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Automatic Vehicle Location for Measurements of Corridor Level-of-Service: Statewide Feasibility Analysis

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Automatic Vehicle Location
for Measurement of
Corridor Level-of-Service:
Statewide Feasibility Analysis

Final Report

Prepared for the
Florida Department of Transportation
by the
Center for Urban Transportation Research
College of Engineering
University of South Florida

December 1994
## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Executive Summary</td>
<td>1</td>
</tr>
<tr>
<td>II. Purpose</td>
<td>3</td>
</tr>
<tr>
<td>III. The Miami Experiment</td>
<td>4</td>
</tr>
<tr>
<td>IV. Other U.S. Applications</td>
<td>10</td>
</tr>
<tr>
<td>TravTek</td>
<td>12</td>
</tr>
<tr>
<td>ADVANCE</td>
<td>14</td>
</tr>
<tr>
<td>TRANSCOM</td>
<td>16</td>
</tr>
<tr>
<td>Houston AVI</td>
<td>17</td>
</tr>
<tr>
<td>Illinois Tollway</td>
<td>19</td>
</tr>
<tr>
<td>CAPITAL</td>
<td>19</td>
</tr>
<tr>
<td>Summary</td>
<td>21</td>
</tr>
<tr>
<td>V. Comparing Two Methods of Data Collection</td>
<td>24</td>
</tr>
<tr>
<td>VI. Comparing Two Methods of LOS Calculation</td>
<td>27</td>
</tr>
<tr>
<td>Variability of Speeds</td>
<td>28</td>
</tr>
<tr>
<td>LOS Calculation</td>
<td>28</td>
</tr>
<tr>
<td>LOS Calculation on Other Roadway Segments</td>
<td>31</td>
</tr>
<tr>
<td>LOS Calculation on Exceptional Roadways</td>
<td>32</td>
</tr>
<tr>
<td>VII. Other Possible Applications in Transportation Operations</td>
<td>35</td>
</tr>
<tr>
<td>Signal Modifications</td>
<td>35</td>
</tr>
<tr>
<td>Incident Detection and Response Techniques</td>
<td>36</td>
</tr>
<tr>
<td>Travel Time Contour Maps</td>
<td>37</td>
</tr>
<tr>
<td>Detour Routing</td>
<td>37</td>
</tr>
<tr>
<td>Speeds Adjustment Factors</td>
<td>38</td>
</tr>
<tr>
<td>Link Speed Calibration for FSUTMS</td>
<td>38</td>
</tr>
<tr>
<td>Dynamic Traveler Information</td>
<td>39</td>
</tr>
<tr>
<td>Goods Movement</td>
<td>40</td>
</tr>
<tr>
<td>Operational Changes in Transit</td>
<td>40</td>
</tr>
<tr>
<td>Special Event Traffic Handling</td>
<td>41</td>
</tr>
<tr>
<td>Impact of Weather on Travel Speeds</td>
<td>41</td>
</tr>
<tr>
<td>Safe Travel Through Work Zones</td>
<td>41</td>
</tr>
<tr>
<td>&quot;Mayday&quot; Alerts Along Isolated and Rural Areas</td>
<td>42</td>
</tr>
<tr>
<td>Summary</td>
<td>42</td>
</tr>
</tbody>
</table>
VIII. Statewide AVL Feasibility

- Dead Reckoning and Map Matching
- Signpost
- Ground-Based Radio-Navigation
- LORAN-C
- Global Positioning Systems (GPS)
- Differential GPS (DGPS)
- Cellular Phones
- Vehicle Location Data Collected by Fleet Operators
- Summary

IX. Conclusion

Bibliography

Appendix A: List of Contacts

Appendix B: Vehicle Trips Used in LOS Calculation
# List of Tables

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Differences Between Observed and Calculated Travel Speed: Confidence Interval Statistics</th>
<th>Page 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2</td>
<td>Summary of U.S. Applications of AVL in Transportation Planning</td>
<td>Page 22</td>
</tr>
<tr>
<td>Table 3</td>
<td>Levels of Service for Basic Freeway Sections</td>
<td>Page 30</td>
</tr>
<tr>
<td>Table 4</td>
<td>Level-of-Service Calculation on South Dixie Highway Btw. 27th Ave. and 17th Ave.</td>
<td>Page 33</td>
</tr>
<tr>
<td>Table 5</td>
<td>Generalized Peak Hour Directional Volumes for Florida's Urbanized Areas: Level-of-Service Criteria</td>
<td>Page 34</td>
</tr>
<tr>
<td>Table 6</td>
<td>AVL Positioning Technologies</td>
<td>Page 47</td>
</tr>
</tbody>
</table>

# List of Figures

| Figure 1  | Difference Between Observed and Calculated Travel Speed Method 1 - Histogram and Normal Distribution | Page 8  |
| Figure 2  | Difference Between Observed and Calculated Travel Speed Method 2 - Histogram and Normal Distribution | Page 9  |
| Figure 3  | Cost of Data Collection Using Conventional and AVL Methods                                 | Page 26|
| Figure 4  | Sample Road Segment - Dolphin Expressway                                                 | Page 29|
I. EXECUTIVE SUMMARY

Florida Department of Transportation has asked the Center for Urban Transportation Research (CUTR) to investigate the statewide feasibility of using automatic vehicle location (AVL) to measure roadway performance. This project builds on the findings from "The Miami Experiment," a previous operational test of ground-based AVL which CUTR conducted for the City of Miami.

The findings of this research are:

• The Miami Experiment is the only IVHS project which currently uses data gathered by automatic vehicle location for transportation planning purposes.

• Using AVL to collect average travel speed can be less expensive than conventional travel-time studies if there are sufficient number of average speed measurements to amortize the fixed costs.

• Average travel speed data collected by the AVL can be used to calculate level-of-service on roadway segments.

• The vehicle location and travel speed information collected by AVL systems is useful in several other transportation planning applications other than level-of-service determination.

• Satellite-based global positioning systems (GPS) offers the best AVL technology option if FDOT wanted to repeat a data gathering experiment similar to the one conducted in Miami in other areas of the state.

• Using vehicle location data gathered by Florida trucking companies whose vehicles are equipped with AVL transponders appears to be a viable option for gathering average travel speeds in the state’s urban areas.

Through the course of this study, CUTR has identified additional areas of research which would be beneficial to FDOT to have investigated in the future:
• Conduct a data gathering experiment similar to the experiment conducted in the City of Miami, in Broward or Palm Beach County, using the ground-based radio-navigation AVL technology available there. Driver recruitment will be specifically targeted at achieving coverage of all congested corridors in the study area in the peak direction during the peak period.

• Conduct a data gathering experiment similar to the experiment conducted in the City of Miami, in an urban or rural area in Florida outside of Dade, Broward or Palm Beach counties, using satellite-based global positioning system (GPS) technology to locate vehicles.

• Further investigate the suitability of vehicle location data gathered by Florida trucking companies whose vehicles are equipped with AVL transponders. Details such as the number of equipped vehicles, routes taken by equipped vehicles and format of vehicle location data need to be specified.
II. PURPOSE

On June 16, 1994, the Florida Department of Transportation entered into a contract with the University of South Florida on behalf of the Center for Urban Transportation Research to investigate the statewide feasibility of using automatic vehicle location to measure roadway performance. This project builds on the findings from a previous operational test of ground-based AVL which CUTR conducted for the City of Miami.

In March of 1994, the City of Miami contracted with the CUTR to conduct a field operational test of the use of ground-based AVL technology to measure vehicle operating speeds on seventeen of the City's transportation corridors. CUTR set up a data gathering experiment that used data compiled from AVL transponders installed in the vehicles of 25 volunteer drivers. The technology vendor of the AVL system was AirTouch Teletrac, which supplied the equipment at minimal cost. The "Miami Experiment" ran from April 25 to August 15, 1994, recording over 4,400 vehicle trips.

This Final Report is a compilation of technical memoranda performed for Tasks #1, #3 and #4 of this project. Other instances of the use of AVL in transportation planning applications are explored, and differences between the cost of AVL and traditional methodologies of collecting data on vehicle operating speeds are compared. This Final Report compares two methods of level-of-service (LOS) calculation on one sample roadway: (1) the Florida Department of Transportation estimation using traffic volume counts input into the Generalized Tables of FDOT's 1992 Florida Highway System Plan: Level-of-Service Manual, and (2) average travel speeds based on the location data gathered by the AVL system.

Several other applications of AVL technology to gather information (besides average travel speeds) useful to transportation professionals are identified. Finally, this report assesses the various AVL technologies in terms of coverage, cost and positional accuracy. This assessment is performed in order to evaluate the feasibility of conducting a similar operational test of automatic vehicle location technology in other areas of the state.
III. THE MIAMI EXPERIMENT

In March of 1994, the City of Miami contracted with CUTR to set up a field operational test of the use of AVL to measure vehicle operating speeds on the city's seventeen transportation corridors. CUTR set up a data gathering experiment which used AVL units installed in the vehicles of 25 volunteer drivers who traversed the City road network as part of their normal daily commute. The technology vendor of the AVL system was AirTouch Teletrac, which donated the equipment at minimal cost. The "Miami Experiment" ran from April 25 to August 15, 1994, recording over 4,400 vehicle trips.

The AirTouch Teletrac AVL system locates vehicles using a positional technology called ground-based radio-navigation, (a.k.a. "terrestrial radio-navigation" and "signal trilateration.") When using this type of positioning technology, the AVL vendor sets up a network of receiving antennas throughout a metropolitan area. Each probe vehicle is equipped with a device (a "transponder") which broadcasts a radio-frequency (RF) signal to all nearby antennas. Based on the time it takes for the signal to travel from the transponder to the antenna, the system can determine the distance between the vehicle and each antenna. If the signal was received by three or more antennas, the vehicle's position can be uniquely determined.

Ground-based radio-navigation uses a less sophisticated technology than the satellite-based global positioning system (GPS) and, consequently, has less precision. Ground-based radio-navigation AVL systems are among the least expensive AVL systems for the user. However, since constructing the necessary infrastructure (i.e. receiving antennae) requires significant financial investment on the part of the AVL vendor, these systems are usually only available in dense urban areas with large market potential. AirTouch Teletrac has radio-navigation AVL systems operating in Los Angeles, Chicago, Detroit, Dallas/Ft. Worth, Houston and south Florida. The south Florida AirTouch Teletrac system can locate a vehicle anywhere in Dade, Broward and Palm Beach counties.

The company guarantees the accuracy of its AVL system to the nearest 150 feet. Due to south Florida's relatively flat terrain, the accuracy of the south Florida system is generally within the nearest 50 feet. AVL systems which use augmented global positioning systems technology are generally accurate to within 16 feet.
The City of Miami was responsible for recruiting volunteer drivers. Many of the drivers were City of Miami or Dade County employees who live on the periphery of the city and commute daily to downtown, thus providing coverage of 5 of the 17 corridors in the peak direction during the peak period. Incentives to participate in the experiment included receiving a free vehicle breakdown and stolen vehicle recovery service for which many south Floridians pay a one-time $300 per vehicle start-up fee plus a monthly $10 service charge. Disincentives included a certain loss of privacy which left some potential volunteers unwilling to make the tradeoff. CUTR, AirTouch Teletrac and the City assured volunteer drivers that their vehicle would be tracked only by its assigned number, and that all vehicle location information would be used only for the stated purposes of the study. (How other IVHS projects handle the privacy issue will be addressed in Section IV. Other U.S. Applications.)

AirTouch Teletrac donated use of its AVL system to the City for minimal cost. CUTR paid AirTouch Teletrac $2,500 for installation and removal of the 25 transponders, for a workstation using FleetDirector™ software for 120 days. AirTouch charges its commercial customers $7,500 plus $250 per month for a similar equipment rental and services.

The AirTouch Teletrac AVL system polled the vehicles for their locations every 30 seconds when the vehicles were on and every 5 minutes when the vehicles were off. The vehicle locations were recorded by the AirTouch Teletrac fleet management software FleetDirector™ at a workstation located at the City of Miami offices. FleetDirector™ wrote the vehicle location data to a file for a 5-hour period in the morning and a 5-hour period in the afternoon peak periods on weekdays, plus a 4-hour period on Saturday. Every week City of Miami staff sent the latest copies of the files to CUTR in Tampa for analysis.

CUTR researchers wrote two software programs to analyze the vehicle location data. One program, SPEED.EXE, averages travel speed for an entire trip, from the moment the vehicle ignition is turned on to the moment the vehicle ignition is turned off. The other, SEGMENT.EXE, correlates the geographic coordinates of road segments to the vehicle’s recorded locations to derive average speeds for particular segments of the commute trip.
Both programs used two methods of calculating average travel speed. Method 1 averages the speed values output by Fleet Director™'s over the entire trip. Method 2 averages values for distance traveled between location readings. The FleetDirector™ software has never before been used to track vehicles to calculate their speed.

To determine if the system was producing valid data, CUTR researchers established a validation process to compare the observed values for average speed over a vehicle trip to values calculated by CUTR’s data analysis software. City of Miami transportation planning staff, who were driving equipped vehicles, recorded the starting and ending times of their trips, plus the distance traveled as recorded by their car odometers.

Comparing the data collected automatically and manually for the 30 validation runs conducting during the 113-day data gathering period, the mean difference was -1.07 mph for method 1 and +1.07 mph for method 2. Assuming that the differences between observed and calculated values follow a normal distribution pattern the 95% confidence intervals for the differences can be calculated, as shown in Table 1.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Difference: Method 1</th>
<th>Difference: Method 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-1.07 mph</td>
<td>+1.07 mph</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.91 mph</td>
<td>2.41 mph</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.71 mph</td>
<td>0.44 mph</td>
</tr>
<tr>
<td>95% Confidence Interval</td>
<td>-1.07 mph ± 1.40 mph</td>
<td>+1.07 mph ± 0.86 mph</td>
</tr>
</tbody>
</table>

Figures 1 and 2 show a histogram of the differences for the 30 validation runs compared with a normal distribution (commonly called a "bell" curve.) Since Method 2 is the more accurate method with a smaller standard error, its normal distribution pattern more closely resembles a bell shape. Since Method 2 is the more accurate, it is used in
Designing and implementing the data gathering experiment was Phase II of a three-phased project CUTR is performing for the City of Miami. In Phase III, it is anticipated that CUTR will use the data analysis software to compute average travel speeds for each of Miami's seventeen corridors in the peak direction during the peak period. The City Planning Division then has the option of using those computed average speeds to assist in its determination of corridor level-of-service.
Figure 1
Difference Between Observed and Calculated Travel Speed - Method 1
Histogram and Normal "Bell" Curve

Average Values
Figure 2
Difference Between Observed and Calculated Travel Speed - Method 2
Histogram and Normal "Bell" Curve

Average Values

Frequency

-3.77 -3.33 -2.89 -2.45 -2.01 -1.57 -1.13 -0.69 -0.25 0.19 0.63 1.07 1.51 1.95 2.39 2.83 3.27 3.71 4.15 4.59 5.03 5.47 5.91

HISTOGRAM
BELL CURVE
IV. OTHER U.S. APPLICATIONS

The term "Intelligent Vehicle Highway Systems" is used to describe projects which apply advanced technologies to improve the efficiency and capacity of transportation systems. Passage of the Intermodal Surface Transportation and Efficiency Act (ISTEA) of 1991, with its emphasis on IVHS, focused national attention on this emerging field. The ISTEA brought more than exposure to IVHS, authorizing $660 million over six years for research and operational test of IVHS technologies. During the Clinton Administration, Congress has appropriated $90 million for IVHS in addition to the ISTEA funding. States and regional authorities have followed the federal lead, also providing funding for numerous IVHS projects.

There are many ways in which advanced technologies can be applied to transportation. The two types of IVHS projects discussed in this report are Advanced Traveler Information Systems and Electronic Toll and Traffic Management. Advanced Traveler Information Systems (ATIS) projects use a variety of technologies to communicate real-time, up-to-the-minute traffic information to travelers using a variety of modes. Electronic Toll and Traffic Management (ETTM) projects enable drivers to pay tolls without stopping their cars at toll plazas, where payment is accomplished using wireless communications between a transponder ("tag") inside vehicle and an antenna installed at the roadside. Automatic vehicle identification (AVI) is the technology which makes ETC systems possible. Since passage of ISTEA in 1991, the U.S. Department of Transportation has funded over 15 ATIS-type projects. Twelve toll authorities in the U.S. have installed and eight agencies are planning to install ETC systems on their toll roads.

While the term ETC describes the use of AVI technology for more efficient collection of tolls, without any action required by the driver or toll collector, ETC is the foundation of electronic toll and traffic management (ETTM) systems. ETTM uses AVI technology not only for toll collection, but also for more broad-based traffic management purposes, such as the projects described in this report.

1 The term "Intelligent Vehicle Highway Systems (IVHS)" is slowly being replaced with "Intelligent Transportation Systems (ITS)". The transition is being made so that the name encompasses all aspects of transportation, including freight and transit, not just passenger vehicles and highways. This report uses "IVHS" throughout the text, although "ITS" may be substituted.
Another type of IVHS application is Automatic Vehicle Location (AVL). AVL is a means of continuously monitoring the location of vehicles in a road network. Typically, vehicles are equipped with a transponder, the size of a video cassette tape, which transmits a radio-frequency (RF) signal to a central location at regular intervals. AVL systems are being used by all kinds of customers in all kinds of applications around the world. Delivery companies use AVL to plan the most efficient dispatch of their fleet vehicles. Transit agencies use AVL in conjunction with information displays to inform passengers when the next bus will actually arrive, as opposed to when it is scheduled to arrive. Paratransit operators use AVL to log the distance traveled by Medicaid patients, and later use this data when applying for reimbursement from the state. Private citizens can even subscribe to an AVL service which will instantly dispatch a tow-truck to their car in the event of a breakdown or to recover their car if it is stolen.

Vendors can set up AVL systems with relatively little investment in infrastructure, and consequently little need for federal or state financial support. GPS World magazine, The IVHS Index, IVHS America’s APTS Vendor Catalogue and the Federal Transit Administration’s APTS State of the Art report list over two dozen vendors of AVL systems using a variety of different positioning technologies: dead-reckoning, map matching, LORAN-C, ground-based radio navigation and global positioning systems (GPS). Eleven transit agencies in North America have installed and fifteen agencies are planning to install AVL systems on their buses. (For more detailed information on Florida transit agencies’ use of AVL, see Section VII. Statewide Feasibility.)

Of the travel information and electronic toll collection projects in the United States, the following are the only projects which use AVL to gather traffic information:

- TravTek - Orlando, FL
- ADVANCE Project - Chicago, IL
- TRANSCOM Project ”E-ZPass” - New York City, NY
- Illinois Tollway ”I-Pass” - Chicago, IL
- Houston AVI - Houston, TX
- CAPITAL - Washington, DC
Each of these projects is profiled, providing information on the following issues:

- Who are the participants?
- What kind of positioning technology does the AVL system use?
- What kind of vehicles are being used as probes?
- How many probe vehicles/drivers are expected to participate?
- How are probe vehicles/drivers recruited?
- How are drivers' concerns about privacy addressed?
- What kind of data is collected?
- What kind of analysis is performed on the data and what is its output?
- Who will use the data and for what purpose?
- What is the current status of the project?
- How much does the entire data collection system cost?

A summary of these profiles appears in Table 2.

TravTek

When IVHS was first conceptualized in the late 1980's, the most popular application of technology to transportation was route guidance, (also called "in-vehicle navigation"). For a route guidance system, special computers are installed in vehicles. The computers contain map databases and have the ability to locate their own position. A driver inputs his desired destination, and the in-vehicle unit gives him directions on how to get there. Development of in-vehicle navigation units has progressed considerably in recent years. Oldsmobile will begin selling in-vehicle navigation units as an option in their Eighty Eight LSS performance sedan in California at the end of 1994.

Dynamic route guidance takes the navigation task one step further by receiving information about current traffic conditions on the road network. In giving directions to the driver, the in-vehicle unit allows the driver to avoid areas and roads with heavy traffic congestion. TravTek, a one-year operational test of IVHS technology conducted in Orlando, FL from March 1993 to March 1994, employed dynamic route guidance. TravTek obtained its information on current traffic conditions from loop detectors embedded in Orlando-area roads, video surveillance cameras installed along Interstate-4
and other stationary sensors. This information was collected and processed at a Traffic Information Center (TIC) staffed by the City of Orlando traffic engineers.

The American Automobile Association, Federal Highway Administration, Florida Department of Transportation, General Motors Corporation and the City of Orlando made financial or in-kind contributions to the test.

Each of the 100 vehicles TravTek was equipped with a computer, touch-screen display, map database on CD-ROM, on-board compass and odometer and global positioning system (GPS) receiver. The positioning system used a combination of GPS, dead-reckoning and map-matching to locate the vehicles.

Volunteer drivers, most of whom were tourists visiting Orlando rented the vehicles through Avis rental car agency at the Orlando International Airport. The American Automobile Association promoted the program to its members nationwide. Over 6,000 volunteer drivers had the opportunity to drive TravTek vehicles. Privacy concerns were not explicitly addressed as part of the project.

Using electronic maps from both Etak, Inc. and NavTech as a base, the TravTek project maintained an estimated travel time for each link in the road network. The map database covered a 1,200-square-mile area of west central Florida, maintaining travel times on over 1,400 links. Traffic management software estimated link travel times from a variety of dynamic sources: surveillance cameras installed on Interstate-4, incident reports logged by the traffic information center operators, the city’s traffic signal control software, the city’s road maintenance and construction schedules, and probe data from the TravTek vehicles themselves. If no dynamic information on a link’s travel time was available, the system used a historical estimate based on the time of day and day of week.

Each TravTek vehicle sent a report every minute to the TIC. Each probe report contained the vehicle ID number, latitude and longitude of the vehicle’s position, speed and direction, and the last three links traveled and their travel time.
Software developed by Farradyne Systems, Inc. fused data from these various sources into one travel time estimate for each link. Probe vehicles accounted for only about 10% of the estimated travel times for links on the road network. The city’s traffic signal control software accounted for 28% of the estimates. The system relied on historical information for 56% of its estimates. The remaining 6% of estimates were based on anecdotal reports of incidents reported by TIC staff.

The dynamic estimates for link travel times were broadcast to the TravTek vehicles, in one-minute intervals, so that the navigation software could use this data in its calculation of the quickest route to each driver’s destination. The dynamic link travel times were not used for any other purpose. Since the conclusion of the TravTek project in March 1993, software developers from Farradyne Systems have not trained Orlando city traffic engineers on use of the traffic management software, which still resides in the Orlando TIC. Although data from the TravTek probe vehicles is no longer being collected, data from other sources could still be used to estimate vehicle travel speeds on road segments. The City of Orlando is in negotiation with Farradyne on this matter.

TravTek was among the first large-scale field operational test of IVHS technologies. The total project cost was $8 million.

ADVANCE

Like TravTek, the ADVANCE project (Advanced Driver and Vehicle Advisory Navigation Concept) tests dynamic route guidance, but will rely much more heavily on data from vehicle probes.

The Federal Highway Administration, Illinois Department of Transportation (IDOT), Northwestern University, University of Illinois at Chicago, and Motorola are participating in the project. Financial support for ADVANCE is provided by the FHWA, IDOT and other private commercial interests.

Each probe vehicle will be equipped with a Mobile Navigation Assistant (MNA). The MNA is composed of a computer, CD-ROM, driver interface, wheel speed sensors, a compass and global positioning system (GPS) receiver. Probe vehicles will report travel
time for road links as they traverse the test area. The data will be collected by on-board equipment then transmitted to a Traffic Information Center (TIC). Information is also collected from loop detectors embedded in various parts of the roadway, plus anecdotal reports from drivers via cellular phone.

The project test area will encompass a 36-square-mile area of Schaumburg, Illinois, an affluent suburb of Chicago, which happens to house Motorola’s Corporate Headquarters. The project is intended to eventually include 5,000 private and commercial vehicles. Driver recruitment began in August 1994. The ADVANCE projects sent press releases to local, regional and community newspapers. ADVANCE staff held promotions of the volunteer program (including a demonstration of the route guidance technology) in local shopping malls. Direct mail advertisements were also distributed to area residents. The ADVANCE project set up a hotline to handle telephone inquiries Mondays through Saturdays. Northwestern University developed criteria to select among willing volunteers; the criteria will ensure that adequate coverage of the test area is achieved, and that the pool of selected drivers is a representative sample of area drivers. Each vehicle will be assigned a unique identification number, and vehicles will be tracked using only that number to maintain drivers' privacy.

The basic data set will be transmitted via radio-frequency signals, including vehicle number, location and time of each reading. The MNA also records the driver's interaction with the system, so that statistics can be compiled on the options selected, route taken, and frequency of use. Argonne National Laboratories will analyze this type of data.

ADVANCE has received substantial funding as part of the annual U.S. Department of Transportation appropriations process, with over $10 million earmarked for the project to date. The estimated total project cost is $52 million. At the conclusion of the test, IDOT will be left with state-of-the-art traffic surveillance equipment and Motorola will have developed an in-vehicle navigation unit which it can sell as an after-market product on passenger and commercial vehicles.
TRANSCOM

Unlike the ADVANCE project or the Miami Experiment, TRANSCOM will use technology developed and implemented for another purpose - electronic toll collection - to collect traffic information using probe vehicles. In electronic toll collection, vehicles are equipped with a transponder which communicates only when they pass near antennas installed at specific points along the roadway. This kind of system is called Automatic Vehicle Identification (AVI) to distinguish it from Automatic Vehicle Location (AVL) in which transponders constantly transmit their location to a central receiving point. Drivers who use the toll road regularly purchase or lease a transponder, plus make a deposit on a payment account of future tolls. Transponders can cost anywhere from $10 to $40. When the driver passes through a toll plaza, the AVI system automatically decrements the driver's pre-paid toll account balance. In this way, the driver pays his toll without having to stop at the toll gate. Toll authorities are turning to electronic toll collection as a way of reducing traffic congestion near toll plazas, and make traveling along those roads more appealing to drivers.

Seven toll authorities in Pennsylvania, New York and New Jersey have agreed to install the same ETTM system for all of their roadways. (Two thirds of all toll revenue collected in the United States is collected in these three states.) The coalition calls itself the Inter-Agency Group (IAG) and the electronic toll collection project "E-ZPass." The IAG recently selected Mark IV Industries as the ETTM vendor. However, prior to Mark IV's selection, two member agencies installed an ETTM system from another vendor - Amtech - for an initial feasibility test. The TRANSCOM project will use the 40,000 drivers who have purchased ETTM transponders as probe vehicles to determine traffic conditions on the New York State Thruway and Garden State Parkway.

When the system is operational, software developed by Farradyne, Systems, Inc. will randomly select a vehicle at a toll plaza equipped with an E-ZPass transponder. The vehicle will be assigned a random tracking code and tracked using RF antennas along the two participating toll roads. Tracking code, location and time will then be recorded and used for real-time incident detection. Farradyne has developed software to analyze vehicle location data, report on possible traffic incidents, and notify emergency response agencies.
TRANSCOM member agencies are currently installing roadside antennas. The system should be operational by October of 1994. However, according to the TRANSCOM office, the committee has no plans to make the travel time data available for transportation planning purposes.

Like ADVANCE and TravTek, TRANSCOM has received substantial federal funding and earmarking through the annual USDOT appropriations process. The estimated project cost for the ETTM portion of TRANSCOM is just over $2 million.

Houston AVI

The Texas Department of Transportation (TxDOT) is involved in two projects involving volunteer drivers as probe vehicles in the traffic network. The first project, entitled the "Cellular Telephone Demonstration Project," used calls from selected drivers via cellular telephone to monitor traffic conditions on a Houston-area travel corridor composed of parallel roads north of downtown Houston - the Hardy Toll Road, I-45 and State Road 59. Two hundred probe vehicle drivers were selected from a pool of drivers who use those routes as part of their normal daily commute. Volunteers received a cellular telephone free of charge. In return, drivers were required to call a central telephone number and report on traffic conditions and incidents that affected traffic flow. As a volunteer driver passed a designated receiving station, he was required to call the TxDOT control center and report the station number and identification number of his vehicle. The operator would record the information, plus the time and date of the call, entering it into a travel time analysis database. Relaying the information and entering it into the database took 10 to 15 seconds per call. Each probe vehicle made between 10 and 12 reports per day.

Software written by the Southwest Regional Transportation Center of Texas A&M University analyzed the database and gave a report of current travel conditions on the selected roadways. TxDOT used the current travel conditions to update its network of eight variable message signs and to instruct its incident response teams. The information was also faxed to the broadcast studios of the three Houston-area traffic advisory services.
The second Houston-area project, like the TRANSCOM and Illinois Tollway projects, uses ETTM patrons as vehicle probes. TxDOT is installing readers at 2 to 4 mile intervals on over 120 miles of freeways and 100 miles of reversible HOV lanes. Installation of readers will be conducted in three phases. Phases I and II cover I-10, I-45, SR 59 and SR 290, and are nearly complete. Phase III will cover I-610 (the beltway) and the Sam Houston Tollway. Amtech Corporation of Dallas, TX was selected by Harris County Toll Authority as the ETC vendor.

The 32,000 drivers who have already purchased ETTM tags will not be used because of privacy concerns. TxDOT has issued 1,000 transponders to drivers who travel I-10, SR 290 and I-45 as part of their normal daily commute. TxDOT plans to issue tags to an additional 3,200 volunteers. A clause in the volunteers’ contract specifically states that the vehicle’s travel time data will not be given to police for the purpose of issuing tickets to drivers. The Metro Transit Authority has also installed transponders on buses which use exclusive high-occupancy vehicle (HOV) lanes in these corridors.

As each vehicle passes a reader antenna, information on the location, time and vehicle identification number is collected at the roadside by the reader and transmitted by radio to nearby field stations equipped with modems and telephone lines. The information is then sent by telephone to the Central Control Facility (CCF). Using software similar to what was used in the Cellular Telephone Demonstration Project, the travel time database is analyzed to produce a summary of current travel conditions. The information is then distributed to various users of real-time information.

In an article published in ITE Journal, two of the Houston AVI project managers allude to using the travel time data to measure roadway performance, however no firm plans exist to date. "Since so many measures of effectiveness rely on the impact of speed and travel times, it is important to have the most reliable data available." stated Steve Levine of TxDOT and William McCasland of the Texas Transportation Institute.

The cost of Phase I installation was $2 million. The cost of the other two installation Phases are unknown.
Along with the TRANSCOM committee and Harris County Toll Authority, the Illinois State Toll Highway Authority has plans to use patrons of an electronic toll collection system as traffic probe vehicles. In June 1994, the Illinois State Toll Highway Authority announced that it had selected AT/Comm as the technology vendor and Science Applications International Corporation (SAIC) as the systems integrator for an ETTM system - called "I-Pass" for over 200 lane miles of toll roads near Chicago. The Authority selected AT/Comm after the vendor had successfully completed a test of the technology on the North-South Tollway, involving 2,500 patrons. The contract requires installation of ETTM equipment on the entire North-South Tollway and on the central portion of the Tri-State Tollway, and involves the distribution over 10,000 electronic toll collection tags.

Following their interest in IVHS with the ADVANCE project, the Illinois DOT has reached an agreement with the Illinois State Tollway Authority that will allow IDOT to use motorists' I-Pass tags as traffic probes. IDOT is negotiating with SAIC to design the hardware and software to determine average vehicle travel speeds on the tollway, based on data obtained by the ETTM readers at the toll plazas.

SAIC's contract for the entire electronic toll collection system is worth about $12 million. The cost of the vehicle travel speed data collection portion of SAIC's work is unknown.

**CAPITAL**

Instead of ground-based radio-frequency signals, global positioning systems, or automatic vehicle identification, the CAPITAL project will test the use of ordinary cellular telephones as AVL transponders. Engineering Research Associates (ERA), a subsidiary of E-Systems based-in Tampa, is developing a technology - called E-CAPS - which essentially turns any cellular telephone switched on to receive calls into an AVL transponder, and any vehicle with such a phone in it into a traffic probe. Bell Atlantic Mobile Systems is the vendor of cellular telephone services which has donated the use of its network for the test. The Maryland State Highway Administration and the Virginia
The Department of Transportation (VDOT) will make use of the traffic data gathered from probe vehicles.

The test will gather traffic data on portions of three interstate highways in Virginia and Maryland outside of Washington, D.C.: I-395, I-495 (the beltway), and I-270, plus some arterial streets which cross the interstates. The operational test is scheduled to begin in the summer of 1995 and last 90 days.

Farradyne Systems is developing software to convert the vehicle location data to real-time traffic data on traffic speed and incident locations. Farradyne will maintain a database of traffic conditions and make available a graphic display of current traffic conditions to VDOT and the Maryland State Highway Administration via a phone line and modem connection. Lines representing the highways on an electronic map will change color to indicate average vehicle speeds. The maps will also highlight the locations of incidents the system has detected.

Privacy concerns are an important issue, since all of the Washington, D.C.'s estimated 117,000 cellular telephone users are potential probe vehicles, but none have explicitly given their consent to participate in the test. ERA also provided documentation that their system will not violate the federal Telephone Disclosure and Disputes Resolution Act, which prohibits the use of scanners that intercept cellular telephone calls. The E-CAPS system only detects the location of the cellular phone, not the content of the calls. Vehicles are identified by number randomly assigned at the time the E-CAPS system locates the vehicle, not by the cellular phone’s telephone number or serial number.

In addition to providing a traffic information database to transportation officials, Farradyne is also developing hardware and software to deliver the database over the cellular telephone communications network to special receivers installed in vehicles. Approximately 10 vehicles belonging to a delivery service that has agreed to participate in the test will receive Farradyne’s traffic information via cellular telephone modems and laptop computers.

The Maryland State Highway Administration is currently installing new software that will use data from multiple sources - in-pavement loop detectors, overhead radar detectors...
and the cellular telephone probes - to monitor traffic flow in real-time. The agency expects this system to be operational in two to three years.

Federal Highway Administration is contributing $5.5 million of the total estimated project cost of $7.1 million, which includes equipment installation, software development, and actual day-to-day expenses of conducting the test.

Summary

Five federally- and regionally-funded projects in the United States projects are using vehicles as probes to collect information on traffic conditions. In each of these five projects, the data is used to deliver real-time traffic information to various users: state department of transportation, incident management and emergency response teams, radio and TV traffic information broadcasters, and even drivers with dynamic route guidance units installed in their vehicles. Only the Houston AVI project has considered the possibility of using the data collected to measure level-of-service. The Miami Experiment is the only IVHS project in the United States to use data gathered from an AVL system for transportation planning purposes.
Table 2
Summary of U.S. Applications of AVL in Transportation Planning

<table>
<thead>
<tr>
<th>Project</th>
<th>Participants</th>
<th>AVL Positioning Technology</th>
<th>Number of Probe Vehicles</th>
<th>Data Collected</th>
<th>Purpose of Data Collection</th>
<th>Current Status</th>
<th>Total Project Cost</th>
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<td>TravTek</td>
<td>• AAA</td>
<td>GPS</td>
<td>100</td>
<td>• surveillance video</td>
<td>• dynamic route guidance</td>
<td>Project was completed March 1993.</td>
<td>$8 million</td>
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<td>• FHWA</td>
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<td>• incident reports</td>
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<td>• AAA</td>
<td>GPS</td>
<td>5,000</td>
<td>• traffic counts</td>
<td>• dynamic route guidance</td>
<td>Driver recruitment began August 1994.</td>
<td>$52 million</td>
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<td>• AAA</td>
<td>GPS</td>
<td>40,000</td>
<td>• vehicle location data from cars passing through toll plazas</td>
<td>• notify radio stations &amp; emergency response vehicles</td>
<td>System should be operational by 1994.</td>
<td>$2 million</td>
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<tr>
<td>Project</td>
<td>Participants</td>
<td>AVL Positioning Technology</td>
<td>Number of Probe Vehicles</td>
<td>Data Collected</td>
<td>Purpose of Data Collection</td>
<td>Current Status</td>
<td>Total Project Cost</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------------------</td>
<td>----------------------------</td>
<td>--------------------------</td>
<td>-----------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>----------------------------------------------------</td>
<td>----------------------</td>
</tr>
</tbody>
</table>
| Houston AVI Project #2  | • Texas DOT  
• Harris County Toll Authority  
• Texas A&M U. | Signpost (electronic toll collection) | 3,300                    | • vehicle location data from cars passing through toll plazas | • variable message signs  
• notify radio stations | Installation of antennae on 3 of out 5 roadways is nearly complete. | $2 million |
V. COMPARING TWO METHODS OF DATA COLLECTION

The start-up costs of conventional travel-time studies are relatively low, while the day-to-day cost of conducting the tests - paying drivers, vehicle rental, gasoline, etc. - is relatively high. In an estimation of costs of different types of congestion management performance measures, JHK & Associates estimate that the start-up cost to be negligible and the operations cost to be $2 per vehicle mile of data collected.

Start-up costs of the Miami Experiment included the $25,000 contract to CUTR to set up the test, supervise installation of the vehicles and write the necessary data analysis software. Although AirTouch Teletrac provided use of its system at a discount, the company usually charges its commercial customers $300 per vehicle start-up fee plus $10 per vehicle per 30 days rental.

Assuming that vehicles make two daily commute trips on weekdays with an average distance of 12 miles, and assuming the data gathering experiment involved 25 drivers, then either method would be collecting average speed data for 600 vehicle miles of travel per day. The cost per mile of data collection using AirTouch’s AVL system and 25 drivers would be:

\[
\frac{32,500 + \left(\frac{10}{30 \text{ days}}\right)(25 \text{ vehicles})(\text{duration})}{\left(\frac{430 \text{ weeks}}{30 \text{ days/week}}\right)(\frac{2 \text{ commute trips}}{\text{day}})(\frac{12 \text{ miles}}{\text{commute trip}})(25 \text{ vehicles})(\text{duration})}
\]

\[
= \frac{(32,500 + 8.33 \times \text{Duration})}{430 \times \text{Duration}}
\]
This model also assumes that:

- no trips are recorded on weekends (Including weekend trips would decrease the cost of data collection per vehicle mile even further.)
- drivers are volunteers and are not paid.

Figure 3 shows the cost of data collection for conventional and AVL methods versus duration of the data gathering experiment. The cost values for the AVL method was obtained using equation for the Miami Experiment described above. For data gathering periods of longer than 45 days (27,000 vehicle miles), the AVL method is the least expensive. For data gathering periods of almost 1 year, the difference in cost is almost two orders of magnitude.
Figure 3
Cost of Data Collection Using Conventional and AVL Methods

Conventional Method

AVL Method

Duration of Data Gathering Period (Days)
Vehicle Miles of Data Gathering (Thousands of Miles)
VI. COMPARING TWO METHODS OF LOS CALCULATION

The original motivation for conducting the Miami Experiment was to determine the feasibility of using automatic vehicle location to measure average vehicle travel speeds, in order to calculate roadway level-of-service. A key finding in this experiment was the comparison between two methods of calculating level-of-service: standard FDOT planning methodology based on traffic volume, and average travel speeds collected by the AVL system. This section of the report compares the two methods of LOS calculation for one of Miami’s seventeen transportation corridors: Dolphin Expressway (SR 836).

The two methods of LOS calculation are:


- average travel speeds based on the location data gathered by the AVL system.

CUTR research staff wrote two software programs, SPEED.EXE and SEGMENT.EXE to analyze the vehicle location data gathered by the AVL system and report average speed. CUTR used SEGMENT.EXE to calculate the average speeds of vehicles along a 1.69-mile segment of Dolphin Expressway between 57th Avenue and 42nd Avenue. A map of this segment is shown in Figure 4. For a more detailed description of the SEGMENT.EXE software program, see the Final Project Report on the Miami Experiment, entitled Automatic Vehicle Location for Measurement of Corridor Level-of-Service: The Miami Method.

Dade County defines the daily peak period as the average of the two highest peak hours. For purposes of this study, CUTR classified Miami’s peak period as 4:00 pm - 6:00 pm. Since the FDOT Generalized Level-of-Service Tables determine level-of-service based on peak-hour directional volumes and speeds, CUTR averaged the speeds of westbound trips (outbound from the central business district) which occurred from 4:00
pm to 6:00 pm. The AVL system collected data on 29 peak period peak direction trips taken during the 113-day data gathering period from April 25 to August 25, 1994. A list of those trips appears in Appendix B.

Variability of Speeds

Examining the list of vehicle trips used in the AVL-based LOS calculation, it is interesting to note the high degree of variability in vehicle speeds from day to day. This high variability differs from standard deterministic transportation planning models which use average speed values, because those models assume that the average vehicle speed in a given hour on a given roadway will be the same day after day.

The list of average travel speeds in Appendix B contains many values which may look like "outlier" points, i.e. values much higher or much lower than the average. CUTR has retained these values in calculation of an average travel speed over the 113-day test period. By including "outlier" points, the average travel speed value can better represent real-world conditions on that roadway. For example, if incidents frequently occur on a roadway which cause significant delays, that roadway offers inferior service than roadways with the same uncongested speed which are not prone to traffic accidents.

Sample Level-of-Service Calculation

CUTR looked to the 1985 *Highway Capacity Manual* published by the Transportation Research Board as Special Report 209 to determine the level-of-service for Dolphin Expressway based on average vehicle travel speeds collected by the AVL system. Since Dolphin Expressway is a freeway, the average travel speed ranges for various grade levels-of-service, for freeways of various travel design speeds, can be found in Table 3-1 "Levels of Service for Basic Freeway Sections", which is reproduced in this report in Table 3.
Figure 4
Sample Road Segment
Dolphin Expressway
### Table 3
Levels of Service for Basic Freeway Sections

<table>
<thead>
<tr>
<th>LOS</th>
<th>Density (PC/MI/LN)</th>
<th>DS 70 mph Speed (^a) (mph)</th>
<th>DS 70 mph v/c</th>
<th>DS 70 mph MSF (^a) (PCPHPL)</th>
<th>DS 60 mph Speed (^b) (mph)</th>
<th>DS 60 mph v/c</th>
<th>DS 60 mph MSF (^a) (PCPHPL)</th>
<th>DS 50 mph Speed (^b) (mph)</th>
<th>DS 50 mph v/c</th>
<th>DS 50 mph MSF (^a) (PCPHPL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤ 12</td>
<td>≥ 60</td>
<td>0.35</td>
<td>700</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>≤ 20</td>
<td>≥ 57</td>
<td>0.54</td>
<td>1,100</td>
<td>≥ 50</td>
<td>0.49</td>
<td>1,100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>≤ 30</td>
<td>≥ 54</td>
<td>0.77</td>
<td>1,550</td>
<td>≥ 47</td>
<td>0.69</td>
<td>1,400</td>
<td>≥ 43</td>
<td>0.67</td>
<td>1,300</td>
</tr>
<tr>
<td>D</td>
<td>≤ 42</td>
<td>≥ 46</td>
<td>0.93</td>
<td>1,850</td>
<td>≥ 42</td>
<td>0.84</td>
<td>1,700</td>
<td>≥ 40</td>
<td>0.83</td>
<td>1,600</td>
</tr>
<tr>
<td>E</td>
<td>≤ 67</td>
<td>≥ 30</td>
<td>1.00</td>
<td>2,000</td>
<td>≥ 30</td>
<td>1.00</td>
<td>2,000</td>
<td>≥ 28</td>
<td>1.00</td>
<td>1,900</td>
</tr>
<tr>
<td>F</td>
<td>&gt; 67</td>
<td>&lt; 30</td>
<td>c</td>
<td>&lt; 30</td>
<td>c</td>
<td>&lt; 30</td>
<td>c</td>
<td>&lt; 28</td>
<td>c</td>
<td>c</td>
</tr>
</tbody>
</table>

\(^a\) Maximum service flow rate per lane under ideal conditions  
\(^b\) Average travel speed  
\(^c\) Highly variable, unstable  

Note: All values of MSF rounded to nearest 50 pcph.

According to the criteria contained in this table, the level-of-service for this section of Dolphin Expressway based on average travel speeds collected by the automatic vehicle location system is LOS F. The average measured speed was 15.92 miles per hour.

**FDOT Planning Methodology**

The most recent level-of-service estimation computed by the Florida Department of Transportation District 6 for this section of Dolphin Expressway is also LOS F.


**Comparing the Two**

It is important to note that the AVL-based measurement reflects travel that occurred during the 113-day data gathering period between April 25 and August 15, 1994; while the FDOT estimation is based on data from 1991. Moreover, the AVL-based measurement is the average of the two peak hours while the FDOT estimation is for the peak (or worst) 15-minute period.

Furthermore, any assessment of AVL's feasibility as a means of determining LOS should consider the fact that AVL is a direct measurement of travel speed while the FDOT methodology is an estimate of speed based on traffic volumes. This point is especially important when calculating LOS for a future year, since the ability to forecast future traffic volumes is widely established whereas predicting future travel speeds is not.

**LOS Calculation on Other Roadway Segments**

It should be noted that the AVL-based level-of-service calculation shown here is not limited to freeways and can also be performed on segments of frequently traveled arterial streets. CUTR performed an AVL-based calculation for a 1.17-mile segment of South Dixie Highway between 27th Avenue and 17th Avenue. The average travel speed
for the 138 peak period peak direction trips made by the volunteer drivers was 18.21 miles per hour, corresponding to a level-of-service value of LOS D.

In addition, CUTR attempted to perform an AVL-based level-of-service for other arterial streets. However, few of the 25 volunteer drivers who participated in the Miami Experiment traveled arterial streets in the peak direction during the peak period as part of their normal daily commute. For example, a compilation of all peak period, peak direction trips recorded on a 1.42-mile segment of US-1 between NW 79th Street and NW 54th Street revealed fewer than 6 trips, clearly not enough to produce a reliable value for average travel speed. Calculating AVL-based level-of-service on infrequently traveled arterial streets highlights the need for a more systematic process for driver recruitment if FDOT were to repeat an experiment similar to the one conducted in Miami.

LOS Calculation on Exceptional Roadways

The AVL-based method of LOS calculation on South Dixie Highway is particularly important because this arterial has signalization characteristics far different from average conditions in the rest of the state. The long green time for the afternoon outbound movement on South Dixie Highway makes this arterial behave much like a freeway, making it a popular commuter route among the volunteer drivers. The Florida Highway System Plan even singles out South Dixie Highway as an example of a roadway for which "actual data and computer models [i.e. ART_PLAN] should be used in lieu of the Generalized Tables." The particular segment of South Dixie Highway analyzed in this study has three traffic signals, one on either end-point [27th Avenue and 17th Avenue] and one at its intersection with 22th Avenue as well.

As stated above, the average travel speed for the 138 peak period, peak direction trips made by the volunteer drivers during the 1994 data gathering experiment was 18.21 miles per hour, corresponding to a level-of-service value of LOS D. The minimum speed recorded was 6.61 mph and the maximum speed recorded was 34.47 mph.

---

To obtain level-of-service from the average travel speed for South Dixie Highway, CUTR looked to the Generalized Level-of-Service Tables for Urbanized Areas published by FDOT in the *Florida Highway System Plan: Level-of-Service Manual* which is reproduced in this report in Table 5.

In contrast, the Florida Department of Transportation level-of-service estimate taken from the Generalized Tables for this roadway segment is LOS E. This estimate is based on 1991 traffic volume count data.

A recent ART_PLAN analysis of this segment using 1993 traffic volume count data resulted in a congested travel speed value of 28 miles per hour, which corresponds to a level-of-service value of LOS B.

Table 4 compares the three methods of LOS calculation on this roadway segment and the resulting level-of-service.

<table>
<thead>
<tr>
<th>Calculation Method</th>
<th>Input Variables</th>
<th>Peak Period</th>
<th>Year Data Collected</th>
<th>Output Speed</th>
<th>Output LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generalized Tables</td>
<td>volume/capacity</td>
<td>worst 15-minute</td>
<td>1991</td>
<td>15 mph</td>
<td>LOS E</td>
</tr>
<tr>
<td>ART_PLAN</td>
<td>volume/capacity, green time/cycle length, etc.</td>
<td>peak hour</td>
<td>1993</td>
<td>28 mph</td>
<td>LOS B</td>
</tr>
<tr>
<td>AVL</td>
<td>average travel speed</td>
<td>worst 2-hour (4:00-6:00pm)</td>
<td>1994</td>
<td>18 mph</td>
<td>LOS D</td>
</tr>
</tbody>
</table>

This table illustrates the high variability of output LOS given the calculation method used for LOS determination.
Table 5
Generalized Peak Hour Directional Volumes for Florida’s Urbanized Areas

Level-of-Service Criteria

<table>
<thead>
<tr>
<th>LOS</th>
<th>Freeways (v/c)</th>
<th>Uninterrupted Multilane (v/c)</th>
<th>State Two-Way Arterials Class I (average travel speed)</th>
<th>State Two-Way Arterials Class II (average travel speed)</th>
<th>State Two-Way Arterials Class III (average travel speed)</th>
<th>State Two-Way Arterials ALL (intersection v/c)</th>
<th>Non-State Arterials' (average travel speed)</th>
<th>Other Non-State Signalized Roadways (stopped delay)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤ 0.35</td>
<td>N/A</td>
<td>≥ 35 mph</td>
<td>≥ 30 mph</td>
<td>≥ 25 mph</td>
<td>≤ 1.00</td>
<td>-</td>
<td>≤ 5 sec</td>
</tr>
<tr>
<td>B</td>
<td>≤ 0.54</td>
<td>≤ 0.45</td>
<td>≥ 28 mph</td>
<td>≥ 24 mph</td>
<td>≥ 19 mph</td>
<td>≤ 1.00</td>
<td>-</td>
<td>≤ 15 sec</td>
</tr>
<tr>
<td>C</td>
<td>≤ 0.77</td>
<td>≤ 0.60</td>
<td>≥ 22 mph</td>
<td>≥ 18 mph</td>
<td>≥ 13 mph</td>
<td>≤ 1.00</td>
<td>-</td>
<td>≤ 25 sec</td>
</tr>
<tr>
<td>D</td>
<td>≤ 0.93</td>
<td>≤ 0.76</td>
<td>≥ 17 mph</td>
<td>≥ 14 mph</td>
<td>≥ 9 mph</td>
<td>≤ 1.00</td>
<td>-</td>
<td>≤ 40 sec</td>
</tr>
<tr>
<td>E</td>
<td>≤ 1.00</td>
<td>≤ 1.00</td>
<td>≥ 13 mph</td>
<td>≥ 10 mph</td>
<td>≥ 7 mph</td>
<td>≤ 1.00</td>
<td>-</td>
<td>≤ 60 sec</td>
</tr>
<tr>
<td>F</td>
<td>&gt; 1.00</td>
<td>&gt; 1.00</td>
<td>&lt; 13 mph</td>
<td>&lt; 10 mph</td>
<td>&lt; 7 mph</td>
<td>&gt; 1.00</td>
<td>-</td>
<td>&gt; 60 sec</td>
</tr>
</tbody>
</table>

'Same as state arterials

Excerpted from Table 3-1 of the *Florida Highway Systems Plan: Level of Service Manual*, Florida Department of Transportation, 1992, page 3-4.
VII. OTHER POSSIBLE APPLICATIONS OF AVL IN TRANSPORTATION OPERATIONS

The Miami AVL demonstration has proven the feasibility of utilizing land-based automatic vehicle location technology to accurately and automatically obtain average travel speeds. Travel speeds along corridors, through intersections, and even over specific roadway network links represent the fundamental indicator of traffic performance. From this basic indicator many other traffic characteristics can also be discerned.

If average travel speeds (and travel times) can be collected more easily and on more of a regular basis, they can assist the transportation professional in numerous ways. For example, speeds taken before and after the implementation of traffic capacity improvements can assess the true effectiveness of the improvement. Further, simultaneous speed measurements along competing travel corridors captured through AVL technology can assist in more effective traffic operations planning by providing comparative performance travel speed data. Finally, travel speed data captured in real-time by AVL-equipped vehicles "floating" in the traffic stream can be utilized to provide the motoring public with more timely congestion information in selecting time, route, and even mode of tripmaking.

Technical Memorandum 1 profiles operational tests of AVL technology currently being conducted in the United States, and describes these projects' use of AVL in transportation planning applications. The only transportation planning application of AVL currently being tested is the gathering of real-time congestion levels for traveler information and dynamic route guidance.

The various types of traffic performance measuring applications for AVL technology can also include the following.

Signalization Modifications

Traffic signal cycle lengths, signal phasing, and signal timing plans are often modified to reflect changes in traffic patterns and demand. However, the ability to assess the effect of signal modifications is time-consuming and thus not routinely performed and
documented under actual driving conditions. Instead, a trained visual observation concludes whether the signalization modifications have adequately addressed the major problem areas. Further, the effects of signal progression improvements along a corridor of traffic signals are typically simulated or estimated, not discerned in the real environment.

AVL technology could monitor total travel time through a particular travel corridor, or determine changes in vehicle approach delays (or dwell time) at individual intersections, as a result of signalization modifications. This application would require a high frequency of polling vehicles' locations as well as a high degree of positional accuracy on the part of the AVL system. For example, the AirTouch Teletrac system used in the Miami Experiment has neither the polling frequency (every 8 seconds) or positional accuracy (within 50 feet) for this application.

Incident Detection and Response Techniques

Incident management teams made up of emergency response agencies and traffic engineers continually attempt to recreate (from memory) the chronology of events following a traffic incident. This recreation of events is done to satisfy the two primary objectives of the teams: (1) to respond to future traffic incidents in the most timely manner, and (2) to restore normal traffic operations as soon as possible. Ideally, it is important to be able to detect an incident before it dramatically impacts the flow of traffic, or, at the very least, quickly restore traffic flow to normal operations following an incident.

AVL-equipped vehicles, continuously reporting travel speeds, can be compared against historical speed data for similar periods to better document deteriorating conditions. As conditions reach a certain threshold in speed reduction, response teams could then be automatically alerted. In the case when an incident is not caught in time, AVL-equipped vehicles passing through the area will be able to record running speeds, and eventually record these speeds in real-time. This speed data profile can then be compared against response team records to assess how quickly response procedures at that time restored normal operating speeds through the incident area. Changes in response procedures can be monitored over time, and overall performance judged from actual data.
Travel Time Contour Maps

Travel time contour maps serve as an illustrative technique to display the general quality of mobility within a metropolitan area. These maps provide a single snapshot of an area in terms of travel times by geographic location and travel corridor. The lines, or contours, indicate the distances for various travel time increments. Typically, these travel time contour maps are shaped like stars, with the points of the star located the farthest out along the radial freeways and expressways of the area. This pattern signifies longer distances being able to be traversed because of the provisions for greater capacity and speed along these types of facilities. Travel time contour maps are usually compared over time to illustrate the effects of increasing congestion (i.e., shorter distances traversed over similar durations of time), and to establish market areas (or "zones of influence") for businesses, hospitals, schools, etc.

AVL-equipped vehicles can provide travel time data for the major travel corridors of an area on a more regular basis to monitor levels of congestion over time. Additionally, as this travel time data is plotted in the form of travel time contour maps, specific areas or corridors with the most rapid travel time deterioration can be visually identified and priorities for capacity improvements better rationalized. The effects of capacity improvements can also be compared and illustrated (by star points that stretch out further) with previous years' corridor travel times.

Detour Routing

The selection of the most feasible detour route during periods of roadway reconstruction and new construction is not always a simple traffic engineering task. The ultimate selection and designation of the detour route should be based primarily on overall minimum travel times, thereby minimizing inconvenience to drivers. Most often, however, detours choices are based on minimum distance, not minimum travel times.

AVL technology can be utilized to analyze and compare alternative detour routes for best selection based on total travel times. If variable message signs can be temporarily located at strategic points along the roadside, motorists can be re-directed to alternate routes as needed based on real-time conditions. With AVL technology, static detour
routes within already congested urban areas can give way to more dynamic routing reflecting changes in congestion levels that typically occur during different times of the day. Adjacent roadway facility speeds supplied by AVL-equipped vehicles in the traffic stream integrated with variable message signs can supply the needed input to perform dynamic detour routing.

**Speed Adjustment Factors**

Similar to traffic counts that can be converted to other periods based on adjustment factors, travel speeds can likewise be adjusted to the desired period. It is well known that traffic counts that are needed for analysis can not always be collected at the desired hour of the day, day of the week, or week of the year. Therefore, based on data gathered at continuous count stations on similar or adjacent roadway facilities, adjustment factors are determined and applied to obtain the desired results. For example, based on a large historical traffic data base, a traffic count taken on the first Tuesday in August can be converted to a traffic count estimate for the second Tuesday in January.

AVL-equipped vehicles in the traffic stream that continuously collect travel speeds simultaneously on various roadways at different times of the year can provide the needed adjustment factors, or ratios, for conversion to the desired travel speeds. For example, modeling peak vs. off-peak or weekday vs. weekend conditions can better be simulated with adjusted facility speeds that represent these particular periods. Trends in historic speed data, by facility, can also be more accurately determined for modeling purposes.

**Link Speed Calibration for FSUTMS**

The Florida Standard Urban Transportation Model Structure (FSUTMS) has been developed to provide transportation planners with a well-tested easy-to-use transportation planning tool. However, many times individual link or roadway segment speeds used in FSUTMS are assumed to represent the average speed for a particular facility type or peak period, and may not reflect actual conditions being experienced. AVL technology not only has the capability to capture total travel time speeds, but can
also assist in obtaining individual link speeds. AVL provides an accurate and reliable way of collecting average link speeds for various analysis periods, i.e. peak, off-peak, mid-day, weekend, etc. Time-distance stamps can be recorded automatically at predetermined node or intersection locations, all with known longitude and latitude coordinates. This capability of AVL technology can more representatively permit calibration and validation of congested and free-flow link speeds for FSUTMS analysis. AVL technology can also assist in identifying bottleneck areas in the roadway network, in order to more efficiently prioritize locations for capacity improvements.

Dynamic Traveler Information

All AVL-equipped vehicles can serve as probe vehicles to provide and verify real-time travel speeds and levels of congestion. This type of information can be captured in real-time, automatically transmitted to traffic management centers, and ultimately provided to travelers. Timely information regarding congestion can be provided to travelers via roadside variable message signs and radio reports en route; and updated radio, television, videotex or audiotex reports prior to tripmaking.

It has previously been shown that accurate and timely information provided to travelers in a desirable fashion can affect tripmaking habits by altering route selection, departure time, and even mode of travel. For example, a survey of callers to the SmarTraveler telephone information system in Boston found that 30% of its users "frequently" changed their time, route or mode of travel, based on the real-time traffic information given out by the telephone service; 96% of callers change the time, route or mode of travel occasionally, based on the SmarTraveler traffic information. (SmarTraveler does not gather the bulk of its traffic information via AVL, but by surveillance cameras and other sources.)

The end result of this AVL technology capability can assist agencies in travel demand management and congestion management.
Goods Movement

The preservation of efficient goods movement through or around a metropolitan area is a primary measure of mobility and economic vitality. Effective management of commercial fleet vehicle operations can reduce or eliminate delays in transport and ultimately minimize the cost of goods passed on to the consumer. AVL technology has already been utilized by many commercial vehicle operators, particularly time-sensitive delivery carriers, to monitor fleet and individual package movements in real-time and redirect drivers as needed to avoid congestion and keep on schedule.

AVL-equipped commercial vehicles themselves can also serve as barometers of mobility by recording the time it takes to traverse a metropolitan area during peak and off-peak periods, on particular routes and during particular periods. This information can be shared with, or even sold to, other commercial carriers. Additionally, the continuous monitoring of hazardous materials and hazardous waste is best served by AVL technology especially when an incident occurs involving a truck carrying hazardous materials. Knowing where the vehicle is at all times and what materials are being transported (through an automatic check of the driver's manifest) provides for the most efficient goods movement under these type of conditions.

Operational Changes in Transit

Many public transit vehicle operators utilize AVL technology, or point-to-point vehicle tracking (automatic vehicle identification) technology for fleet management and on-time performance monitoring. Transit agencies in Tampa, Miami, Fort Lauderdale and Palm Beach all either have AVL systems currently operating or have plans to procure and install an AVL system for their bus fleet. Operational changes are often made to improve the quality and reliability of transit service. These operational changes can include bus stop re-location/consolidation, re-routing, bus pull-outs, signal pre-emption, high-occupancy vehicle lanes, etc. Through AVL-equipped transit vehicles, improvements in travel speeds, or headways, can be monitored in real-time under actual operating conditions to assess the "before" and "after" impact of the various types of transit operational improvements previously mentioned.
At the same time, transit vehicles are being monitored for improved service, non-transit vehicles equipped with AVL technology can be monitored for travel time improvements as a result of the transit operational improvements. For example, the construction of bus pull-outs and a consolidation of bus stops along a congested arterial roadway will certainly improve the flow of non-transit vehicles in the traffic stream by reducing vehicular conflicts. AVL has the capability to monitor and record the magnitude of non-transit traffic flow improvement.

Special-Event Traffic Handling

The arriving and departing traffic patterns along corridors serving major sports arenas, concert halls, outdoor theaters, and other special event venues can be recorded in real-time by AVL-equipped vehicles. Other one-time or annual events, such as sidewalk art festivals, fireworks displays, parades, etc., can also cause significant traffic congestion. Historical speed data profiles, gathered by AVL-equipped vehicles, can be analyzed to determine the best temporary facility operational improvements: signal timing modification, parking restrictions, turning restrictions and conversion of two-way streets to one-way travel. Full or partial automation of this procedure may also reduce or eliminate the need for traffic control personnel and manual override of the traffic control system.

Impact of Weather on Travel Speeds

Traffic congestion increases dramatically during periods of inclement weather because (1) people generally tend to drive more slowly and (2) the increased likelihood of accidents. Compilation of historical speed data by AVL technology, by facility, during periods of inclement weather can determine spot locations where variable speed limit signs or other temporary facility improvements may be necessary to prevent incidents.

Safe Travel Speed Through Work Zones

Excessive speeds (or inadequately posted speed limit signs) through construction work zones are the cause of many fatalities each year across the nation’s highways. Particularly on long, continuous segments of reduced speed, drivers can become...
impatient and attempt dangerous passing maneuvers. AVL-equipped vehicles passing through the "work zones" can monitor travel speeds to determine extent of violation and the need for improved enforcement.

"Mayday" Alerts Along Isolated and Rural Areas

AVL technology, because of its ability to continuously track vehicles, can be used as a distress call when destinations are not reached in the normal time expectations. Similar to the flight plans pilots submit to the air traffic controller, known routes and expected travel times can predict likely arrival times with AVL technology. In fact, many AVL vendors include the added feature of a "mayday" button which immediately indicates vehicle location and signals a distress warning to the dispatcher or vehicle tracking center attendant. In September 1994, AirTouch Teletrac announced that it will be offering such a "mayday" AVL-system in conjunction with Avis Rental Car company in Miami. The system is specifically marketed to address fears of anti-tourist crime.

Even when a panic button is not included, AVL can monitor travel progression against expected travel times. For example, in south Florida, Alligator Alley is a 75-mile stretch of rural Interstate 75 through the Everglades National Park, its primary exits being a toll booth on each end. No significant intersections or interchanges exist along this stretch, so travel time from one end to the other can be accurately predicted. An AVL-equipped vehicle traveling along a remote corridor such as this can be continuously tracked, and significant delays in completing the journey can trigger an alert to the proper authorities.

Summary

The application of AVL technology, and innovative utilization of data obtained with AVL technology can significantly reduce traffic congestion, improve mobility, and even enhance traveler safety. AVL technology allows for easy, cost-effective, and accurate performance monitoring of the transportation system, and the measurement of traffic flow improvements following the implementation of capacity improvements. Real-time travel speed data collected through AVL technology can better assist the transportation professional in meeting the challenges of more efficient and effective transportation planning.
VIII. STATEWIDE AVL FEASIBILITY

The specific type of AVL system used in the Miami Experiment - ground-based radio navigation - is currently only available in six U.S. metropolitan areas: Los Angeles, Chicago, Detroit, Dallas/Ft. Worth, Houston, and the greater Miami area. In south Florida, AirTouch Teletrac's current coverage area includes only Dade, Broward and Palm Beach Counties. (AirTouch Teletrac has plans to expand coverage to Orlando, but to no other areas in the state.) If FDOT wanted to implement an AVL-based system for gathering average vehicle travel speeds in other parts of the state, another type of AVL positioning technology would have to be used until tri-lateration became available. This section contains an assessment of the alternative types of AVL positioning technologies, weighing such factors as coverage, cost and positional accuracy. This assessment is summarized in Table 6. The purpose of this section is to assist FDOT in determining the most appropriate technology for conducting the next phase of the Miami Experiment in other parts of the state.

Dead-Reckoning and Map-Matching

Dead-reckoning systems monitor a vehicle's internal compass and odometer and calculate its position by measuring its distance and direction from a central starting point whose position is already known. Because of the low accuracy of vehicle odometers, dead-reckoning systems frequently get off track, and are often corrected using a technique called map-matching. Map-matching systems store a map of the vehicle's coverage area in a database and assume that when a vehicle changes direction it must have turned from one road to another. When a vehicle makes a turn, map-matching systems alter the vehicle's recorded location to the nearest possible point at which the turn could have taken place. Because of the low degree of positional accuracy of both dead-reckoning plus map-matching and dead-reckoning alone, most AVL systems use more advanced technology options.

Signpost

When vehicles regularly travel a fixed route, such as transit buses, many fleet operators have found that signpost-based positioning systems offer an affordable alternative to
more advanced AVL technologies. Antennas are placed at locations throughout the vehicle’s known route and record the time when the vehicle passes. A signpost-based AVL system can also be a valuable by-product of systems intended for other purposes. Electronic toll collection systems in Houston, Chicago and the New York metropolitan area use the automatic vehicle identification (AVI) tags to track vehicle speeds and measure congestion. Drawbacks of signposts-based systems include their inability to track vehicles off their normal route, and the signposts’ potential to be subject to vandalism.

Of the four transit agencies in Florida currently using or planning to use AVL to track their bus fleet, three agencies [Hillsborough Regional Transit Authority in Tampa; Broward County Transit in Ft. Lauderdale; and Jacksonville Transportation Authority in Jacksonville] use a signpost-based system available from Motorola. (The fourth, Metro Dade Transit Agency in Miami, is currently in the process of procuring a GPS-based system from Harris Corporation.) Hillsborough Area Regional Transit Agency (HARTline) has offered to make its bus location data available to the Hillsborough County Congestion Management System, in order to measure levels of congestion as one of the CMS performance measures. One drawback to this approach is that HARTline buses can only be tracked on their predefined bus routes. In addition, because buses must stop frequently to take on and let off passengers, they are difficult to use as probe vehicles to measure average vehicle travel speeds.

Ground-Based Radio-Navigation

In "terrestrial" or "ground-based" radio-navigation, the AVL vendor sets up several receiving antennas in a metropolitan area. Each equipped vehicle broadcasts a radio frequency signal (usually in the 902-928 MHz range) to all nearby receiving antennas. From the time its takes for the signal to travel to the antenna, the distance of the vehicle to the antennas can be determined. If the vehicle’s signal was received by three or more antennas, the vehicle’s position can be uniquely determined (i.e., multi-lateration).

The AirTouch Teletrac system used in the Miami Experiment employs ground-based radio-navigation. The cost for such a system (without cost-sharing) is a start-up cost of $300 per vehicle, plus a monthly service fee of $10 per vehicle. Fleet management
expenses, such as a computer workstation running the FleetDirector™ software, are included in the per-vehicle start-up fee. AirTouch Teletrac guarantees its system to be accurate to within 150 feet. AirTouch Teletrac staff state that, because of South Florida’s relatively flat terrain, the system is accurate to within 50 feet.

LORAN-C

LORAN-C (Long-Range Aid to Navigation) uses low frequency radio waves to provide signal coverage. The federal government set up the communication system to aid the U.S. Geological Survey in mapping. Instead of using multiple receivers to locate a signal transmitter, LORAN uses a single receiver to locate multiple transmitters. LORAN-C often experiences radio frequency and electromagnetic interference. Close proximity to overhead power lines and RF signal boosters stations in urban and industrial areas can cause significant error on the time difference calculations. In addition, LORAN-C position systems can experience error due to poor signal reception in urban canyons. Due to these drawbacks and uncertainty about the government’s future plans for this system, a decrease in the number of commercial AVL systems using LORAN-C has occurred.

Global Positioning Systems (GPS)

Global Positioning Systems (GPS) use a network of 24 satellites in a geosynchronous orbit with the Earth. Antennas capable of receiving these satellite signals can determine their own location. GPS antennas receive the satellite signals free of charge; however, a license must be obtained. The U.S. Department of Defense launched the satellites in order to track objects of interest on the ground. The system was used to track tanks and even individual soldiers during the Persian Gulf War. GPS-based AVL systems are used in the federally-funded TravTek and ADVANCE traffic management/traveler information projects.

CUTR obtained price and accuracy information from three GPS-based AVL system vendors. Auto-Trac’s AVL system costs a one-time activation fee of $7,000 per vehicle and is accurate to within 50 feet. Highway Master’s system costs a one-time start-up fee of $2,000 per vehicle and is accurate to within 30 feet. QualComm’s system costs a one-time start-up fee of $4,500 per vehicle plus a monthly service charge of $170 per
vehicle per month. The QualComm system is only accurate to within 500 feet. (Qualcomm offsets the low positional accuracy with extensive fleet management software support.) For all three systems, fleet management expenses are included in the per-vehicle start-up fee.

**Differential GPS (DGPS)**

One potential problem with using GPS for automatic vehicle location is that the Department of Defense intentionally degrades the accuracy of GPS positioning data used for non-defense purposes. Several companies have addressed this need for additional accuracy by manufacturing systems that broadcast these corrections to special receivers ("differential GPS receivers") using a variety of wireless transmission media.

CUTR obtained price and accuracy information from two DGPS system vendors. A "premium" AVL system available from Differential Corrections, Inc. (DCI) costs $600 for one year's service, plus a one-time activation fee of $615 per vehicle. DCI's system is accurate to within 1 meter (3.3 feet). The Acc-Q-Point system costs $1,200 per receiver for one year's service, plus a one-time activation fee of $519 per vehicle. The Acc-Q-Point system is accurate to within 1 meter (3.3 feet). For all three systems, fleet management expenses are included in the per-vehicle start-up fee.

**Cellular Phones**

A few AVL systems use the still-experimental positioning technology based on cellular phones. These systems use the passive RF signals emitted from cellular phones to detect the location of a vehicle, using special-purpose receiving antennas. The cellular phone technology is being tested in the CAPITAL project in the Washington, D.C. metropolitan area. Engineering Research Associates will use the system to track Washington, D.C.'s estimated 117,000 cellular telephone users during the 90-day test. The total project cost is $7.1 million. The positional accuracy of this type of AVL technology is currently not known, and is one factor which will be measured during the CAPITAL project.
Table 6
AVL Positioning Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Coverage</th>
<th>Capital Cost (per vehicle)</th>
<th>Operating Cost (per vehicle per year)</th>
<th>Accuracy</th>
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<tr>
<td>Dead-reckoning + map-matching</td>
<td>Local</td>
<td>Low</td>
<td>Low</td>
<td>Poor</td>
</tr>
<tr>
<td>Signpost</td>
<td>Predefined routes</td>
<td>High</td>
<td>High</td>
<td>Good</td>
</tr>
<tr>
<td>Ground-based radio-navigation:</td>
<td></td>
<td>Low:</td>
<td>Low:</td>
<td>Good: 150 ft (50 ft in SE Fla)</td>
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<tr>
<td>AirTouch Teletrac</td>
<td>Predefined metro areas</td>
<td>$300</td>
<td>$120</td>
<td></td>
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<td>LORAN-C</td>
<td>North America</td>
<td>Medium</td>
<td>Medium</td>
<td>Good</td>
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<tr>
<td>GPS:</td>
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<td>Very High:</td>
<td>Low:</td>
<td>Very Good:</td>
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<td>$4500</td>
<td>$170</td>
<td>500 ft</td>
</tr>
<tr>
<td>DGPS:</td>
<td>Global</td>
<td>Medium:</td>
<td>Medium to High:</td>
<td>Excellent:</td>
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<td>DCI</td>
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<td>$600</td>
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<td>Acc-Q-Point</td>
<td></td>
<td>$519</td>
<td>$1200</td>
<td>3.3 ft</td>
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</table>

Source: *Metro Magazine*, May/June 1994, p. 44; and AVL vendors.

Vehicle Location Data Collected by Fleet Operators

In addition to assessing the various AVL positioning technologies, CUTR also investigated the availability of data being collected by local and national fleet operators currently using AVL systems. CUTR contacted AVL system vendors, asking for names and contact information of their customers who travel through Florida. Qualcomm, Inc., a manufacturer of GPS-based AVL systems gave the names of three of its Florida customers: Terri Dicks Trucking of North Central Florida, Armellenian Trucking of Southeast Florida, and Commercial Carriers of Lakeland. **All the fleet operators contacted said they were willing to share their vehicle location data with FDOT**, given assurances that their drivers' privacy would be respected.
If FDOT were to use vehicle location data from Florida-based trucking companies, several details regarding the AVL system these companies use would have to be specified:

- How many equipped vehicles will be providing location data?
- What are the routes regularly traveled by these vehicles?
- What is the accuracy of the AVL system used?
- How often does the AVL system poll vehicles' for their location?
- What is the format of vehicle location data?
- How would vehicle location data be converted to average travel speeds by vehicle trip? By link or road segment?

These questions should be answered in subsequent phases of this research.

**Summary**

If Florida Department of Transportation were to conduct another technology evaluation similar to the Miami Experiment outside of Dade, Broward and Palm Beach counties, an AVL system based on global positioning systems (either with or without differential correction) offers the technology option which best suits FDOT's needs. The global coverage of GPS and DGPS enables FDOT to track a vehicle on any route. FDOT would need a technology which offered positional accuracy at least as good as that used in the Miami Experiment, i.e., to within 50 feet. The accuracy of GPS and especially DGPS technologies enables FDOT to measure average travel speeds. Finally, GPS and DGPS automatic vehicle location system are available from multiple vendors, enabling FDOT to compare multiple bids.
IX. CONCLUSION

Five federally- and regionally-funded projects in the United States are using vehicles as probes to collect information on traffic conditions. In each of these five projects, the data is used to deliver real-time traffic information to various users: state department of transportation, incident management and emergency response teams, radio and TV traffic information broadcasters, and even drivers with dynamic route guidance units installed in their vehicles. Only the Houston AVI projects has considered the possibility of using the data collected to measure level-of-service. The Miami Experiment is the only IVHS project in the United States to use data gathered from an AVL system for transportation planning purposes. AVL systems can be expensive than conventional methods of collecting travel information for long-term data gathering periods and more vehicle miles of travel.

The Miami Experiment showed that automatic vehicle location is a viable method for measuring average vehicle speeds on Miami's roadways. This study showed that vehicle speeds measured by an AVL system can be used to calculate roadway level-of-service, based on the LOS criteria outlined in the 1985 Highway Capacity Manual. On the sample roadway analyzed in this study, the official FDOT level-of-service value is LOS F. Similarly, the level-of-service measurement based on average travel speeds collected by the AVL is also LOS F. These LOS values are based on measuring travel speed characteristics for different time periods. The AVL-based method reflect travel which occurred during the 113-day data gathering period between April 25 and August 15, 1994; whereas the official FDOT level-of-service value is based on traffic volume data taken in 1991. Another significant finding in this research was the high day-to-day variability of average travel speeds during the same hour of the day on the same roadway segment.

The vehicle location and travel speed information collected by AVL systems is useful in several other transportation planning applications other than level-of-service determination. However, only the transportation planning application of AVL currently being tested in other areas of the United States is the gathering of real-time congestion levels for traveler information and dynamic route guidance.
Finally, the satellite-based technology global positioning systems (GPS), whether augmented with accuracy-enhancing differential GPS receivers or not, offers the best coverage statewide. Using vehicle location data gathered by Florida trucking companies, equipped with AVL transponders which use GPS positioning technology, appears to be a viable option for gathering average travel speeds in the state's urban areas. Several factors regarding these companies and their use of AVL need to be investigated in subsequent phases of this research.
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• QualComm brochure.


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• Trimble Navigation brochure.

• Turner, Clark P., AICP. *Transportation Corridors: Meeting the Challenge of Growth Management in Miami.* Miami, FL: City of Miami Department of Planning, Building and Zoning, August 1989.


• Il Morrow brochure.
APPENDIX A
List of Contacts

IVHS Project Contacts

TravTek
City of Orlando
400 S. Orange Ave., 8th Floor
Orlando, FL 32801
Tel: (407) 246-3255
Contact: Harry Campbell - City Transportation Engineer

ADVANCE
Illinois Department of Transportation(IDOT)
120 West Chester Ct
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Tel: (708) 705-4800
Fax: (708) 705-4803
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TRANSCOM
Transportation Operations Coordinating Committee
111 Pivonia Ave, 6th Floor- Newport Square
Jersey City, NJ 07310
Tel: (201) 963-4033
Fax: (201) 963-7488
Contact: Pete Dwier - Manager of Operations Center

Houston AVI
Texas Department of Transportation
7721 Washington Ave
Houston, TX 77251
Tel: (713) 956-4013
Fax: (713) 956-2784
Contact: Mark Conway - Senior Traffic Management Engineer

Illinois Tollway
One Authority Drive
Downers Grove, IL 60515
Tel: (708) 241-6800
Fax: (708) 241-6109
Illinois State Toll Highway Authority
Contact: Nick Demaris

CAPITAL
Maryland State Highway Administration
7941 Connelley Drive
Hanover, MD 21076
Tel: (410) 787-5884
Contact: Glen McLaughlin

AVL Vendors

Acc-Q-Point
2737 Campus Drive
Irvine, CA 92715
2925 California Street
Torrance, CA 90503
Tel: (310) 618-7076
Fax: (310) 618-7001
Contact: Michael Dyment, Director of DGPS Communications

AirTouch Teletrac
3330 N.W. 53th Street, Suite 302
Ft. Lauderdale, FL 33309
Tel: (305) 484-1300 ext. 412
Fax: (305) 486-2799
Contact: Stephen Tine, Manager of Commercial Sales

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9330 LBJ Freeway, Suite 900
Dallas, TX 75243
Tel: (214) 480-8145
Fax: (214) 907-2292
Contact: Pat Friend, Director of Sales
Differential Corrections, Inc.
20045 Stevens Creek Blvd.
Cupertino, CA 95014
Tel: (408) 446-8350
Fax: (408) 446-8383
Contact: Bruce Noel, Product Manager

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16479 Dallas Parkway, Suite 780
Dallas, TX 75248
Tel: (214) 732-2500
Fax: (214) 250-0182
Contact: Ken Mitchell, Executive Vice President of Sales and Marketing

QualComm, Inc.
10555 Sorrento Valley Blvd.
San Diego, CA 92121-1617
Tel: (619) 587-1121
Fax: (619) 587-8276
Contact: Dan Hooper, Atlanta Office

Trimble Navigation
645 North Mary Avenue
P.O. Box 3642
Sunnyvale, CA 94088-3642
Tel: (408) 481-8000
Fax: (408) 730-2997
Contact: Charlie Vlcek, Eastern U.S. Sales Representative

II Morrow (pronounced "Two Morrow")
United Parcel Service of America, Inc.
P.O. Box 14135
2777 19th Street
Salem, OR 97309
Tel: (503) 391-3684
Fax: (503) 581-7205
Contact: Karl Poley, Marketing Administration Manager

Florida Trucking Companies

Terri Dicks Trucking, Inc.
Route 3, Box Number 96
Lake City, FL 32025
Tel: (904) 752-1093

Armellenian Trucking, Inc.
3446 Southwest Armelleni Ave.
Palm City, FL 34990
Tel: (407) 287-0575
Contact: Gary Sherak

Commercial Carriers, Inc.
502 East Bridgers Ave.
P.O. Box 678
Auburndale, FL 33823
Tel: (813) 967-1101
Contact: Micky Foutz

Dade County Level-of-Service Analysis

City of Miami
Department of Planning, Building and Zoning
275 N.W. Second Street
Miami, FL 33128
Tel: (305) 579-6086
Fax: (305) 358-1452
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Florida Department of Transportation
District 6
602 South Miami Avenue
Miami, FL 33130
Tel: (305) 377-5910
Fax: (305) 377-5967
Contact: David Henderson, Transportation Planner
### Appendix B

**Vehicle Trips Used in LOS Calculation**

<table>
<thead>
<tr>
<th>Segment</th>
<th>Direction</th>
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<th>Day of Week</th>
<th>Date</th>
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