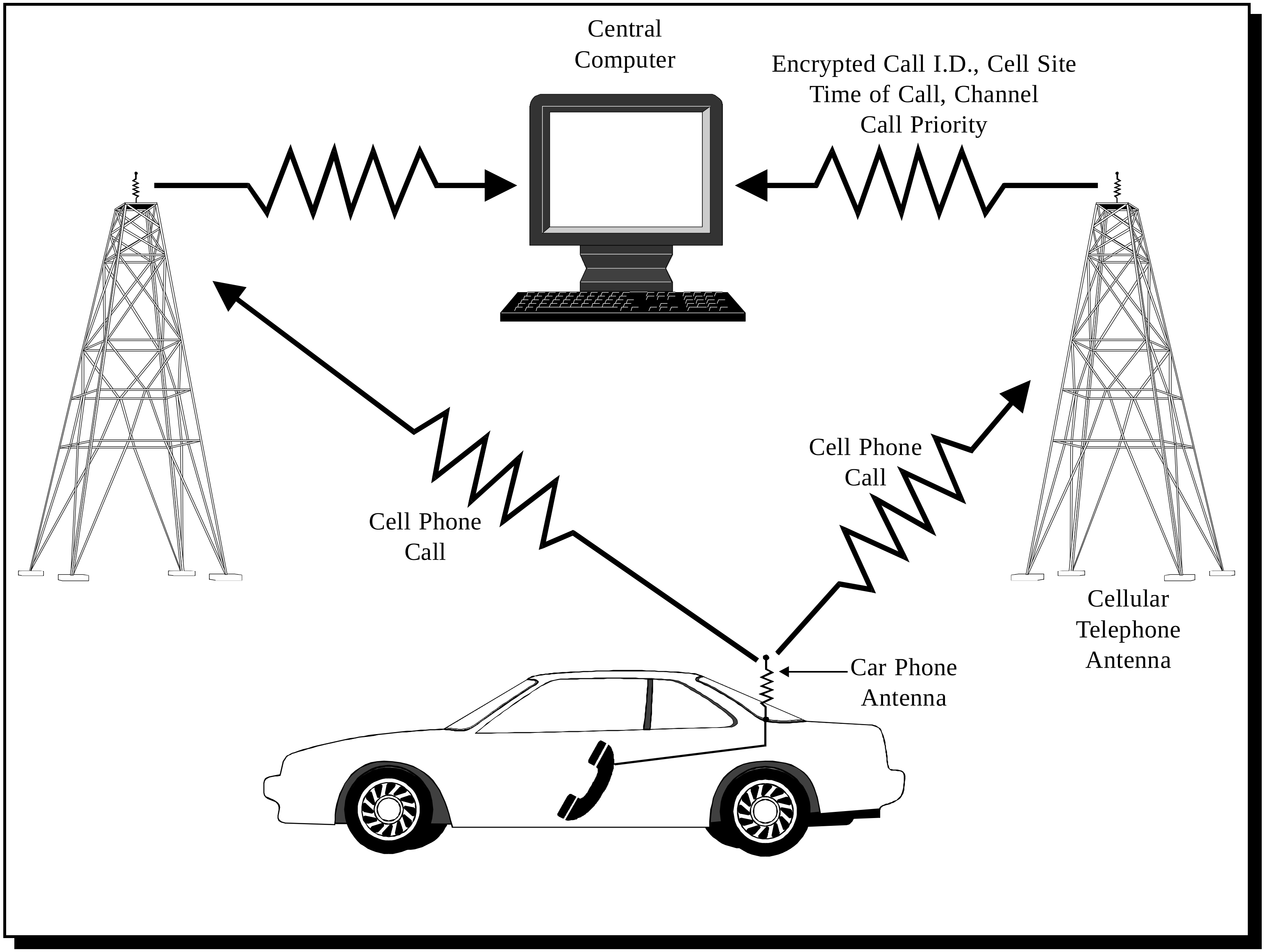


Figure 5-8. Cellular Geolocation Communications

5.4.1 Advantages and Disadvantages

The **advantages** of cellular geolocating for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Driver recruitment not necessary** - The system utilizes samples from the existing population of vehicles equipped with cellular telephones. It is not necessary to recruit volunteers or designate personnel to collect data.

- **No in-vehicle equipment to install.**

- **Large potential sample** - Studies have suggested that cellular telephone use increases as congestion increases (35). As cellular telephone ownership increases, the number of potential probe vehicles increases.

The **disadvantages** of cellular geolocating for travel time collection (relative to other ITS probe vehicle techniques) are:

- **Experimental technology** - To date, cellular geolocating has been tested only once through the CAPITAL Operational Test in the Washington, D.C. area.

- **Privacy issues** - The nature of cellular geolocating may offend persons concerned that cellular telephone calls may be monitored and that their vehicles may be tracked.

- **Infrastructure dependent** - Since the system is constrained by existing cellular infrastructure, it is impractical to readily modify the study area for data collection. Extending or adjusting the study area requires moving cellular towers and/or the geolocating equipment. Study is limited to links within the coverage area of the cellular network.

- **Cellular phone use dependent** - Travel time data collection can break down during periods of low cellular telephone use.

- **Low accuracy** - Testing of this technology has suggested it is adequate for determining if a probe vehicle is on a particular road, however, it was shown to be accurate at estimating travel times in 20 percent of all instances. Often geolocating a vehicle's position is impaired by topography and line of sight barriers. Testing of the geolocating system reported average geolocating errors between 107 to 650 meters (351 to 2,133 feet) (31).

- **Potentially biased sample -** Sample is biased towards motorists which have and use cellular telephones. There may exist personality aspects of cellular phone users which may or may not affect driving behavior.

5.4.2 Cost and Equipment Requirements

All information on the cost of equipment for cellular geolocation is based on the findings of the CAPITAL Operational Test. Much of the total system cost was attributed to research and development of the technology. The CAPITAL study assessed the capital and installation investments; however, operational and maintenance costs are not known.

A cellular geolocating system requires the presence of a cellular infrastructure of cellular towers and vehicles equipped with cellular telephones. It is also necessary to establish permission to utilize the cellular network from the cellular system operator. The CAPITAL system consisted of two primary components that were necessary to collect probe vehicle data: a geolocation component and a traffic information component.

Geolocation Component

This component is responsible for recognizing cellular calls, monitoring call switching between cellular channels, prioritizing calls, and calculating geolocations, lines of bearing, and time-differences-of-arrivals for signals. The geolocation component contains specially designed arrays of antennas and electronic equipment which monitor call initiation signals from cellular phones to provide directions from the cell towers to the telephone locations. Signals from multiple towers are used to derive latitude and longitude of phone locations. Within the geolocation component are several subcomponents, which utilize various equipment to perform the necessary geolocation component tasks. The three sub-components and the respective equipment requirements are (31):

- **Transmission Alert System** - This element was responsible for identifying new calls and alerting the geolocation control system with call data. This subcomponent costs approximately $200,000 per unit, including equipment and installation costs (31). The Transmission Alert System requires:

    - Wideband cellular call receivers; and
    - Digital narrowband cellular call receivers.

- **Geolocation Control System** - This subcomponent is needed for calculating the geolocation of probe vehicles. The installation and equipment costs for this subcomponent are approximately $150,000 (31). It requires personal computers.

- **Direction Finding System** - This subcomponent is necessary for calculating the lines of bearing and time differences in arrival of signals. One such system cost $310,000 (31). The directional finding equipment are installed at existing cellular tower sites. Some electronic equipment must be housed in an environmentally controlled structure. It requires:

- eight-element antennas;
- math processor;
- Octal digital receiver;
- synchronized system clocks (accurate within 100 nanosecond); and
- GPS receiver.

Traffic Information Component

A central facility receives all data and processes them into useful travel information. This component is responsible for determining the locations, travel times, and speeds of probe vehicles.

5.4.3 System Design Considerations

This section describes several issues which can affect the quality of travel time data. These are potentially problematic issues which should be addressed in the design of a cellular geolocation system.

Insufficient signal strengths - Cellular service providers are required to use certain amounts of the radio spectrum. A provider's usable radio spectrum is divided into channels. Each call requires two channels: receive and transmit. In areas with large cellular service demands, the cellular network is designed to reuse channels by managing the power and direction of signals from the tower to the telephone and managing the power of the signal from the telephone to the tower. An ideal power level is strong enough for calls to be interpreted yet weak enough to prevent cross-talking between phones in different cells using the same channel. Reusing channels is more critical as cellular telephone use increases. Additional antennas are installed and signal strength is further weakened to avoid cross-talk.

Insufficient tower infrastructure - If signal strength is too weak, the existing tower infrastructure may be insufficient to interpret signals for accurate geolocation. The installation of additional tower sites may be necessary. The use of directional antennas, as opposed to omni-directional, restricts the ability to interpret signals, as well.

Observe legal issues - Use of this type system should comply with the Telephone Disclosure and Disputes Resolution Act and Federal Communications Commission (FCC) Docket 93-1 which implements that act given that the phone call receiving equipment is used under contract with the federal government and in concert with licensed cellular providers.

Observe privacy issues - The identity of telephone numbers or electronic serial numbers should not be accessible to anyone operating the system. Voice conversations should not be monitored. The system can function even if transmissions are assigned random or encrypted identification numbers which do not allow specific caller information to be obtained.

5.4.4 Data Reduction and Quality Control

This section describes several problems which can occur when geolocating vehicles. These problems have been encountered in previous cellular geolocation studies (35). Data collection of quality travel time data can be impaired by:

- **Bridge structures** - it can be difficult to interpret the altitude of a probe vehicle to determine if it is atop or underneath a bridge structure.

- **Adjacent roadways** - the location system does not have pin-point accuracy, and it can be difficult to determine if vehicles are on adjacent roadways to the freeway.

- **Roadside emergency phones** - it is necessary to identify if a call is coming from a roadside emergency phone or roadside cellular phone.

5.4.5 Previous Experience

The CAPITAL operational test in the Washington, D.C. area is the only identifiable case of cellular geolocation. This section presents the data flow involved in the data collection process and also more detailed descriptions of design considerations.

In the CAPITAL project, the travel time data collection process involved four basic steps:

1. Call initiation received by geolocation control system and a message sent to the traffic information center containing the following data:

    - time stamp;
    - encrypted ID number;
    - latitude and longitude;
    - information on whether or not a 911 call was initiated;
    - flag to indicate if call was initiated within boundary of study;
    - sector number indicating specific area of cell tower; and
    - confidence factor of the latitude/longitude accuracy.

2. Traffic information center receives data. If data is within bounds, it is not discarded and the system determines if the phone is on a mapped traffic link. If the phone is not on a map link, monitoring is stopped. If the vehicle is on a map link, additional geolocating is performed to more accurately determine its location. At this point,

direction is unknown, however, it is determined that the vehicle is on either directional link.

3. The geolocation system performs additional geolocation functions and the received data are sent to the traffic information system.

4. When the traffic information system receives the second geolocation data package on an identified phone ID, the direction of the vehicle is determined and the travel speed is calculated based on the vehicle's travel time between two locations on the link.

Static geolocation accuracy tests were conducted at several locations of known latitude and longitude (U.S. Geological Survey markers and state benchmarks). With a sample of 24 static test locations tested during four days, the errors in geolocation accuracy fell between 107 m (350 ft) and 649 m (2,130 ft) (31). Differential GPS units served as a comparison to the cellular geolocation results. The error was defined as the difference between the cellular geolocation data and the differential GPS data. The poor location accuracy was attributed to topographic interference and line-of-sight problems.

The system's ability to estimate average speeds was tested in a comparison of system output to test vehicle output. Study results suggested that reasonable speeds were estimated only 20 percent of the time (31). Reasonable speeds were those determined similar to results from test vehicle runs.

University of Technology, Sydney, Australia

A recent study at the University of Technology in Sydney, Australia evaluated the use of Mobile Telephone Positioning Systems (MTPS) for vehicle positioning applications (36). The study presents the potential for success of MTPS in the future. More specifically, the study compares MTPS with the more common application of using the global positioning system (GPS) for positional information. The study describes how positional information can be supplied through a MTPS system for use in applications such as fleet operations, occasional location determination, congestion detection, navigation and route guidance, and geographic referencing.

The study makes the following points when comparing GPS and MTPS (36).

- Cellular networks in major cities operate hundreds of base stations, often with many different frequencies. This gives a far greater diversity than GPS, which may only have at best four to eight satellites visible at a particular location. This diversity is particularly important in urban areas where occlusion and multipath can seriously degrade GPS positioning.

- Many ITS applications require a communication facility as well as positioning. An MTPS can provide both facilities in a single system.

- Although the cost of GPS receivers is dropping, it will always be a finite cost. A positioning facility can be added to some cellular communication systems with no changes to the mobile handsets and relatively minor changes to the network.

Although the study presents these benefits of using MTPS, the study also discusses issues that are associated with the successful development of an MTPS. These complications include interference from co-channels or adjacent channels, equipment delay time, signal occlusion, and geometrical errors to name a few. Ingenuity and careful design are suggested to help alleviate these concerns. Privacy and security, two non-technical but equally important issues, are also discussed by the authors as critical considerations in the development and implementation of such a system.

With increasing bandwidth availability of new cellular systems, the authors expect an increase in the use of MTPS. The authors also note the anticipated increases in accuracy and coverage of MTPS in the future.

5.5 Global Positioning System

The Global Positioning System (GPS) was originally developed by the Department of Defense for the tracking of military ships, aircraft, and ground vehicles. Signals are sent from the 24 satellites orbiting the earth at 20,120 km (12,500 mi) (see Figure 3-1). These signals can be utilized to monitor location, direction, and speed anywhere in the world. A consumer market has quickly developed for many civil, commercial, and research applications of GPS technology including recreational (e.g., backpacking, boating), maritime shipping, international air traffic management, and vehicle navigation. The location and navigation advantages of GPS have found many uses in the transportation profession (37).

The reader is encouraged to review Section 3.3.1 for additional discussion of GPS including its operation and increasing usage. Chapter Three discussed the use of GPS as a test vehicle data collection technique. The test vehicle technique involves collecting data with the aid of an instrumented vehicle capable of receiving GPS signals for position information. The data are collected in the field and then downloaded to a central data storage computer after data collection is complete. The global positioning system may also be used to collect real-time positional information from vehicles. Real-time probe vehicle location information is then sent to a central control center for vehicle monitoring. The equipment requirements and set-up are similar to the test-vehicle needs, however, there is the additional need for a two-way communication link (i.e., the probe vehicle must be able to return a signal to a control center).

IMPORTANT ☞ GPS used for ITS probe vehicles has several distinct differences from GPS applications for test vehicles. These include the on-board logging capability, driving behaviors of instrumented vehicles, and accuracy levels.

Currently, there are many applications of automatic vehicle location (AVL) that employ GPS for vehicle tracking in real-time. These include emergency service vehicles (e.g., police, fire, ambulance), rental cars, commercial fleets, taxis, and transit vehicles (38). GPS has proven to be a valuable tracking mechanism for these vehicles to a central location. For emergency service vehicles, dispatching the nearest vehicles is facilitated with this technology. Further, for taxi and transit applications, the technology allows users to know the location of buses and the estimated time of arrival at bus-stops and transit centers. Many transit agencies throughout the country utilize GPS of bus fleets. One of the largest instrumented systems is the Dallas Area Rapid Transit (DART) that has approximately 1,200 buses instrumented with GPS receivers for AVL (39). These probe vehicles that are already instrumented and operating on the transportation system provide a unique opportunity for the collection of travel time data.

This section of the handbook describes the use of GPS for ITS probe vehicle applications to take advantage of vehicles that are already instrumented and operating on the transportation system for the collection of travel time information.

5.5.1 Advantages and Disadvantages

The GPS probe vehicle technique has the following **advantages** (as compared to other ITS probe vehicle methods):

- Relatively low operating cost after initial installation.
- Provides detailed data that are collected continuously along the entire travel time corridor.
- GPS is becoming increasingly available as a consumer product.
- Data collection is automated.

The GPS probe vehicle technique has the following **disadvantages**:

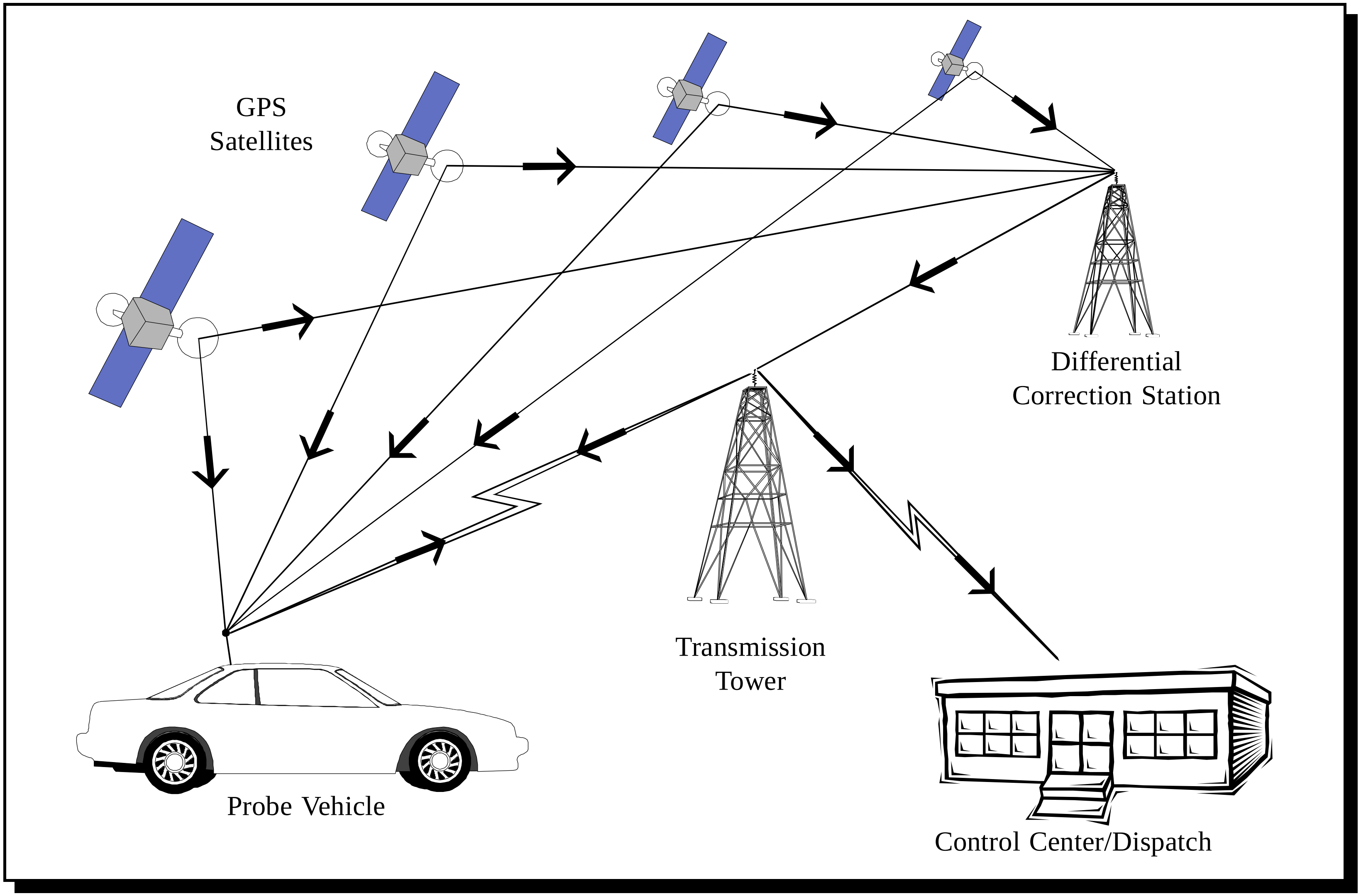
- Privacy issues become a concern when installing GPS receivers on the vehicles of volunteer motorists.
- Signals can be lost in urban areas due to large buildings, trees, tunnels, or parking garages.
- It is difficult to have consistency between drivers due to differences in driving behavior.
- It is necessary to install two-way communication systems to send and receive signals.
- Relatively high installation cost. Since the hardware investment may be initially purchased for a purpose other than travel time data collection, coordination is necessary with the agency that installed the system.

5.5.2 Cost and Equipment Requirements

This section will detail the personnel, hardware, and software needs necessary when considering the use of GPS as a probe vehicle travel time data collection method. Figure 5-9 shows a typical configuration for a GPS-based probe vehicle system. The following sequence of events describes the process of providing positional communications for a probe vehicle as shown in Figure 5-9 (40). This is how existing AVL systems utilizing GPS operate.

- The GPS receiver on the vehicle uses signals from a minimum of four satellites to determine the vehicle's position;
- This information is stored and "waits" to be processed with differential correction data;
- The differential information is then calculated at the differential correction station;
- The differential information is sent by a DGPS beacon transmitter a digital repeater on a transmission tower;
- The digital repeater then transmits this data forward to a second tower or to all probe vehicles within its range;
- The probe vehicles receive the data through a digital radio transceiver that receives and transmits data to and from the transmission tower through the digital repeater. The data are translated by the modem and passed along to the GPS receiver;
- The stored GPS information is then corrected with the differential data;
- The corrected location data is passed to the modem, translated to digital data package, and transmitted back to a digital repeater located on a transmission tower; and
- The digital repeater then verifies the data transmission, and either transmits the data to the control center or relays the data to the next transmission tower until it reaches the control center.

Dispatch and vehicle monitoring personnel would be located in the control center. It is this individual's responsibility to monitor the vehicle location information for bus operations. For emergency vehicles, the dispatcher would be responsible for ensuring that the most appropriate vehicle (generally closest) responds to the emergency.



Source: adapted from reference (40).

Figure 5-9. Typical Configuration for Satellite-Based Probe Vehicle System

For the system shown in Figure 5-9 to operate, there are several equipment needs and considerations. This figure only shows the system required to get the information to the control center. Once the data are received by the control center, reduction of the data into travel time information may also be necessary depending upon the system design.

Considerations When Using GPS Probe Vehicles

There are several additional considerations when using GPS probe vehicles for travel time data collection. As shown in Figure 5-9, the largest difference is the communication that must take place between the probe vehicle back to the control center. Many technologies exist for the transmission of position information. These include conventional radio, cellular systems, satellites, beacons and signposts, and paging systems. Conventional radio is the most commonly used communications system for AVL systems throughout the world (41).

IMPORTANT ☞ The amount of bandwidth for these systems is limited, therefore, it can often be difficult and expensive to obtain a frequency for communications, especially in large cities.

The coverage area is another consideration when developing a system, and the larger the area that must be covered with the system, the more towers that may be necessary to cover the area. It is also necessary to consider what tower will be used for setting up the antenna for the system (i.e., will a private transmission tower be used or will a locally-owned tower be rented). Further, when a conventional radio channel is desired for communication, an application for a license from the Federal Communications Commission (FCC) is required (38).

IMPORTANT ☞ The speed at which data must travel through the communication system is also an important consideration when determining the required system hardware.

For GPS probe vehicle systems, a modem combined with a conventional radio bandwidth converts data to an analog signal for transmission. Generally, modems for mobile radio operations use 2400, 4800, or 9600 baud. Some applications of GPS that are currently in use for buses or emergency vehicles, utilize several radio channels to provide more capacity. Some configurations called Time Division Multiple Access (TDMA) schemes allow for the transmission of data in a given time slot. Time slots can actually be assigned for smaller fleets. Conversely, large fleets may operate with a communication system in which the time slots are dynamically assigned to optimize the effective use of the transmissions. Generally, GPS probe vehicle systems will provide location information about a vehicle every 10 seconds (38).

Table 5-6 presents estimates of hardware, software, and personnel costs for using GPS for probe vehicle data collection. Ranges of costs are provided. Equipment costs and user fees are included except for some components that have a large variation in cost. The hardware, software, and personnel costs are further described below.

GPS Receiver - Required to process GPS signal information from the earth-orbiting satellites.

Radio Frequency (RF) Modem - Allows for two-way communication of positional information to the control center.

GPS Antenna - Required to receive GPS signals from the earth-orbiting satellites.

Differential Correction Receiver (if desired) - Receives signals from GPS satellites to determine corrected positional information. This information may be transmitted from a U.S. Coast Guard beacon or a private service (see differential signal service fee).

Differential Signal Service Fee - Fee charged for the use of the FM signal or other frequency band for obtaining differential correction information. Fees vary based upon the desired positional accuracy.

DGPS Antenna - Receives signals from the differential correction station.

Transmission Tower Costs - Towers are necessary for radio transmissions. Transmission tower costs vary depending upon several factors. If cable must be installed to the transmission tower, related costs will be incurred. The height of the transmission tower also becomes a factor. Rental fees may vary depending upon the ownership of the transmission tower. Service fees for radio frequency use can also vary. One factor that affects this cost is the availability of bandwidth.

Digital Repeater - Aids in sending radio signals from tower to tower (if necessary) and to probe vehicles or the control center.

Portable Computer - Necessary for positional data collection in the field.

Power Supply - Necessary for both the GPS receiver and the portable computer. Generally supplied through the cigarette lighter or a battery pack.

Data Storage Computer - Generally located back at the office or in the control center. This computer is used to store the positional data obtained in the field.

Table 5-6. Estimated Costs for GPS Probe Vehicle System

Equipment/Personnel	Unit Cost (1998 dollars)
Hardware	
GPS Receiver	\$300 to \$500
RF Modem	\$600 to \$700
GPS Antenna	\$100 to \$150
Differential Correction Receiver (Hardware) FM Signal Service Fee: Sub-meter accuracy 2-5 meter accuracy 10-meter accuracy	\$350 to \$500 \$700 to \$800 per year per unit \$200 to \$300 per year per unit \$70 to \$100 per year per unit
DGPS Antenna	\$30 to \$70
Transmission Tower Costs	Varies
Digital Repeater	\$1,000 to \$1,200
Portable Computer (Laptop/Palmtop)	\$1,500 to \$3,000/\$500 to \$700
Data Storage Computer	\$2,000 to \$3,000
Software	
GIS and Compatible Analyses Software	\$2,500 to \$3,500
Personnel	
Control Center Personnel	\$6 to \$10 per hour
Supervision and Management	Varies

GIS and Compatible Analyses Software - GIS software allows the positional data to be viewed on a roadway network. Compatible analyses software, generally within the GIS framework, allow for the calculation of desired measures (e.g., travel time, average speed).

Control Center Personnel - These individuals ensure that the probe vehicles are being monitored accurately in real-time on the GIS interface at the control center.

Supervision and Management - This includes management personnel who monitor the overall data collection, data reduction, and analysis of the system operation. This cost varies depending upon the size of the system, computer automation, and study needs.

There are several additional system designs to consider when developing a system for probe vehicle travel time data collection. Software packages are an integral part of the success of such a system. The GIS interface must be able to receive the GPS information in real-time for processing. Additional "packaged" software is available that is capable of placing a vehicle identifier on the vehicle that is being shown traveling in real-time on the computer screen at the control center. Analysis software is available that is able to compute real-time travel time information for predetermined routes.

In addition, dead reckoning systems may also be considered in the system design. Dead reckoning provides a means for vehicle locations to be determined when GPS satellite signals are not being received (i.e., they are being blocked by trees or buildings).

5.5.3 Data Reduction and Quality Control

Several steps are necessary in the reduction of GPS probe vehicle data:

1. **Insert necessary information into the base map at the control center**. There are several input requirements to the base map that are necessary to perform reduction of the data. These inputs include street names, cross-street information, and reference (checkpoint) locations for travel time segment definition.

2. **Convert raw GPS data from the field to a trackable vehicle on the control center screen**. With the aid of GIS software applications and related analyses software, the raw data obtained from the GPS receiver in the field is converted to a moving and labeled vehicle on the control center monitor.

3. **Adjust collected data to match base map (if desired)**. Apply map matching or appropriate software algorithms that "snap" the real-time data to the base map information.

4. **Compute travel time for a given segment**. The GIS software is capable of being programmed to calculate the travel time of vehicles traveling through predetermined links. In addition, the data being brought into the control center can be backed up for quality control and further analyses purposes. It should be noted that segment definition has caused some dispute in the profession as some professionals say that segments should be defined as a given length, while others argue that segment length should be defined in units of time since GPS data is obtained in real-time.

UNKNOWN
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There are differing opinions about whether to aggregate GPS data into predefined roadway segments. If data storage is available, all GPS data points should be stored to permit "dynamic segmentation."

Quality Control Considerations

Several checks can be performed to ensure that adequate results are being achieved. The following quality control considerations can be applied in the data reduction stages.

- **Monitoring the course of vehicles being tracked**. The individual responsible for monitoring the vehicles being tracked in real-time can monitor the vehicles on the computer monitor. If the general routes of the labeled vehicles on the computer monitor are known, the individual watching the screen can recognize inconsistencies in vehicle trajectories if the vehicles appear to be off course.

- **Selected "spot checks" of real-time data being collected**. Although the data are being collected and transferred in real-time, data log files can be stored. These files can be randomly selected to evaluate the travel time information they are producing. Based upon the historical operation of the predetermined segments, the analyst can use this technique to determine if the results are accurate.

- **Evaluation of locations where GPS signals are temporarily lost**. In the absence of a dead-reckoning system, the path of a traveling vehicle may be lost when GPS signals are blocked. During periods when the GPS signal is lost, with or without the use dead-reckoning, it may be beneficial to check the travel time results provided for these routes.

5.5.4 Previous Experience

ADVANCE, Illinois Department of Transportation (IDOT)

The Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE) was undertaken in 1991 as a test of dynamic in-vehicle route guidance. The partners in the project include the Illinois Department of Transportation (IDOT), the Federal Highway Administration (FHWA), the American Automobile Association (AAA), Motorola, and the Illinois Universities Transportation Research Consortium (Northwestern University and the University of Illinois at Chicago) with the cooperation of the Argonne National Laboratory. ADVANCE has established a very useful Internet site where complete reports on every aspect of the project are available for the use of those interested (43).

Real-time route guidance information was provided to individuals to evaluate if they would alter their trip to avoid congestion and reduce the travel time of their trip. Many technologies were utilized in the study to provide the real-time information to travelers. These included the global positioning system (GPS), wireless communications, CD-ROM map storage, and data fusion. The Transportation Information Center (TIC) was the core of the system receiving information from several sources, processing the data, and transmitting it to users (43).

As a major effort to establish an in-vehicle real-time route guidance system to travelers, many lessons were learned from the ADVANCE project that are applicable to the establishment of travel time data collection utilizing GPS technology. The study used radio frequency communications between the vehicles and the control center through modems in the vehicles for transmission of information. Differential correction information was also supplied to the vehicles for correction of the GPS information. Although two channels were established for communication purposes, there were times when the system could become slowed down because the modems in the vehicles could not handle real time info as fast as it could be sent.

Privacy issues, such as the concern that "big brother" will be watching, is always a concern when the instrumentation of private vehicles is being considered. Although ADVANCE used project cars donated by car manufacturers, the original intent was the instrumentation of private vehicles. Therefore, experience was gained in soliciting and preparing motorists for driving the test vehicles. Very limited advertisement of the project was performed to solicit individuals to apply for the instrumentation of their vehicle for the study. However, there was a large response by individuals to test the new route guidance system. Selection criteria were established to aid in determining which individuals would be allowed to participate in the study. The participants were told of all aspects of the project including a briefing that included presentations from the partners in the project to provide information about the project including a user's manual, quick reference guide, brochure on the ADVANCE project, and other related materials (44).

The ADVANCE project team did have a modem identification number in the database used for analysis. It would be possible to match this identification number with the individual driver with some work. Therefore, the team disclosed this information to interested drivers to ensure they were not concerned about the fact that they could be monitored. The full disclosure of exactly how the system was being used and the data being collected aided in the understanding, comfort, and interest of the volunteers in the study.

Predetermined segment links in the 780 sq-km (300 sq-mi) ranged from 0.016 to 3.2 km (0.01 to 2.0 mi) in length. Predetermined routes were also used in the study, and data collection was performed over different times of the day. Computer processing was provided in each vehicle with the aid of on-board computers. Therefore, the computation of travel time information on the predetermined links was performed in the vehicle and transmitted to the TIC. This reduced the computation that was necessary at the TIC. The TIC would then gather the information from probe vehicles and loop data from the transportation system and process it every five minutes. This information was then reported back to the probe vehicles.

The project team was satisfied with the ADVANCE in-vehicle route guidance effort. The use of the GPS technology was advantageous because it provided minimal overhead costs. This is because of the simple fact that it relied on another trustable system since GPS is maintained closely by the Department of Defense. For these reasons, ADVANCE has provided many beneficial lessons for application of future probe vehicle applications for travel time data collection.

Texas Transportation Institute (TTI), College Station, Texas

The objective of one current research effort within the Texas A&M Intelligent Transportation System (ITS) Research Center of Excellence (RCE) is to develop, demonstrate, and evaluate an AVL/GPS system for rural transit. Brazos Transit District (BTD) was selected as the transit agency to be instrumented with the AVL system. BTD presently covers 23 counties in the State of Texas. It is the largest provider of rural transit services in the state (40,42). This example is provided to describe to the reader an AVL system that is being studied in an effort to aid the practitioner in realizing the potential use of existing probe vehicle systems such as AVL for travel time data collection. The reader is encouraged to review Figure 5-9 for an illustration of such a system.

GPS technology was selected for use in determining vehicle positioning. The system was set-up similarly to Figure 5-9 except the probe vehicle was a transit vehicle. The communications system included the use of two-way UHF radio bandwidth operating in the 460 MHZ range. Differential correction improved vehicle position data from a range of 10 to 15 meters (33 to 49 feet) to 2 to 5 meters (7 to 16 feet). Real-time information is sent from the transit vehicle to a transmission tower and back to the Texas Transportation Institute (TTI) and the BTD dispatch office (42).

This study has provided several lessons learned. The first noteworthy lesson is the concern that “big brother” is watching over the transit driver. Many of the bus drivers were concerned that they were being monitored when they were traveling with the GPS receivers in the vehicle. The drivers would often shut off the GPS receivers prior to driving their scheduled route. Although the drivers were educated thoroughly that they were not being monitored while on their scheduled routes, this was a common problem. The problem could be resolved to some degree by ensuring that the GPS receiver was hidden from the view of the driver (42). Keeping the equipment out-of-sight of the driver is a valuable lesson for consideration when GPS equipment may be installed on private vehicles as well. Even when the drivers are informed that they are not being monitored, if the driver is unable to see the unit, they may not be reminded or become tempted to disconnect it. Of course, the driver must be informed that the equipment is on-board the vehicle.

The study has found that the GPS technology is applicable and effective for rural transit applications as well. Since the location was rural, there was no difficulty in obtaining RF bandwidth for the two-way communications. The critical factor is the rental fee and equipment cost for the transmission tower(s). For this study, it was necessary to install the antenna and cable into the tower for communications. As discussed previously, the coverage area will determine the number and spacing of transmission towers. One tower was able to adequately cover the Brazos County area in this study. Continued tasks in the study are evaluating the range of the transmission of the tower.

The study also describes the software packages that were used to integrate digital maps, mapping software, relational database capabilities, and GPS real-time information into one system. Further, the software that was used can track individual buses with unique identification tags (42). In addition, analysis packages compatible to the GIS software can be created that can compute real-time travel time and speed information based on the incoming real-time GPS information for predetermined links.

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See Chapter 3 for further GPS references related to test vehicle techniques.