AUTOMATIC VEHICLE MONITORING

Program Digest

U.S. Department of Transportation
Urban Mass Transportation Administration

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Contents

Overview

This document describes the Urban Mass Transportation Administration (UMTA)'s program to evaluate the application of automatic vehicle monitoring (AVM) in transit operations. After providing an overview in which AVM is defined, the document summarizes the history of the development and deployment of AVM in both Europe and the United States, culminating in UMTA's two-phase program, Advanced, Area-Coverage Automatic Vehicle Monitoring (Chapter 1). In Chapter 2, different types of AVM system components and their operations are explained, with particular attention to UMTA's demonstration system in Los Angeles. Chapter 3 summarizes AVM's costs and benefits and takes a look at future directions for AVM technology.

The energy conscious seventies and eighties have seen a rebirth of interest in public transportation. In response to the national need for improvements in this area, transit properties are looking for ways to make their services safer, more efficient, and more reliable. AVM, a sophisticated information and communications system, is a possible means of achieving these goals. An AVM system *automatically* (i.e., independently of the vehicle operator or dispatcher) *monitors* the location and progress of

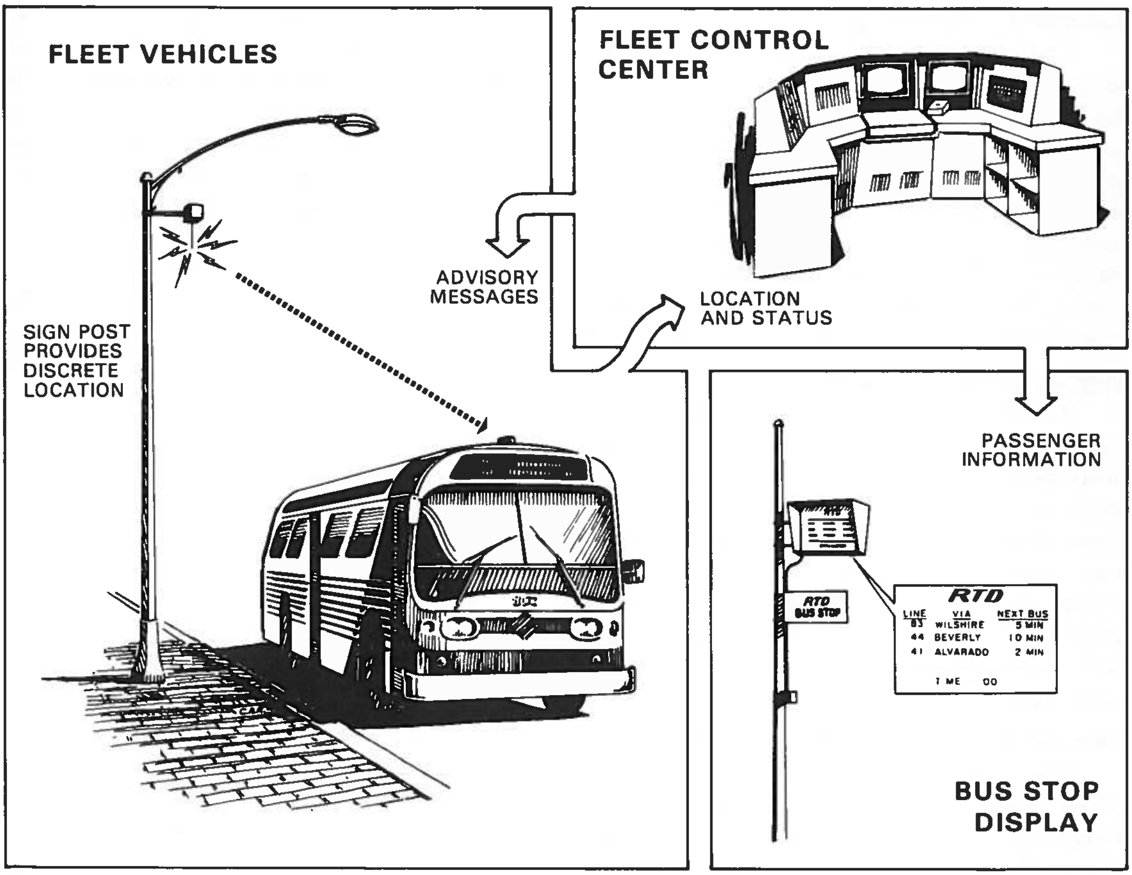


Figure 1. AVM: an Information / Communications / Control System

vehicles in a fleet by means of electronic and computer technology. AVM provides:

- Information to assist bus drivers in maintaining schedules,
- Information to assist dispatchers in controlling route operations,
- Running time and passenger load information to aid planners and schedule-makers, and
- Enhanced security for passengers and drivers by alerting the dispatcher to an emergency and the precise location of the vehicle in trouble.

AVM also has potential for application in police, taxi, firefighting, and emergency medical service operations.

Key Elements

Location Technology

Considered a crucial element in terms of the accuracy, reliability, and cost of an AVM system, the location technology, interfaced with the computer at the control center, makes it possible for a dispatcher to know the location of each vehicle at any time on route. Three broad categories of location technologies are available for use in AVM: proximity, radio frequency, and dead reckoning. Within each category, a variety of technological configurations is possible.

Digital Communications

An AVM system makes use of digital communications to transmit a variety of "canned" messages. Some systems may be able to share digital/voice communications. Although the digital data may be transmitted on existing two-way voice radios, a separate digital radio increases the amount of information which may be transferred, allowing better monitoring and tactical control of a fleet, while maintaining the same level of voice communications.

Central Data Processor and Displays

The data processor collects and stores data on route performance, stores dispatcher instructions, controls the polling cycle, and displays bus route and schedule status for dispatchers on consoles at the control center. The data processor also generates advisory commands which are transmitted digitally to the vehicle operator.

In addition, transit vehicles may be equipped with automatic passenger counters, which provide useful information to dispatchers for controlling route operations, and, most important, to managers for planning service. Three available automatic passenger counter sensors are the treadle mat, infrared beam, and ambient light.

Program Organization and Objectives

Building upon prior AVM experiments in Europe and the United States, in 1974 UMTA initiated plans for a program to further the development of AVM and to refine, demonstrate, and evaluate its application in an urban transit environment.

The first phase of the program, which took place in Philadelphia in 1975-1977, involved field-testing of several location technologies. The second phase, currently in progress in Los Angeles, involves the demonstration and evaluation of a complete AVM system used in both fixed- and random-route operations.

Other potential applications for AVM are firefighting and medical emergency service operations.

1. History of AVM Development

Principally in Europe, but also in the United States, many isolated tests and studies of AVM-related technology were performed during the past twenty years. Today roughly 3000 vehicles are operating in two dozen active AVM projects, and the prospect of a steady increase in new projects during the 1980's looks bright. (34)[1]

Although a considerable amount of data was produced during the first decade of AVM experimentation, a firm and consistent framework for the purposes of comparison and evaluation was missing. In the early 1980's, the Urban Mass Transportation Administration (UMTA) began planning a full-scale AVM program which would remedy this situation.

The first part of this chapter briefly describes the international history of AVM experimentation in public transit systems. U.S. AVM applications to both public transit and police operations are examined separately. Finally, the history and status of the UMTA AVM program are discussed in more detail.

An International Perspective

The most extensive experimentation with AVM technology has taken place in Europe, where efficient public transportation has long been a high priority. Beginning with London Transport's Bus Electronic Scanning Indicator (BESI) in 1959, over twenty European cities have deployed some type of AVM system to improve public transportation, most often in the form of demonstrations or pilot projects. Nine of the projects are currently active, four are expanding, and nine others are in developmental stages. (34)

Although no comprehensive evaluation of any of the European systems exists, in 1975 the Transportation Systems Center (TSC) investigated deployments in four cities: London, Hamburg, Zurich, and Paris.[2] From this investigation, it was apparent that the primary objective in these cities was to improve transit service through fleet monitoring and control by dispatchers. The potential economic benefit of AVM was less important.

When the first international AVM symposium was held in Toronto in 1976, Hamburg and Zurich were the only cities deploying AVM, though on a limited scale, in regular operations. AVM demonstrations or pilot projects had taken place or were occurring in eight other European cities, two cities in Japan, one in Canada, and two in the United States. Toronto had plans at that time to transform its own phased demonstration program into a full-scale operation. Beginning with 100 vehicles in 1979 and ultimately expanding to include 1600 buses, street cars, and trams, the Toronto operation could become the most ambitious AVM deployment in the world.

In the meantime, Dublin, site of the second international AVM symposium in the spring of 1979, has implemented what is currently the largest AVM deployment, one involving the entire 900 bus fleet.

A survey of worldwide AVM developments conducted in 1979 by ECO PLAN, an international consulting firm, noted the following trends:

- The gradual shift over the last few years away from basically experimental initiatives and to the phased introduction of proven AVM techniques.
- The increasing dominance of operators over their equipment and technology sources, especially in cities with strong transit undertakings.
- The emergence of the Germans, Swiss, French, Canadians, and Americans

[1] Numbers in parentheses refer to references listed at the end of the document.

[2] The investigation was conducted as part of Phase One activities of the UMTA AVM Program.

TABLE 1
AN INTERNATIONAL SUMMARY OF AVM EXPERIMENTS IN PUBLIC TRANSPORTATION

City/Country	Year Initiated	Original Target	No. of Vehicles	Main Supplier	Status in 1979
London, U.K.	1958	Simple AVL	240		Life expired
Hamburg, F.R.G.	1969	Limited AVM	165	Prodata	Active/expanding
Chicago, U.S.A.	1969	AVM demo	500	Motorola	Completed; EVL active
Zurich, Switzerland	1971	Limited AVM	150	Hani-Prolectron	Active/expanding to full
Paris, France	1973	AVM demo	35	Matra	Terminated (1976)
Bristol, U.K.	1973	AVM demo	100	Marconi	Withdrawn (1974)
London, U.K.	1973	AVM demo	44	Marconi	Concluded
Tokyo, Japan	1973	AVM demo	75	Tokyu	Completed
Nottingham, U.K.	1974	Limited AVD	8	Philips	Active
Dublin, Ireland	1974	AVM demo	900	Storno	Active/expanding
Toronto, Canada	1974	AVM demo	100	—	Pilot/evaluation
Nagoya, Japan	1974	AVM demo	17	Denso	Completed
Besancon, France	1974	AVM demo	60	Thomson CST	Active/completed
Toulouse, France	1975	AVM demo	16	C.G.A.	Terminated
Cincinnati, U.S.A.	1975	TIS demo	30	GM/Motorola	Active/expanding
Brescia, Italy	1976	AVM demo	90	Italtel	Demo suspended - strike (1977)
Hanover, F.R.G.	1976	AVM demo	150	Bosch	Evaluation
Berne, Switzerland	1976	AVM pilot	12	Hani-Prolectron	Expanding
Stockholm, Sweden	1977	AVM pilot	60	Datasaab	Evaluation
Friederichshafen, F.R.G.	1977	DRT + AVM	12	Dornier	Active demo
Graz, Austria	1977	Full AVM	225	Hani-Prolectron	Active
Mississauga, Canada	1977	AVL + info. system	35	—	Active/expanding
London, U.K.	1978	AVM demo	50	—	Pilot project
Wunstorf, F.R.G.	1978	DRT + AVM demo	5	MBB	Active
Strasbourg, France	1978	AVM demo	180	C.G.A.	Being developed
Gothenburg, Sweden	1979	Parallel demonstration projects for combination taxi-dispatching/AVL system. Developed by Volvo and SRA Communications with Swedish Taxi Drivers Organization.			Being developed
Malmo, Sweden	1979				
Stockholm, Sweden	1979				
Darmstadt, F.R.G.	1979	AVM pilot	80	Hani-Prolectron	Being developed
Rome, Italy	1979	AVM pilot	37	Italtel	Being developed
Regensburg, F.R.G.	1979	AVM pilot	15	Siemens	Being developed
Wiesbaden, F.R.G.	1979	AVM pilot	25	Siemens	Being developed
Ausburg, F.R.G.	1979	AVM pilot	25	Siemens	Being developed
New York City, U.S.A.	1979	Full AVM	241	Motorola	Being developed
Los Angeles, U.S.A.	1979	AVM demo	200	Gould	Being developed

Key
AVL = automatic vehicle location
AVM = automatic vehicle monitoring
AVD = automatic vehicle dispatching
DRT = demand responsive transportation
EVL = emergency vehicle location
TIS = transit information system

Adapted from 1979 EcoPlan Status Report on AVM Development and Prospects (34)

among the leaders in the field in recent years, and

- A steady expansion of activity, especially since 1977. (34)

Table 1 illustrates chronologically the international history of AVM experimentation.

U.S. Experiments

The most significant development of AVM in this country has occurred since 1968, when the Department of Housing and Urban Development (HUD) initiated a program to improve public transportation. Under the HUD program, the Chicago Transit Authority (CTA) was to develop a demonstration AVM system for its bus fleet. Concurrent with the preliminary Chicago bus system studies, a conference held in Washington, D.C., brought together forty manufacturers and representatives from a variety of Federal agencies to discuss both the technology and potential applications of AVM.[3] These two events or activities, both an outgrowth of the HUD program, spurred widespread interest in AVM as a new market for industry and as a new tool for users to improve their operations.

Transit Applications

Chicago, then, became the site of the first U.S. AVM deployment in public transit. Motorola developed a proximity AVM demonstration system for the Chicago Transit

[3]The Public Urban Locator Service (PULSE) Conference in October, 1968.

London was one of the first cities to deploy AVM-related technology.

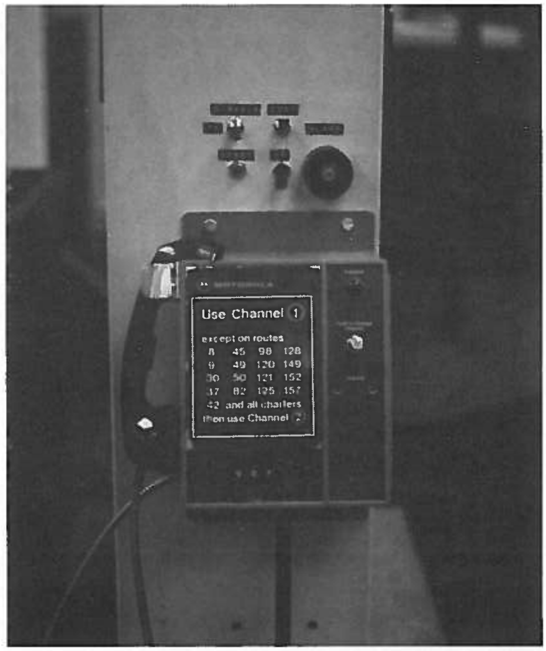
Authority (CTA).[4] Funding was provided by UMTA, which assumed sponsorship of the former HUD program in 1969. The demonstration began with 500 buses on the "owl" (night) routes of the CTA district, and during the next five years, the number of equipped vehicles grew beyond the original intent of the demonstration. Early in 1975, CTA management initiated plans for an independent evaluation of the system. The task force performing the evaluation recommended that given the size of the CTA operation and CTA's current needs and priorities, a different type of system would be more effective.

Following the recommendations of the task force, in late 1975 CTA began operating a limited-purpose Emergency Vehicle Location (EVL) system, which capitalizes on the most successful AVM element during the demonstration, the silent alarm interfaced with the location technology. Each bus operator has a side panel-mounted switch, which, when activated, transmits an alarm. When the switch is pushed, the equipment automatically shifts to the voice channel and transmits, continuously for two minutes or until acknowledged, the identification and the location of the bus. Thus, EVL is being used to address one of the major concerns of the CTA, the safety of operators and passengers. Currently 2420 buses are equipped with this system. (9, 37)

Several other demonstrations and deployments of AVM-related technology have taken place in U.S. public transit operations, some funded by UMTA, and others by local or state governments or by private industry. In 1975 the Urban Transportation Laboratory (UTL) of General Motors conducted a phased demonstration of a Transit Information System (TIS) in Cincinnati, Ohio. Consisting of wayside bus locators (similar to those being used in Chicago), on-board passenger counting equipment, and a central computer, TIS can provide current and accurate information on passenger loads, run times, and schedule adherence on a system-wide, continuous basis. Although TIS has the capability, it is not being used in Cincinnati for real-time control of operations. In the

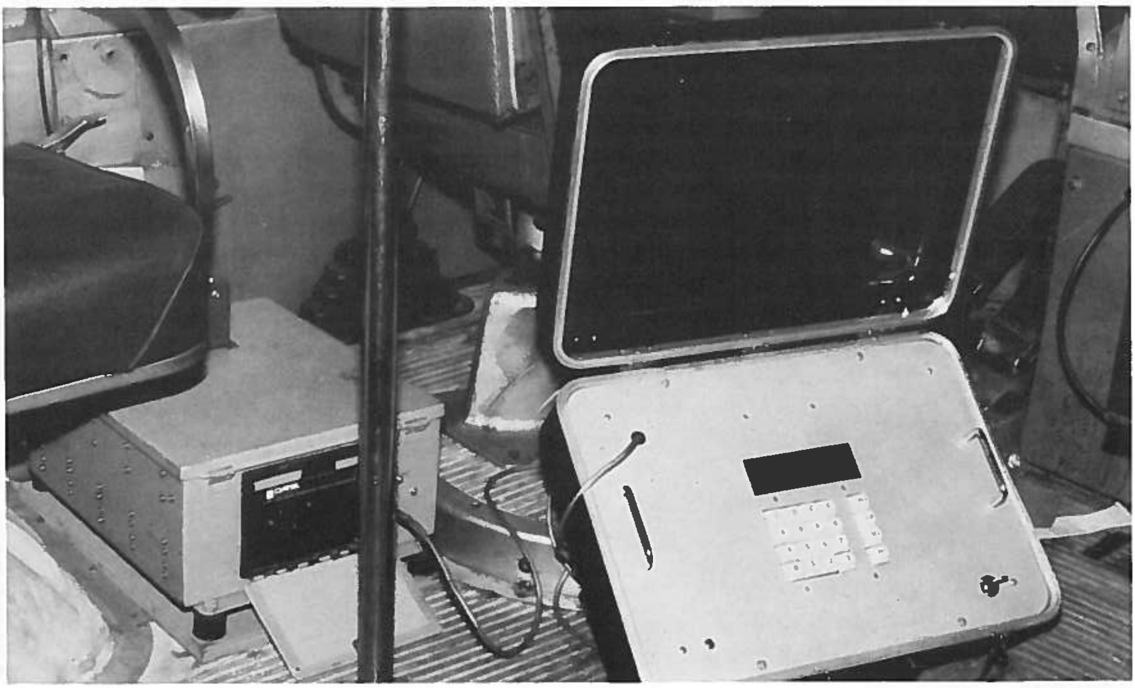
[4]In a proximity system vehicles are located according to their nearness to fixed reference points, often called "signposts." See Chapter 2 for a more detailed description of the different location technologies.

An AVM-equipped streetcar in Zurich.



On-Vehicle communication equipment set up at the CTA control center for training staff. (Chicago)

The portable data collection unit demonstrated in Columbus provides information on passenger loads, run times, and schedule adherence. (Photo by General Motors)



Cincinnati system, the central computer edits the data transmitted by radio and generates reports for later use in service planning and scheduling.

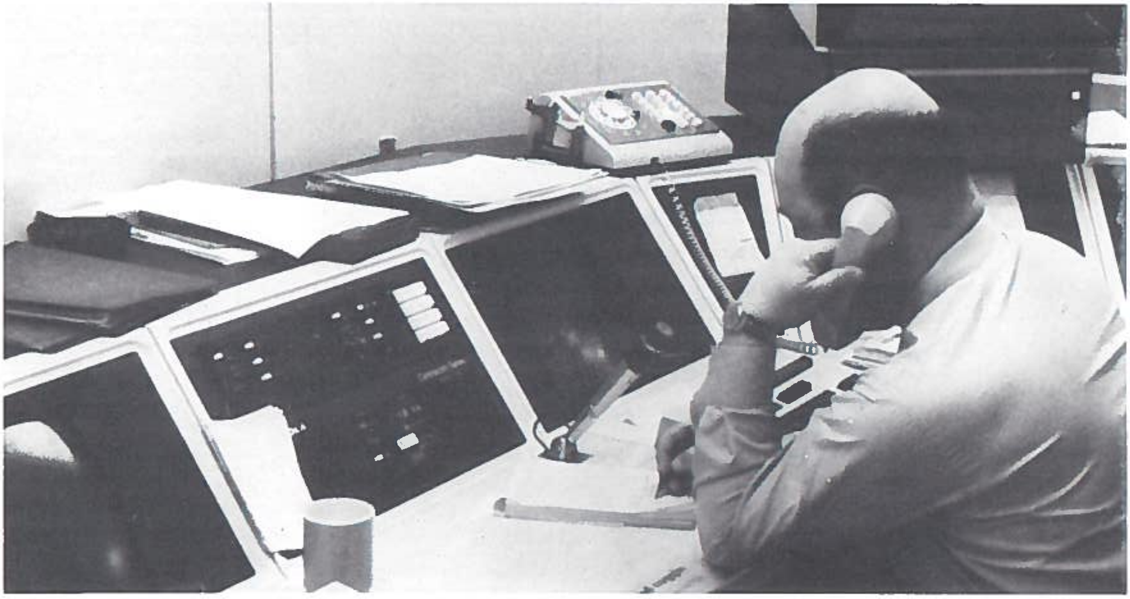
The TIS prototype developed by General Motors has been deployed with some 30 buses (seven percent of the fleet) on selected Queen City Metro transit routes since 1977. A 1979 UMTA-sponsored TSC evaluation concluded that a properly functioning TIS system appears to be economically viable for system-wide use in Cincinnati. In the fall of 1980, Cincinnati was awarded UMTA capital grant funding to equip 80-90 buses for the same generic system as TIS. (8, 42)

During the late summer of 1980, General Motors completed a Transit Resource Productivity Demonstration in Columbus, Ohio. Known as an On-Board Data Collection System (ODCS), the technology demonstrated in Columbus utilizes portable cassettes to collect data. Another demonstration of this technology is taking place in Jacksonville, Florida, during the spring and summer of 1981. With state funding, the city of Kalamazoo, Michigan, recently purchased an ODCS system for its transit operations. It will be installed in the fall of 1981. (42)

With local government funding, the New York City Transit Authority began implementing a proximity AVM system in Queens Village in 1979. Currently 84 wayside bus locators cover the twelve routes on which 241 AVM-equipped buses operate. The system was designed so that digital communications are a priority, but voice communication is always available. The computer continually updates location, status, and schedule performance information and displays it for the dispatcher in both tabular and graphic forms. Each bus is polled once every 60 seconds. Recently, six mechanical sensors have been installed on each bus to check such items as engine overheat, oil pressure, and fare box tampering.

The AVM system which Motorola developed for Queens Village has contributed to reduced bus bunching and better distribution of passengers among buses. Management estimates that pay-back time will be three years. The transit authority plans to install a similar system in Staten Island. (38, 44)

On this console in Queens, New York City, data on location, status, and schedule performance are displayed for the dispatcher. (Photo by Motorola)



A FLAIR-equipped patrol car in St. Louis. (Photo by Boeing)

Police Applications

In 1966 the President's Commission on Law Enforcement and Administration of Justice promoted AVM systems as a potential tool for increased command and control in law enforcement. In the early 1970's, the police department in Montclair, California, performed one of the first experiments with AVM in police operations. Conducted in two phases and funded partially by the California Council on Criminal Justice, the demonstration project was to provide a model for other law enforcement agencies. Montclair's proximity AVM system, called LOCATES, used fifty wayside transmitters to locate a small number of mobile units within a geographic area of 5.2 square miles. (33)

The first full-scale AVM deployment in a major metropolitan police department began in St. Louis, Missouri, in 1974. Funded largely by the Law Enforcement Assistance Administration (LEAA), and developed by Boeing, the AVM system (FLAIR)[5] was first tested in one district of the city. Since 1977, implementation has been city wide. The number of equipped vehicles has increased from 25 to 200 (all the marked patrol cars, or a third of the entire fleet). By March of 1980, these vehicles had logged fifteen million miles of operational tracking.

FLAIR first made use of a computer-assisted dead reckoning technique to track equipped vehicles.[6] Because of cumulative error build-up with dead reckoning, a location technology enhancement was tested in the ninth district, a high crime area. Thirteen proximity transmitters were installed at selected street locations, and decoder software was added to the fifteen patrol cars in the district. The transmitters permit automatic re-establishment of an equipped vehicle's location. Significant improvements resulted, and St. Louis plans to install these transmitters city wide.

[5]FLAIR = Fleet Location and Information Reporting.

[6]In a dead reckoning system, equipment on the vehicle continuously measures heading and distance travelled for tracking purposes. To correct cumulative errors, drivers must periodically re-establish their location by voice communications. See Chapter 2 for a further explanation of this location technique.

Another feature of FLAIR is an extensive digital communications subsystem which allows 99 numerically coded messages to be transmitted to the dispatcher. This reduces the use of voice communications for routine status messages.

The FLAIR system also provides each dispatcher with a color display console, from which he or she can select one of three map scales of the city. The most detailed map reveals all the streets in the area. The dispatcher can follow a single vehicle as it travels over the city streets or view all the cars in a particular area at once. When a patrol officer signals an emergency, the dispatcher has two sources from which to choose the closest available cars to send: the display map of the area and a list of the six closest available cars displayed in a column on the console. In sending the closest available car to the scene of a crime or emergency, dispatchers may overlook beat boundaries when necessary. In one of its districts, St. Louis is experimenting with the open-beat concept, for which AVM is ideally suited. (36, 40)

Two other major police departments in the U.S. have implemented AVM, those in Huntington Beach, California, and Dallas, Texas. Manufactured by Gould and installed in 1977, the Huntington Beach automatic vehicle locating (AVL) system, as it is called, was interfaced with a computer-aided dispatch (CAD) system in 1980. Currently the AVL system is operating with 56 marked patrol cars (over half of the total). Utilized in this application are 483 wayside location units, which cover the entire 30 square mile area. They are situated so that their transmission signals overlap, thus eliminating the need for an odometer, and providing location information for the dispatcher at any time during an equipped vehicle's journey through the area. The advantage of this location technology is that fewer wayside units are required to obtain a high level of accuracy. (39)

Following a period of feasibility testing, the Dallas Police Department began a pilot program in a low-rise area of the city in April, 1980. Dallas's AVM system, developed by Hazeltine, is fully integrated with its computer-aided dispatch

A display console used for tracking patrol cars in St. Louis. (Photo by Boeing)

system. The radio frequency location technology involves seven receiver sites to which equipped vehicles in the area transmit signals.[7] On-board equipment for the transfer of information and reception of calls from the dispatcher consists of a transponder, a keyboard similar to that used for pocket calculators, and a display panel. (Approximately 50 vehicles are so equipped.) The automatic transfer of location and status information takes place at regular, two-second intervals during the all-car polling cycle. At the dispatch center, this information is shown on color, computer-generated displays. (41,43)

Like St. Louis, Huntington Beach and Dallas both received capital grant money from LEAA for their AVM systems during a period when such funds were more available than they are today. A number of other law enforcement agencies in this country have expressed interest in installing AVM, but currently do not have the necessary funds.

[7]Simply stated, in radio frequency (RF) technologies, vehicles are located by means of the transmission of RF signals (pulses) between the vehicles and a relatively small number of receivers or transmitters located at known geographic points. See Chapter 2 for a further explanation of these technologies.

TABLE 2
AVM DEPLOYMENTS IN U.S. LAW ENFORCEMENT AGENCIES

City	Year Initiated	System Name	Manufacturer	Location Subsystem	No. Equipped Vehicles	Current Status
Montclair (CA)	1970	LOCATES	Products of Information Systems	Proximity Signposts	6	Demonstration Terminated 1974
St. Louis (MO)	1974	FLAIR	Boeing	Dead Reckoning/ Signposts	200	Active
Huntington Beach (CA)	1977	None	Gould	Proximity Signposts	56	Active
Dallas (TX)	1978	None	Hazeltine	Radio Frequency (Pulse Trilateration)	50	Active Pilot Program

The Advanced, Area-Coverage Automatic Vehicle Monitoring Program

Pre-Program Testing

The history of the Advanced, Area-Coverage AVM Program dates back to 1970, when UMTA first attempted to develop a framework within which valid comparisons among different AVM systems could be made. At that time, UMTA solicited proposals and selected four companies to develop systems to demonstrate the feasibility of several different AVM techniques.[8] Three of the selected systems used radio frequency location technology, and one deployed proximity signpost location technology. Feasibility testing took place in 1972 in Philadelphia, a rigorous environment typical of that in which an AVM system would be required to operate. Only the proximity AVM system (developed by RCA) met the location accuracy requirements: a maximum error of 500 feet for 95 percent of all location indications.[9] Further development was deemed necessary.

Phase One

In 1975 UMTA initiated a two-phase program to advance the development of AVM technology and to quantify its benefits for several potential users.[10] From the 1972 feasibility testing in Philadelphia, UMTA had learned that the location technology was the highest technical risk to the successful deployment of an AVM-type system. Phase One of the program, conducted again in Philadelphia, was therefore devoted to testing and evaluating four candidate location technology concepts (two radio frequency and two proximity signpost concepts), selected from a range of industry proposals.[11]

To gather the data sample for evaluation of fixed-route performance, the test vehicle was required to simulate bus operations (speed levels and stop patterns) on a specified route approximately 15 miles long. A different route was assigned to each contractor; however, all routes were similar, passing through a mixture of low- and high-rise areas. To evaluate random-route performance, the test vehicle was required to simulate police car (or taxicab) average speeds

[8] The four companies were Teledyne Systems, Sierra, Cubic, and RCA.

[9] For a single AVM-equipped vehicle, the location error is the radial distance between the true position and that measured by the location technology.

[10] Transit, police, taxi, and paratransit operators either using AVM independently or sharing a system.

[11] Contractors who developed these concepts were Fairchild Space and Electronics, Hazeltine, Hoffman Information Identification (now a subsidiary of Gould Electronics), and Teledyne Systems.

Philadelphia offered a rigorous environment for testing location technologies during Phase One. (Photo by Philadelphia Convention and Visitors Bureau)

while moving with the traffic over a ten-mile route. Each company was assigned a specific territory, comprised, again, of a mixture of high- and low-rise areas. A large number of test runs was made to ensure that the data obtained would represent the performance of the location technologies in a full range of urban operations.

Table 3 summarizes field-test performance results for the four different location technologies. For both fixed-route buses and random-route police cars, maximum location errors of 300 feet for 95 percent of all location indications, and 450 feet for 99.5 percent were specified. The Transportation Systems Center (TSC), which developed the specifications for DOT, felt that very large errors would be extremely disruptive to the control of buses or the dispatch of police cars.

All four location technologies were judged to be feasible for future AVM activities, and a cost-benefit analysis indicated a favorable outlook for AVM application to transit, police, and taxi fleets. As a result of the field tests and an evaluation of contractor proposals for Phase Two, Hoffman Information Identification, Inc. (now Gould Electronics, Information Identification Division) was awarded a contract in September of 1977 to design, develop, and implement an AVM system for Phase Two.

Phase Two

The principal objective of Phase Two is the operational testing, deployment, and subsequent evaluation of a state-of-the-art, multiuser AVM system in an operating transit environment. Related tasks include:

- Developing standards for the technology and guidelines for deployment,
- Quantifying benefits and costs, and
- Disseminating information through reports, seminars, and workshops/ conferences.

Site selection. Among the considerations in selecting a demonstration site were route structure, transit property facilities, and management interest. Six of the nineteen transit properties being considered were examined in detail: Boston, Seattle, Dallas, Fort Worth, Miami, and Los Angeles. The latter appeared most suitable, given the criteria for the demonstration site. The Southern California Rapid Transit District (SCRTD) in Los Angeles offered strengths in

TABLE 3
PHASE ONE TEST RESULTS

Location Subsystem	Manufacturer	Edited Location Test Results*		Time of Passage Determination Accuracy for Fixed-Route Operations
		Fixed Route	Random Route	
Proximity Signpost (narrow beamwidth)	Fairchild	95% 81' 99.5% 125'	95% 220' 99.5% 430'	95% 1 sec. 99.5% 2 sec.
Proximity Signpost (broad beamwidth)	Hoffman	95% 105'+ 99.5% 188'+	95% 282'+ 99.5% 367	95% 5 sec. 99.5% 8 sec.
Radio Frequency (pulse trilateration)	Hazeltine	95% 191-325' 99.5% 490-665'	95% 270-460' 99.5% 693-940'	95% 15 sec. 99.5% 30 sec.
Radio Frequency (LORAN-C)	Teledyne	95% 291' 99.5% 383'	95% 325-472' 99.5% 375-819'	95% 8 sec. 99.5% 16 sec.

*Edited data results more nearly represent the performance levels that would have been achieved had the overall Phase One test system performed optimally or had the system deployment been optimal.
+Non-edited test result.

Adapted from Reference 11.

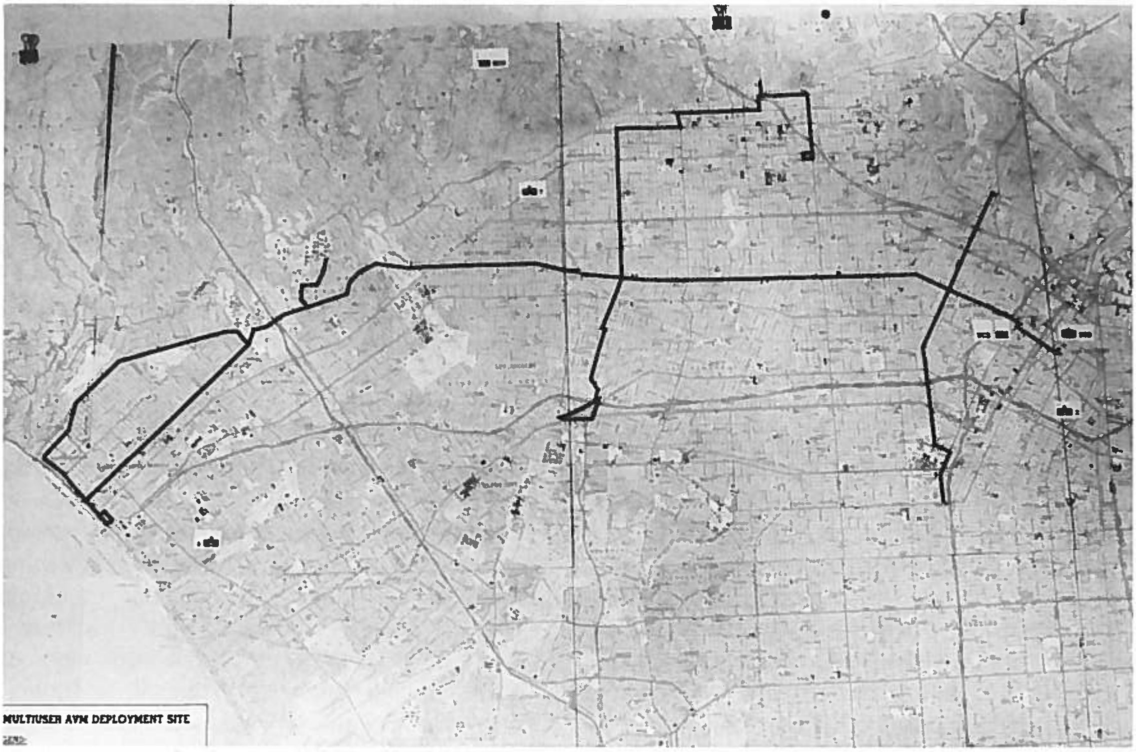
Los Angeles was selected for UMTA's AVM demonstration site. (Photo by Greater Los Angeles Visitors and Convention Bureau)

management and operational control. In addition, the SCRTD, the Los Angeles Police Department (LAPD), and Yellow Cab were enthusiastic about participating in the experiment. Because of various obstacles, however, the LAPD and Yellow Cab were unable to participate. An alternate plan conceived for random-route testing involves specially equipped SCRTD "service" vehicles (supervisor cars, transit agency cars, etc.) simulating a variety of random-route operations.

System design and implementation. The contractor, Gould Electronics, designed the AVM system being demonstrated in the winter of 1981 and is providing support in planning and conducting experiments.[12] The AVM system is being used to record test vehicle performances and to monitor present-day scheduling, dispatch, and field supervision methods. Control features of the AVM system are being introduced, and their effect on operations is being evaluated.

The demonstration involves 200 buses operating on four fixed routes of the SCRTD and 15 service vehicles travelling on random routes within a 54 square mile area of central Los Angeles (the same area in which the LAPD operates). The bus operations represent a full range of those found in urban transit: i.e., feeder, cross-town, close headway, express, and local services. Special experiments with the dispatch and operation of random-route service vehicles will establish requirements for emergency service, as well as paratransit (i.e., taxi and other demand-responsive transportation) applications.

[12]The different components of the Los Angeles AVM system are described in Chapter 2, following the discussions of each AVM element.



A map showing the four SCRTD routes being used for UMTA's AVM demonstration.

Serving as a liaison, the American Public Transit Association has provided input into an assessment of the experiment design and execution and is assisting with the dissemination of the program results to potential users, other transit properties. The SCRTD, the operator and user of the demonstration AVM system, is evaluating the benefits of AVM from a management and maintenance perspective.

Current status and planned activities. AVM system fabrication, testing, and installation took place during 1979-1980. Various AVM elements, including the hardware and software, were implemented in stages in order to introduce dispatchers and operators gradually to the full range of AVM capabilities. Operational use of the AVM system began in mid-September of 1980. Following a four month learning phase for SCRTD personnel, a comprehensive evaluation of the system began in January and will continue through June of 1981. By the end of this time, the SCRTD should be prepared to take over complete operations and management of the AVM system. In October of 1981, SCRTD, if they so decide, will assume ownership of and responsibility for the system.

In the meantime, software has been developed to generate management reports using the daily recorded AVM data. After the completion of the demonstration, reports evaluating the AVM system from different perspectives (those of SCRTD, TSC, and UMTA) will be issued and a comprehensive information dissemination program will begin.

2. Operational and Performance Characteristics of AVM Components

Manufacturers have developed a variety of configurations for AVM systems, but all consist of some type of:

- Automated location technology involving on- and off-vehicle electronics.
- Digital and voice radio communications.
- Central data processor and displays.

In addition, some type of silent alarm system to signal emergencies is often used with AVM, and a variety of sensors, such as automatic passenger counters, may be deployed in transit operations.

These components work together to provide more information, better communication, and more control over external circumstances. The availability of near real-time data on vehicle location, fleet performance, and passenger loads makes it possible to implement control tactics which improve the productivity of a fleet and make service more efficient and reliable. In addition, this data maintained off-line can be used to develop planning and scheduling strategies.

This chapter describes how AVM system components operate to achieve these goals. Within the discussion of each system component, the type of component being demonstrated in Los Angeles is examined.

Location Technologies

The location technology allows dispatchers to keep track of the location and headway of all vehicles in a fleet without having to communicate directly with the drivers. With this information, dispatchers can implement tactics that help individual drivers adhere to their schedules. In the case of a bus breakdown or an emergency, dispatchers know exactly where to send help.[13] Accurate and current information on bus headways can be used later to develop or refine published schedules and to plan more efficient fleet operations.

[13]Emergencies are signaled by a silent alarm installed in each vehicle.

Since the communication and processing components of AVM are designed to match the location technology, the type of location technology distinguishes one type of AVM design concept from another. Four types of location technologies are generally recognized: proximity, inverted proximity, radio frequency, and dead reckoning. The basic characteristics of each type are explained below.

Proximity and inverted proximity technologies. A proximity location subsystem is typically composed of on-vehicle electronic receivers and microprocessors, and an adequate number of low-level radio transmitters, frequently called "signposts," attached at intervals to stationary objects throughout the area served. Other devices such as optical scanners, microwave beams, or magnets with unique coding may be used instead of radio transmitters in this type of system. The proximity technology is so designated because the vehicle and its location are identified when it passes within the proximity of a "signpost" along the route. Typically, each signpost periodically transmits a digital message containing a unique code. When a signpost transmission is received in a bus, the code is extracted and the signal level is quantified. Logic in the vehicle microprocessor utilizes the code and signal level of each signpost to form a code which represents a unique location either at one signpost or between adjacent signposts. The most current location/region code is stored until it is replaced by a new code, as a result of the vehicle having moved. When interrogated by the base station computer, the vehicle microprocessor responds with the location/region code (as well as other data). At central control, the AVM computer looks up the location/region code in a data base table, extracts a prestored location, (X,Y coordinate and alphanumeric identification) and measures the vehicle's schedule performance. The computer then presents this information to the dispatcher.

With an inverted proximity technology, the pattern of transmitting information is reversed. The vehicle transmits a signal to an electromagnetic or optical sensor attached to a stationary object. When interrogated by the base station computer, the sensor relays by wire the identity code of the last vehicle that has passed by. If two or more vehicles are within the detection of a signpost, the signpost could confuse their identities. Because the inverted proximity technology requires an extensive wired data collection network linking a potentially large number of signposts to the control center, the cost of this system may be prohibitive if facilities do not already exist.

Either a broad or a sharp signpost may be used with proximity and inverted proximity technologies. The broad signpost is so named because it radiates a unique coded signal in a *broad pattern* (within a range of 50-100 feet). Odometers may be used to determine vehicle location between signposts, or signposts may be positioned so that the signal patterns from adjacent signposts overlap. As an AVM-equipped vehicle moves through the coverage area, the vehicle senses the transition through signpost regions corresponding to strengths of overlapping signal patterns.

The narrow or sharp signpost, on the other hand, provides a position location at a *particular*

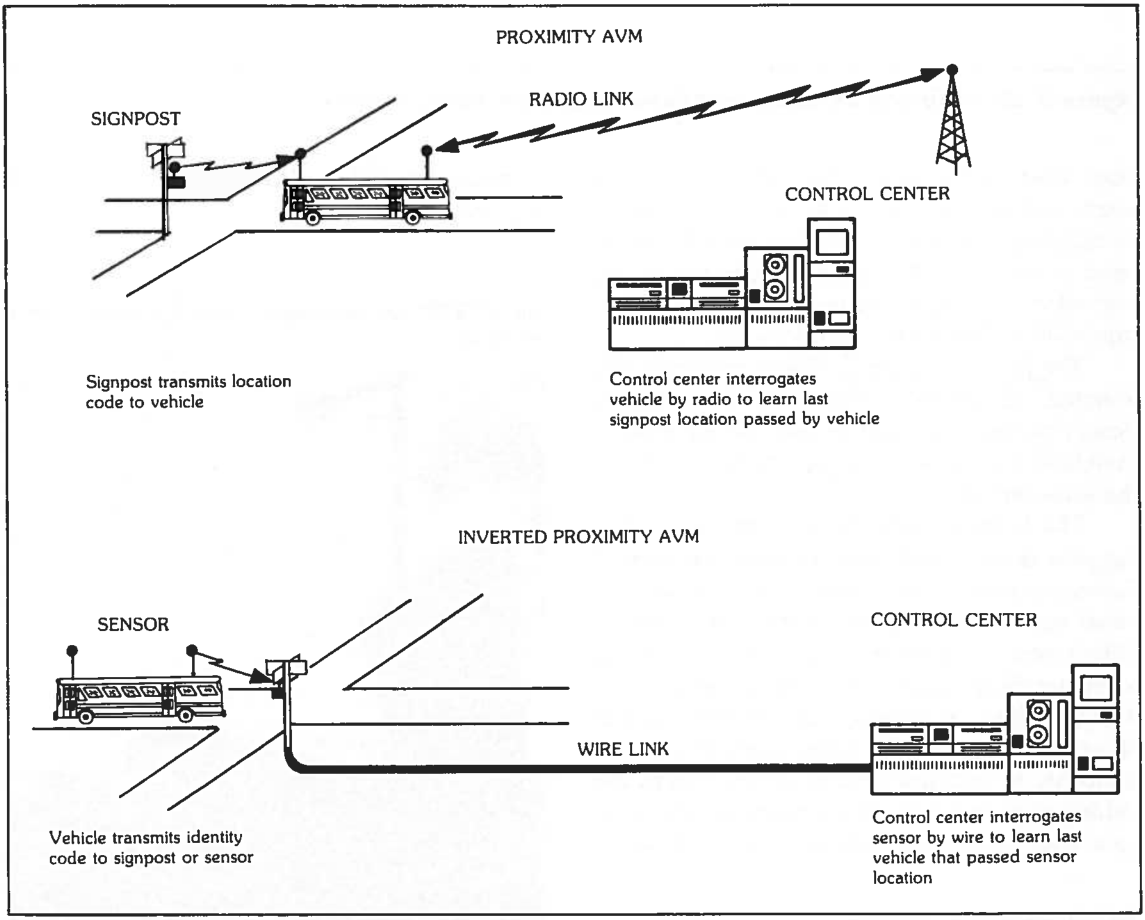


Figure 2. Signal Transmission Patterns in Proximity and Inverted Proximity Location Technologies

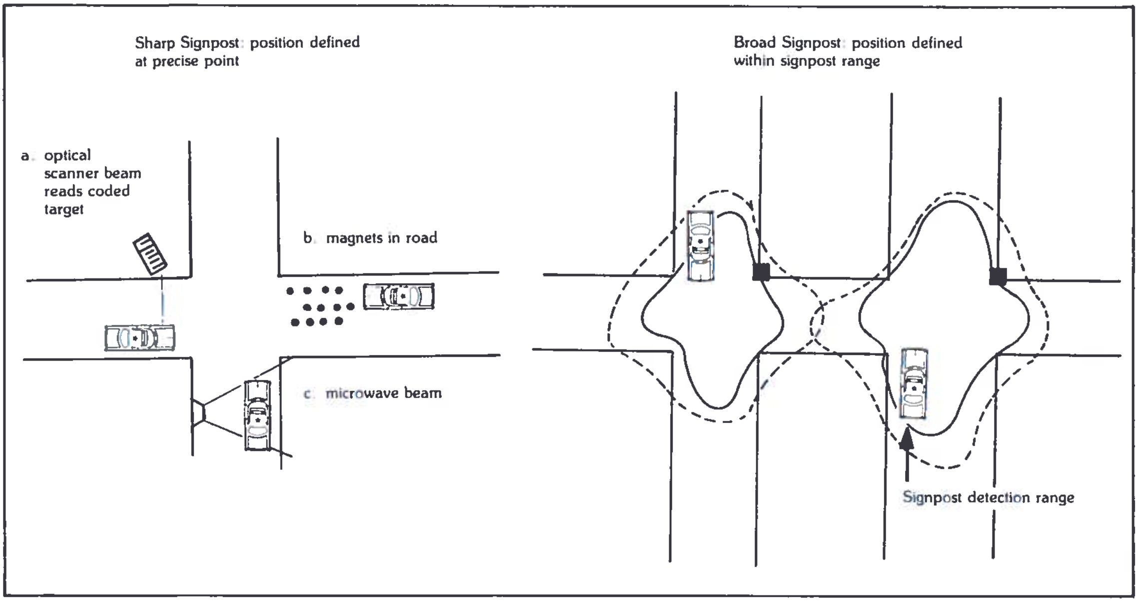


Figure 3. Comparison of Sharp and Broad Signpost Technologies

point which is crossed by the vehicle. A narrow beam optical scanner, a microwave transmitter, or magnets imbedded in the road surface may be used to interact with vehicle electronics in this operation. Typically, vehicle location between signposts is determined by odometer.

The level of accuracy of both proximity and inverted proximity technologies is a system design choice, and may or may not be proportionate to the number of signposts (or sensors) in the area served.

The location technology being used in Los Angeles is the broad signpost proximity type.[14] Battery-powered transmitters are installed on street lights or utility poles at intervals of 250 to 300 meters along the bus routes. Each transmits a unique digital code every 666 milliseconds at 49.860 MHz. A receiver and microprocessor aboard the bus use the signal levels of adjacent signposts to produce a code which locates the vehicle at one of five segments between the adjacent signposts. The location technology is accurate to within 100 meters at the 95th percentile.

An SCRTD bus receives a location code from a signpost.

[14]A hybrid location technology is also being tested as an alternative for use in random-route operations. This technology is described later.

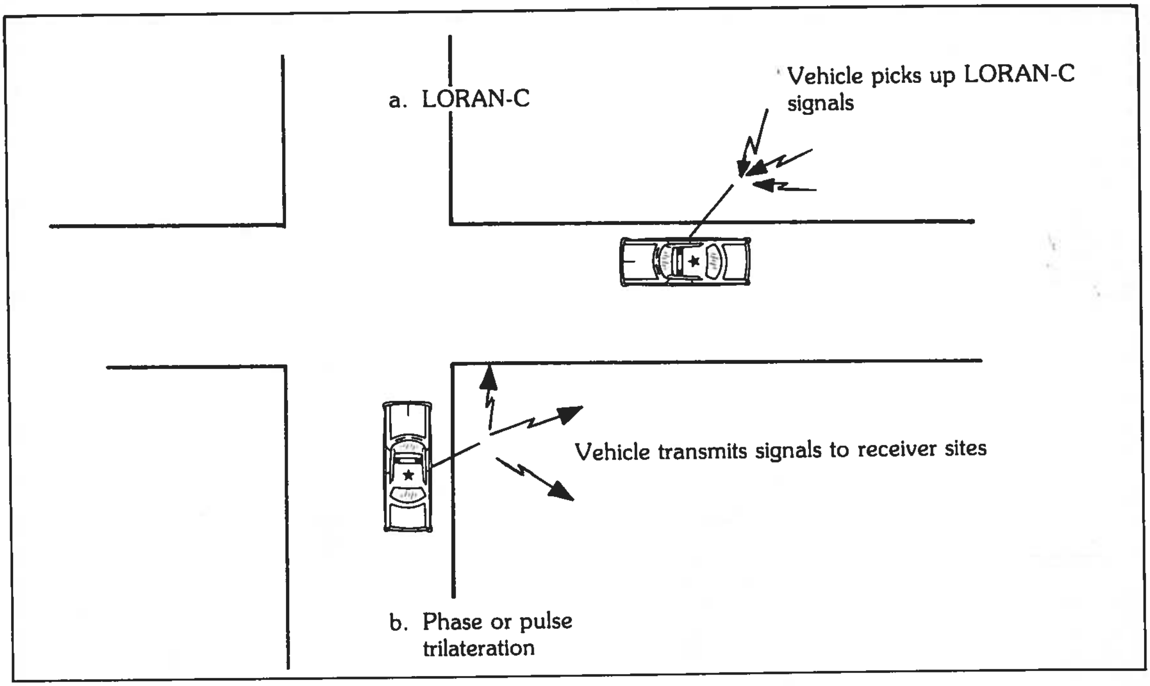


Figure 4. Signal Transmission Patterns in Radio Frequency Location Technologies: Position Defined at All Points

Radio frequency (RF) technologies. Radio frequency location technologies are based on radio navigation concepts that utilize time-of-arrival or phase differences of synchronized RF signals from (or to) three or more transmitters (or receivers) located at known geographic points. Phase trilateration, pulse trilateration, and LORAN are a few RF technologies being tested for use in AVM.

With the simplest kind of phase trilateration, the vehicle, when addressed by control, emits an RF carrier frequency modulated by an audio tone. Phase delay measurements of this signal at three or more fixed receiver sites yield difference in time-of-arrival of the signal at each station, and thus the difference in range from the vehicle to each station. With this location technology, the same radio transceiver in the vehicle can perform three functions of AVM (location, and voice and digital communications) operating within the standard 25 KHz allocation of the land mobile radio.

A pulse trilateration location subsystem consists of a network of receiving stations, spaced two to six miles apart in urban areas. At an assigned time during the polling cycle, each vehicle emits a sharp rise-time pulse, followed by a message code. The times of pulse arrival at the receiving sites are established and then relayed by wire to the central computer. Here the vehicle position is calculated by a trilateration algorithm using the pulse arrival times at three of the receivers best situated to determine the vehicle's position. Pulse trilateration can provide greater accuracy than phase trilateration. It may require additional radio equipment on board (one wide-band transmitter for the pulse system, and a transceiver in the normal VHF, or UHF mobile voice communications band).

With LORAN, three geograhically separated transmitters continuously transmit pulsed 100 KHz carrier signals. (Two of the transmitters are time-slaved to the third so that the time differences of pulse arrivals are noted.) Each vehicle receives the signals and stores the time differences. When polled by central control, the vehicle transmits the time differences to control, where location computations are made.

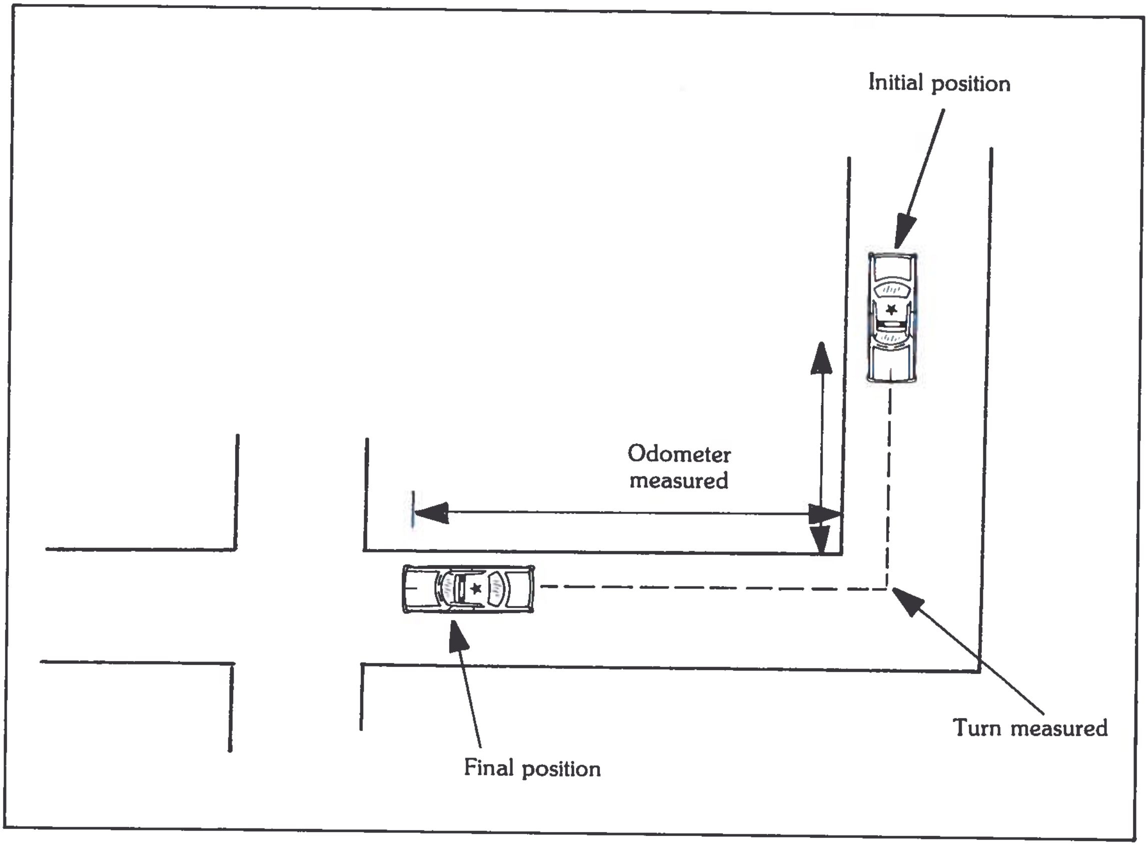


Figure 5. Dead Reckoning Location Technology: Position Defined at All Points

LORAN provides wide area coverage which can serve sparsely settled communities as well as large cities. A unique advantage of LORAN is that transmitters already exist in the environment, courtesy of the U.S. Coast Guard. LORAN does require, however, expensive on-vehicle receivers capable of performing phase comparisons of the transmitted signals.

Radio frequency technologies share to different degrees the problem of interference from high buildings, hills, noise, or other radio signals. The accuracy of phase trilateration is most drastically affected by such interference. Increasing the spectrum width or the number of receiver sites, or placing receivers away from strong reflectors may alleviate the problem.

As part of the Los Angeles AVM demonstration, a hybrid location technology which takes advantage of the long-term stability of LORAN positioning and the short-term tracking capability of a dual odometer is being tested. Three of fifteen transit service vehicles are equipped with prototype LORAN-C/differential odometer electronics and a Z80-based MDX microprocessor. These three vehicles will be tracked over a wide area during random-route operations. After being tested, the hybrid prototype can be added to all transit service vehicles without design modifications.

Dead reckoning technology. In contrast to proximity and radio frequency technology, dead reckoning typically provides location at any point in a service area without reference to external signals. With dead reckoning, high quality sensors (usually an odometer and some kind of heading indicator) continuously

SCRTD service vehicles are being used to test a hybrid location technology for random-route operations.

measure the distance and direction of travel. The stream of data thus produced is either used directly in a continuous position computation on board the vehicle, or held in a buffer for rapid relay to central control, where all vehicle positions are computed. In either case, some type of on-board microprocessor is necessary.

Dead reckoning sensors are subject to cumulative errors caused by wheel slip, differences in wheel size, tread wear, and tire inflation, and driving factors such as lane changes and weaving within a lane. These errors may be reduced by techniques like map-matching and recalibration.[15]

[15]Map matching is a process in which every vehicle-reported location is compared to a digital representation of the area street network. Each time a new report is received, corrections for known sensor biases on the reporting vehicle are made, and the vehicle is located on the "most probable" street. An initial calibration point is the known location of the vehicle at the beginning of its tour. Recalibration, then, involves redefining the precise location of the vehicle from time to time, either by direct communication with the driver or by some other means.

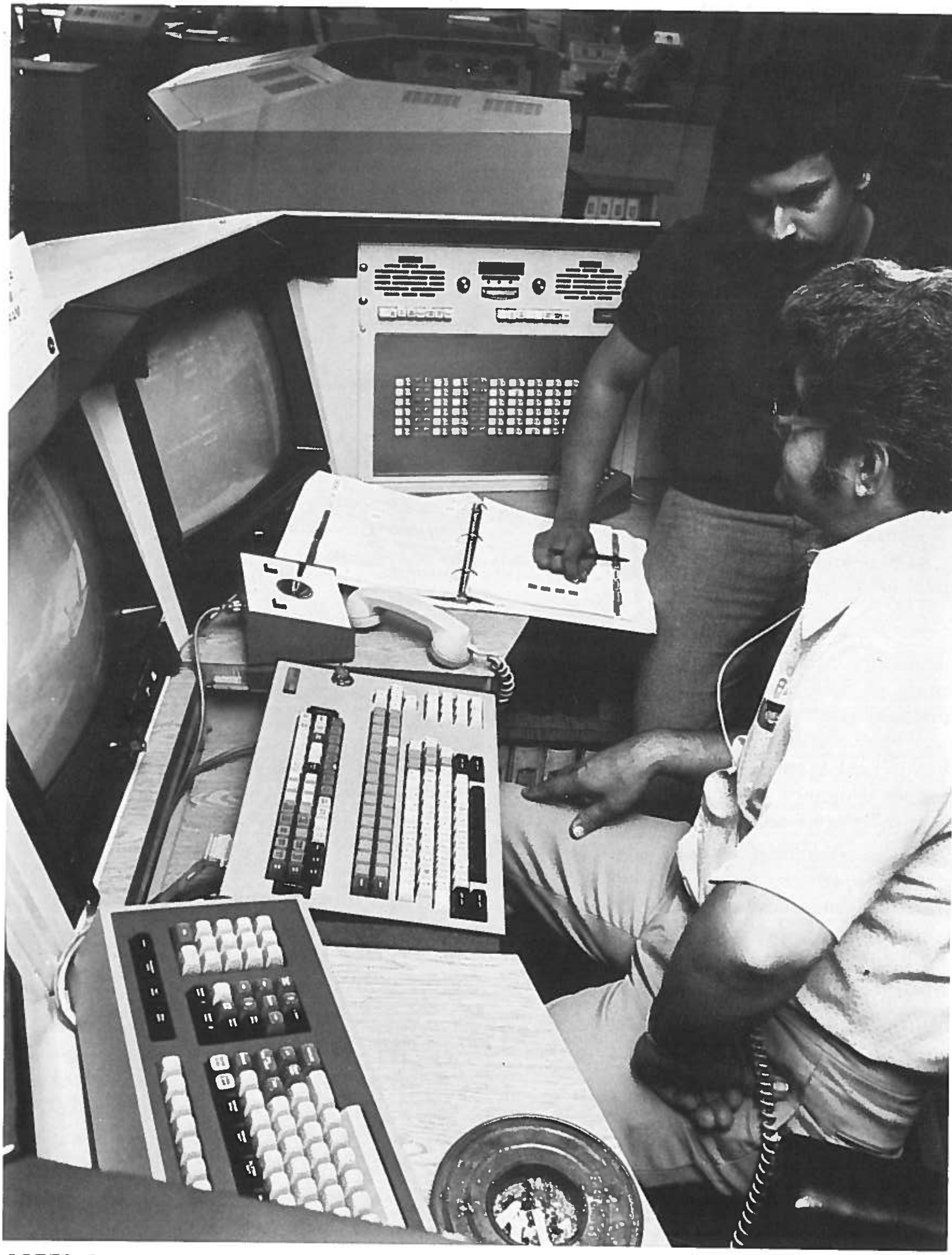
Communication Components

In an AVM system, a great deal of data on fleet operations is gathered and passed on automatically to a central processor during regular polling cycles. Dispatcher consoles display continuously updated information for the immediate use of the dispatcher in controlling the operation of the fleet. Control is accomplished by the dispatchers communicating with the drivers in one or both of two ways:

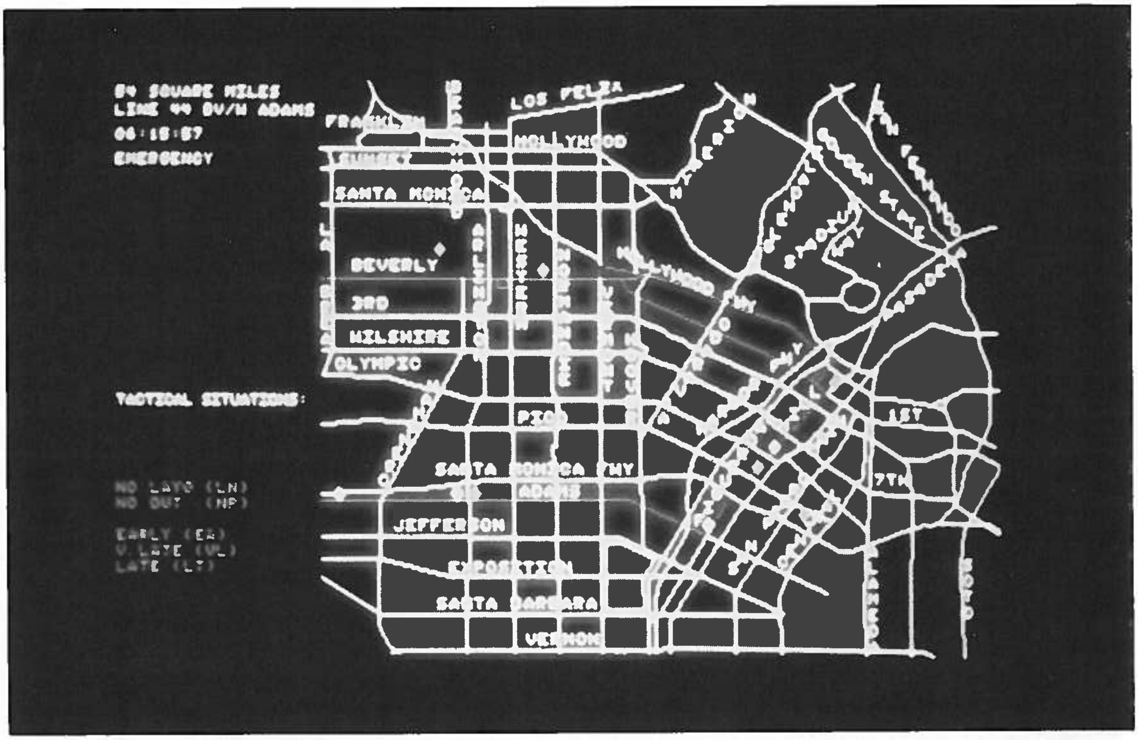
- Through a conventional two-way radio.
- Through digital messages (canned instructions) which light up on the vehicle display panel.

In police or other random-route operations, it is also important for dispatchers to have other kinds of information regarding the status of each vehicle (i.e., whether the vehicle is available for service, engaged on a call, etc.). Several of the canned digital messages used in random-route operations relay this kind of information from the driver to control.

The communication devices being utilized in Los Angeles illustrate more precisely what

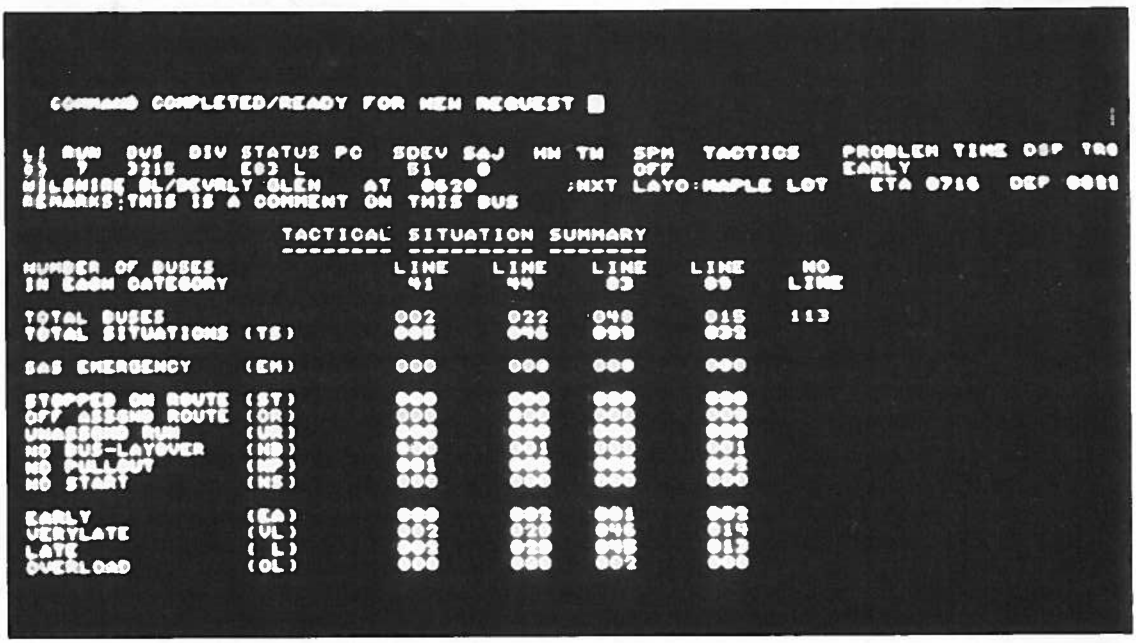


SCRTD dispatchers working at the console displays.



Random-route vehicles are tracked on this graphic display at the SCRTD control center.

On the alphanumeric display, dispatchers can review data on the entire fleet or on individual buses.



kind of information may be communicated and what kind of equipment may be involved.

In Los Angeles, voice communication is provided over an existing SCRTD voice channel. Two frequencies in the 800 MHz band (one channel pair) are used for digital communications between central control and the vehicles. The selection of the 800 MHz frequency was strictly a function of channel availability at the voice frequency. On the basis of the location of the route, vehicles are assigned to one of two base stations. A third hot-standby base station serves as a backup to the primary base station (i.e., the one with maximum vehicle coverage). Each base station has a General Electric MASTR II transmitter and receiver, a DB-480 antenna from Decibel Products, and a microprocessor that provides automatic communications link diagnostics in conjunction with the central computer. Vehicle equipment consists of a General Electric Executive II 800 MHz transceiver and a D106R 800 MHz antenna. In addition, a microprocessor on board each vehicle receives and stores data provided by the location technology and the passenger counter, and controls the flow of information to and from the driver's display panel, as well as the base station or control center.

Dispatcher displays. Two dispatcher consoles provide central dispatchers with a monitoring and control capability through an interface with the central processor. Each console includes a color graphic display (GMR-27 Grinnell Graphic Controller) and a color alphanumeric display (Aydin 5217). On the graphic display, the dispatcher may view a full route or any 1/5th or 1/10th portion of a route and observe the following information:

- System time
- Route identification
- Location of all buses (indicated by the location of the bus symbols)
- Direction of travel of all buses (indicated by the orientation of the symbols)
- Type of service of each bus (limited, alternate, etc., noted alongside the bus symbol)
- Schedule status (on schedule, behind schedule, significantly behind schedule, or ahead of schedule, indicated by the color of the bus symbol)
- Emergencies (line number, bus number, passenger count, and bus symbol are shown red, blinking until acknowledged, then red non-blinking)
- Stopped buses (line number, bus number, and passenger count of buses stopped over XX minutes).
- Off-route buses (line number, bus number, and passenger count of buses that are off route, but not scheduled to be so).

The dispatcher may vary data to be displayed by using a joystick and/or keyboard inputs. The color graphic display is automatically updated once each polling cycle (approximately every 40 seconds) — except that buses having activated silent alarms are updated once every 10 seconds.

An alphanumeric screen provides detailed information on individual buses or summary data on the line or the entire fleet. Through use of a split screen display, the dispatcher may simultaneously observe information from the data base while changing other data or sending information to selected buses. On this display, request-to-talk messages from buses are also identified and trouble reports are entered and updated.

On-vehicle display panels. Both bus and random-route vehicle display panels contain pushbuttons by which the driver can request to talk with the dispatcher on a priority or non-priority basis. A TEST button causes the vehicle to conduct a series of self-tests on AVM functions. A digital clock automatically synchronized with time at central control is also part of both types of display panels.

Other features of the display panels reflect differences between the types of operation. The bus display panel has a schedule performance meter, which is controlled by the central computer based on dispatcher-entered schedule deviation thresholds. Performance is characterized as significantly behind schedule, behind schedule, on schedule, or ahead of schedule, with three intermediate points quantified as well.

The bus display panel also allows the dispatcher to transmit 14 different digital control messages to the driver. Some of these ("observe schedule," for example) involve normal or routine tactical control. An *ACK* button acknowledges that the driver's message to the dispatcher has been received.

The random-route display panel, on the other hand, allows the driver to communicate "canned" status messages to control: vehicle in or out of service; operator in or out of car; available, on route, at scene of call.

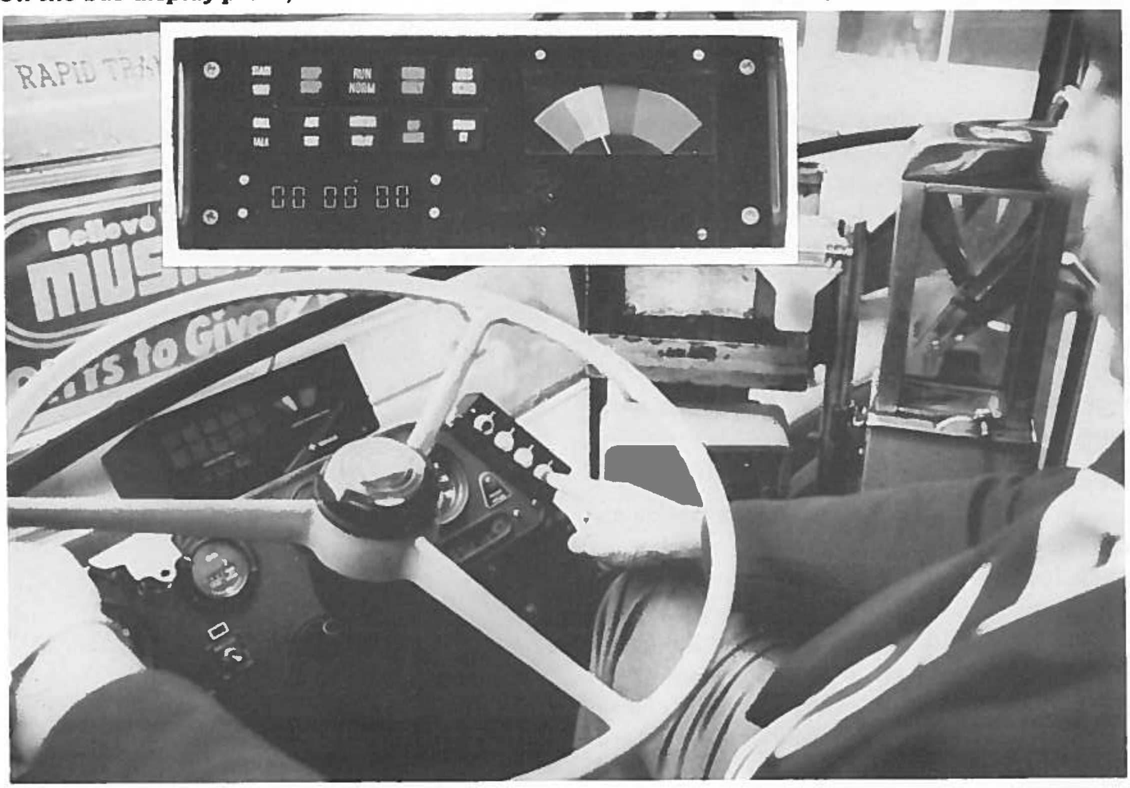
Silent alarm. Although it is not unique to AVM, the silent alarm feature must be considered part of the total communication subsystem, and certainly a vital part from the point of view of driver and passenger safety. All SCRTD vehicles in Los Angeles are equipped with a silent alarm switch for emergencies. Buses with active silent alarms are automatically placed into a priority polling queue.

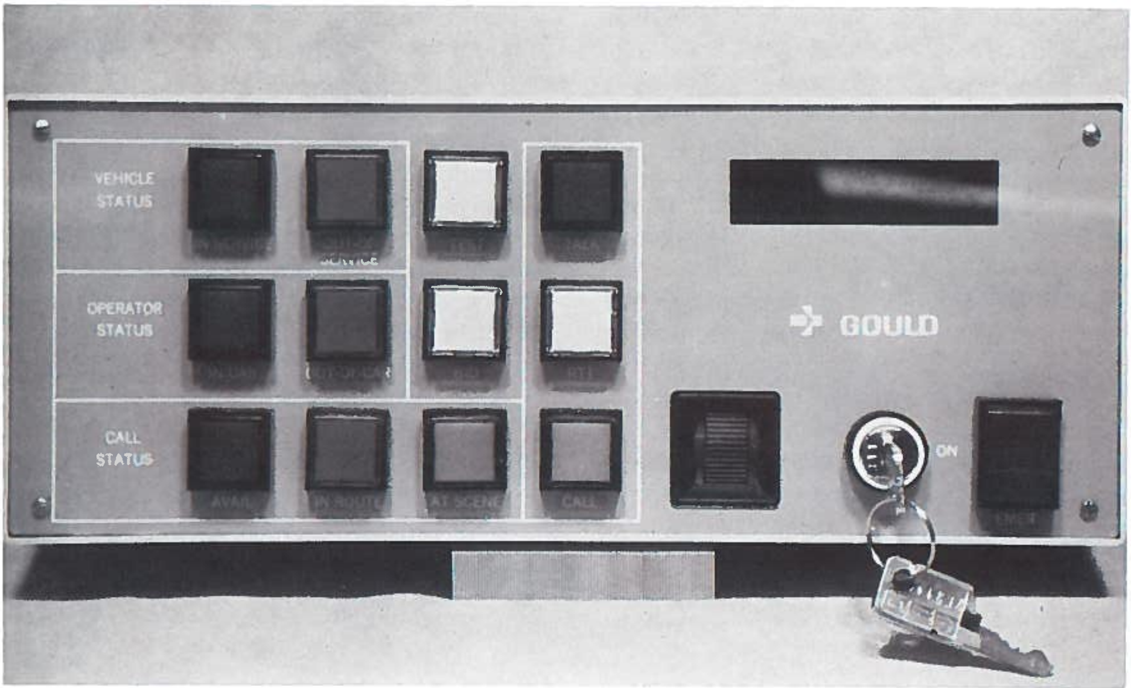
Bus stop displays. Used for experimental purposes in the Los Angeles demonstration, four portable bus stop displays provide information on the time of day, type of service, current headway, and estimated time of arrival of the next buses. The display contains an 800 MHz radio to receive data from central control over the digital radio link. A microprocessor controls the flow of updated information.

Central Data Processor

The "brain" of the AVM system is the central data processor and its software, which control the polling cycle and the displays and store dispatcher instructions and data used by dispatchers for tactical control of the fleet or by management in planning improved service.

On the bus display panel, SCRTD drivers receive "canned" instructions from central control.





A close-up view of the display panel for random-route vehicles being tested in Los Angeles.

The Los Angeles demonstration system is using a DEC PDP-11/60 minicomputer with 256K bytes of memory. Secondary random access storage is provided by two DEC RK06's with 14M byte disks. A DEC TWE 16 magnetic tape records all data transmitted over the communications link. Other processor support equipment includes a DEC LP11-VA high speed printer, a LA36 DECWRITER, and a WWVB receiver, which synchronizes the processor clock time.

Passenger Counters

In a conventional mass transit operation, checkers periodically count the number of passengers boarding and alighting from a bus at each stop along a route, and an average load factor is computed from the data. An AVM system applied to bus operations may incorporate an automatic passenger counter, which contributes to the efficiency of the overall operation.

Bus stop displays such as this prototype will be evaluated in Los Angeles.

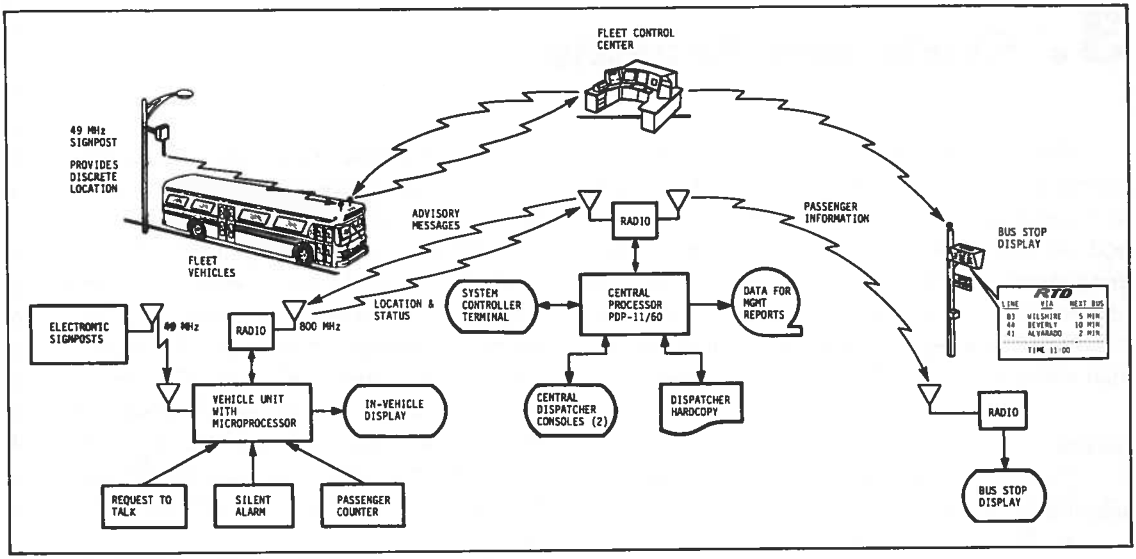


Figure 6. Flow Chart of the Los Angeles AVM System

Three types of passenger counting sensors are available:

- Treadle mat,
- Infrared beam, and
- Ambient light.

Placed in the steps of the bus, the treadle mat is a kind of sensor that responds to pressures exerted by boarding passengers. The infrared beam, located across the doorway to the bus, records the number of passengers by counting each time the beams are broken in a certain sequence by persons passing by the device. The ambient light sensor, usually located in the stairwell of the bus, counts passengers by responding to changes in the ambient light levels as persons pass by it.

To date, only the treadle mat and the infrared beam have been tested, and the treadle mat has proven to be more accurate. (10) For the Los Angeles demonstration, a treadle mat is being used. Passenger load data is processed by the computer at central control.

Figure 6 illustrates the relationship among the different AVM system components being demonstrated in Los Angeles.

3. Costs and Benefits

The primary objective of early AVM experiments, both in this country and abroad, was to improve service reliability and safety. Because cost savings were not a major concern, these early experiments produced little data on the operational and financial impacts of AVM. By contrast, an assessment of costs and benefits is a vital element of the UMTA AVM program.

Costs

The cost of implementing an AVM system is affected by several interrelated factors:

- Type of operation and the kind of location accuracy needed or desired.
- Size, density, and geographical characteristics of the service area.
- Type of location technology used.
- Size of fleet to be equipped.

The bulk of AVM costs are for capital equipment. The cost of the communication and computer equipment at central control is tied strictly to the type of location technology, and thus is least affected by variables. On the other hand, the costs of on-vehicle and wayside equipment vary considerably and are dependent not only on which type of location technology has been selected, but also on the number of vehicles to be equipped, the size of coverage area, and the accuracy desired. These factors, in turn, are dependent on the size and type of operation (e.g., bus, police, taxi); the type of route service (fixed or random); and characteristics of the field of operations (urban/suburban, high-/low-rise buildings, density, etc.).

To illustrate further the relation among factors affecting AVM costs, a maximum location error of 1000 feet may be adequate for many transportation systems, while 50 feet may be required by others. Although a police department demands greater accuracy than a taxi service, the maximum location error allowed by different departments may vary as much as from 50 to 550 feet. In choosing a location technology, then, the potential AVM user must weigh its own accuracy requirements with the costs of the technologies which would meet them.

For purposes of comparison, Table 4 rates several generic location systems in terms of accuracy and costs. The accuracy ratings are based on performance tests conducted during Phase One of the UMTA AVM program. (11) Both the sharp and broad proximity signpost technologies met TSC specifications of a 300 foot maximum allowable error for 95 percent of all location indications, and 450 feet for 99 percent.

The cost ratings for the location technologies are based on the TSC cost-benefit study performed at the conclusion of Phase One. (17) TSC found that for all four fleet configurations, (single user bus, police, and taxi, and the multiuser), sharp signpost and dead reckoning were the most costly by a factor of nearly two to three. Both of these technologies require sophisticated and expensive on-vehicle components.

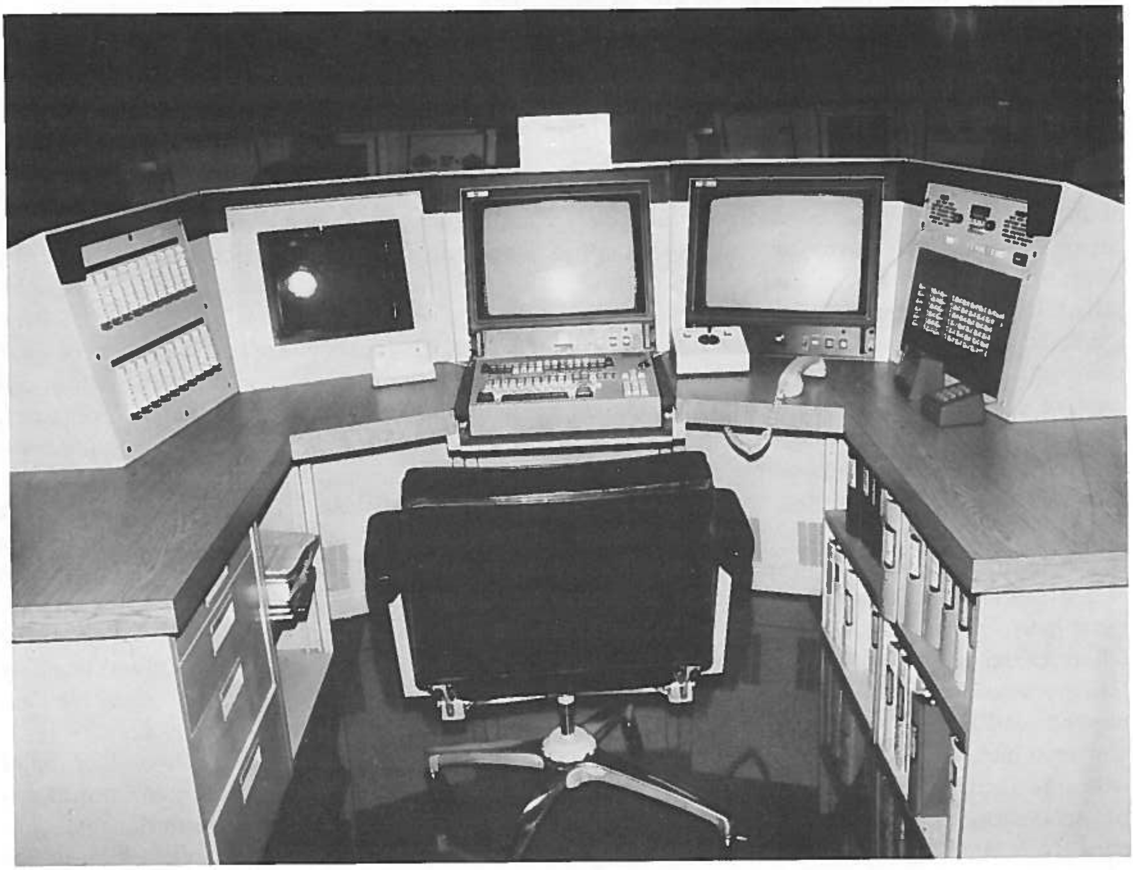
The broad signpost location technology appeared to be the most economical for large transit operations, including bus and multiuser fleets. The cost advantage of this technology is explained by the relatively inexpensive on-vehicle equipment and, for bus fleets, the ability to place wayside components only on bus routes. In a multiuser system, the cost of wayside equipment would be shared according to area usage.

Although radio frequency location technologies require the least expensive central computer and communication equipment, this cost advantage is offset for large fleets by expensive on-vehicle equipment. Smaller operations like police and taxi, on the other hand, have fewer vehicles to equip, and thus radio frequency technologies are the most economical choices for them. Better accuracy could be obtained by supplementing the RF technology with a few signposts.

TABLE 4
A COMPARISON OF FOUR GENERIC AVM LOCATION TECHNOLOGIES

Location Technology	Accuracy (1 = most accurate)	Cost (1 = least expensive)
Proximity		
Broad Signpost	2	1 for bus operation and multiuser fleet
		2 for police/taxi
Sharp Signpost	1	3 for bus and multiuser
		4 for police/taxi
Radio Frequency	3	1 for police/taxi
		2 for bus and multiuser
Dead Reckoning	NA	3 for police/taxi
		4 for bus and multiuser

Capital equipment like this dispatcher console represents the bulk of AVM costs.



Passengers' waiting time is often long or unpredictable.

Benefits

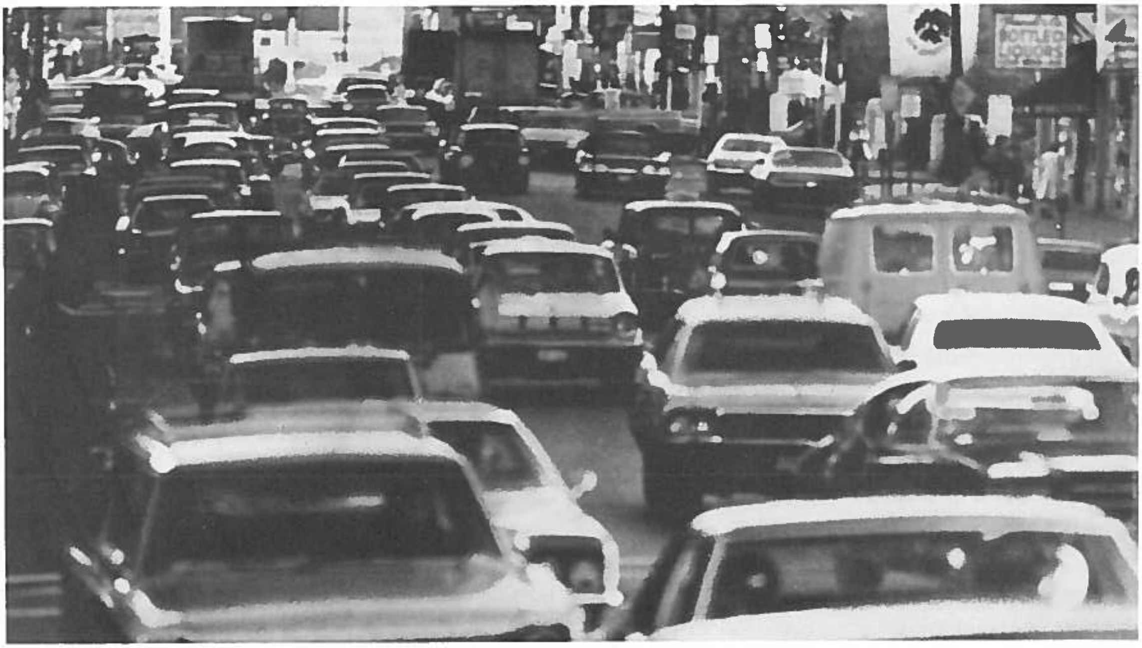
Benefits for transit operations. Complaints about public transit service in this country are well known. Service may be infrequent, and/or area coverage may be insufficient. Buses may run ahead of or behind schedule. In large transit systems, or on heavily traveled routes, buses often bunch together, creating long headways after the consecutive arrival of several buses at each stop. To avoid missing the bus, the passenger must get to the bus stop well in advance of the scheduled arrival time. If he or she misses a bus, the waiting time for the next one may be unconscionably long, or, worse for some people, unpredictable.

It is understandable, therefore, that for the most part, Americans use public transit only when (or because) they have no other means of transportation. Even today, with the escalating cost of gasoline and the national imperative to conserve fuel, the majority of Americans are unwilling to sacrifice their private automobiles for a transportation service that is known to be inconvenient and unreliable.

The unreliability of public transit, and of bus service in particular, is due partially to the limited control dispatchers have over the movement and progress of their fleet. An AVM system would improve the dispatcher's control capability for two reasons noted earlier. First, the dispatcher has immediate access to real-time information on the location and performance of each vehicle in the fleet. Secondly, the dispatcher can use this information to determine control tactics, which are passed on to the drivers via the communication equipment described earlier.

To what extent bus schedule adherence would be improved by use of AVM is not known. Obstacles such as high traffic density or stop light patterns may be difficult to overcome. One of the purposes of the UMTA demonstration in Los Angeles is to compare and evaluate fleet performance before and after the implementation of AVM.

In addition to unreliability, two other major complaints about conventional public transit service, that it is infrequent or that it does not provide sufficient area coverage, may be answered



AVM may have little control over heavy traffic.

by AVM. All of the data on fleet performance and passenger loads is stored by the data processor at central control for off-line analysis. Using this information, management can plan more efficient or productive use of the fleet by rescheduling vehicles. With increased fleet productivity, either expanded service or cost savings through reduction in the number of vehicles in a fleet are possible. Although high achievement of both objectives is unlikely, a balance may be struck between them.

AVM cost savings vary widely between cities because of extreme differences in cost factors such as insurance and service operating characteristics of transit properties. Still, the TSC cost-benefit study indicated that savings for transit properties are significant, with approximately half of the total savings made possible by automatic passenger counters, interfaced with AVM, which replace manual checkers. (17) Other costs are saved through reduction in personnel who check and control schedule adherence. Further costs savings may occur through reduction in the number of vehicles needed to maintain the same level of service.

To summarize the specific benefits to transit service, use of AVM could result in:

- Increased on-time service, with buses never early and seldom late.
- More uniform headway adherence on short headway routes.
- Shorter waiting time for passengers.
- More even distribution of passengers between vehicles.
- Increased passenger safety due to silent alarm feature used with AVM.
- Reduced layover time due to reduced uncertainty of total travel time. Thus, fewer vehicles and drivers are necessary to maintain given frequency of service on major routes.
- Cost savings through reduction in personnel and a more productive fleet.

Benefits for police operations. Police in cruisers conduct preventive patrols and respond to emergency and routine service calls originating from the district or "beat" to which they are assigned. AVM gives the dispatcher more precise information

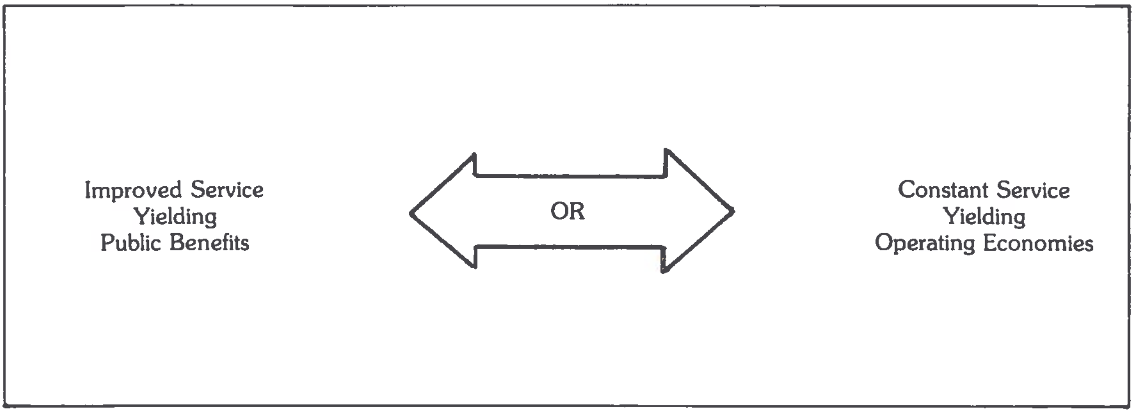


Figure 7. Increased Efficiency Requires Choice by Local Policy Makers

as to the location of each cruiser within a district. When a call comes in, then, the dispatcher can send the police who are closest to the scene, thus shaving seconds or even minutes from response time. Such improvements in field supervision and control would increase the likelihood of the apprehension of criminals and improve the protection of people and property. In addition, as much as ten percent of the distance traveled by police responding to specific calls could be saved. (Mileage in routine preventive patrol would be unaffected.) Over time, the fleet of cruisers and patrol personnel could be reduced in numbers without affecting the level of service or protection. This long-range effect would result in large cost savings (96 percent of total savings) because of the high expense of staffing patrol cars. (17)

By way of summary, AVM would:

- Improve the quality of field supervision, deployment, and tactical control.
- Reduce emergency response times, thereby improving protection of people and property.
- Improve productivity of the fleet.
- Reduce mileage and personnel costs.

Benefits for taxi operations. Similar to police operations, taxi operations involve a random-route fleet from which vehicles are selected to respond to service calls. AVM shortens taxi response time and reduces mileage because the dispatcher can send the closest available vehicle to the location of a call.

Normally, 50 percent of a taxi fleet's mileage is accumulated in non-revenue producing travel. According to the TSC cost-benefit study, AVM can help reduce the number of "deadhead" miles taken up by cruising in search of fares and returning from passenger drops to central pick up or dispatch points. Reduction in deadhead miles translates into a fleet reduction of at least 4 percent (compared to only 0.8 percent for police fleets). Because taxi drivers are paid on a commission basis, however, AVM would not produce large payroll savings such as are possible with police. While personnel costs would account for an estimated 96 percent of police savings, they would comprise only 28 percent of taxi savings. (17)

In conclusion, the TSC study suggests that although AVM would make a taxi fleet more productive, the actual cost savings may not outweigh the expense of the system.

Multiuser benefits. AVM benefits for a multiuser fleet are a summation of the benefits noted earlier for individual fleets, plus any additional cost savings which occur because of shared use of the system. Only one quarter of AVM costs are eligible for sharing: the costs of the computer and electronics equipment at central control, which are divided among users in direct proportion to the total number of vehicles in each participating fleet, and the cost of wayside equipment, which is divided according to area usage. Moreover, the cost savings for some participants is diluted if the AVM system

AVM can shorten significantly police response time.

AVM can reduce a taxi's "deadhead" mileage.

being shared is not the optimal system for them as individuals — either for economic or technological reasons. Only modest cost reductions are therefore possible with a multiuser system.

The TSC cost-benefit study revealed that a random-route or blanket coverage system with a minimal variation in service area boundaries would benefit most from multiple user AVM. In this case, the same location technology is more likely to be the most economical one for all users, and the proportion of wayside costs eligible for sharing would be increased. A test run of a multiple user system serving only police and taxi fleets resulted in cost reductions of 6 percent for the police and 14 percent for the taxi. (This compares to only 1 percent savings for police and 9 percent for taxi in the originally tested multiuser fleet, which included fixed-route buses as well.) (17)

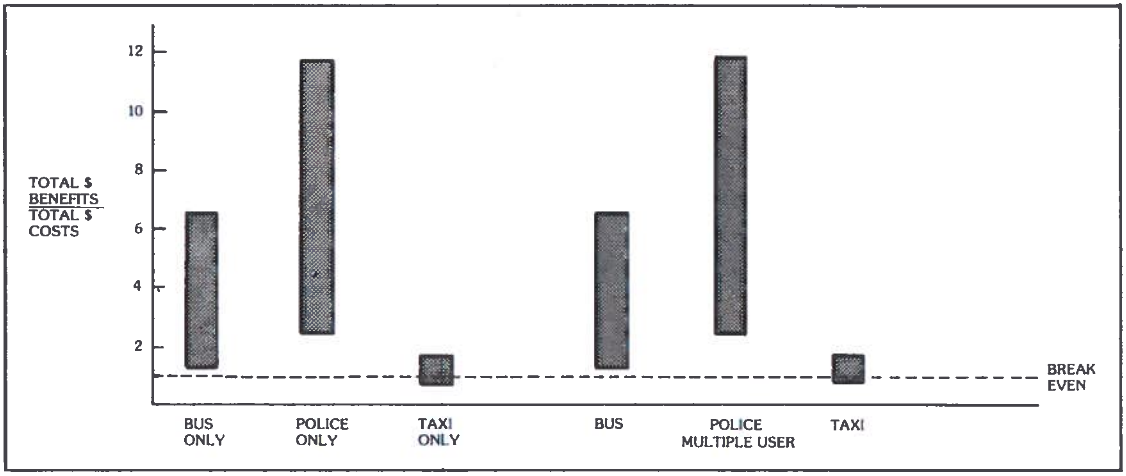


Figure 8. Benefit/Cost Ratios for AVM Used in Different Types of Operations

A Summary of Benefit/Cost Relationships for AVM[16]

Figure 8 shows TSC's estimated benefit/cost ratios for different fleet configurations, each using its low cost location technology.[17] In order to account for uncontrollable variables and uncertainties, TSC projected two sets of benefits, one conservative (low) and the other reasonably optimistic (high).

The police fleet carries the most attractive benefit/cost ratio, 2.4 in the low case, and 11.7 in the high. The ratio is improved by only 1 percent when a police fleet shares AVM costs in a multiuser system. The benefit/cost ratio for bus fleets ranges from a low of 1.4 to a high of 6.5, with a multiuser system having negligible impact. Financially, AVM benefits taxis least of all. The low benefit/cost ratio (0.7) is below the breakeven point, while the high (1.5) is in between the low estimates for bus and multiuser fleets. Participation in a multiuser system improves the taxi benefit/cost ratio by 9 percent. (17)

Future Deployment of AVM Technology

It is important to note that the Los Angeles AVM demonstration is an experiment only, and that even a favorable report does not imply that AVM is the system for everyone. Some transportation agencies may not require, or be able to afford, the extensive amount of information provided by AVM. Some transit properties, for example, may feel that automatic passenger counters alone may meet their objectives: to determine more realistically their total transportation requirements, and at the same time reduce the costs of manual data collection. Other agencies may wish to use AVM-related technology in a limited way. As has been shown, the Chicago Transit Authority, most concerned with safety in high crime areas, opted for an emergency alarm, interfaced with a location subsystem, and limited digital communications. Chicago's EVL system is used for neither real-time control of fleet performance, nor management planning. Cincinnati's information collection system, TIS, on the other hand, is used exclusively by management for planning purposes.

[16]Benefits here refer strictly to capital, operating, and personnel cost savings. Savings estimates are based on the number of vehicles which may be eliminated without affecting services.

[17]A broad signpost location technology for bus and multiuser fleet configurations, and a radio frequency technology for police and taxi.

A number of possible configurations of fleet management systems exist, including, but not exclusive of:

- Two-way voice radio.
- Voice communications with a selective call button and silent alarm.
- Digital communications with some manual input.
- Computer-aided dispatch.
- Automatic vehicle location or identification.
- Fully-automated vehicle location and status monitoring.

A transit property, police department, or taxi company interested in improving its service through a more advanced fleet management system should examine carefully its particular needs and a variety of ways of meeting them. Some important considerations are:

- The objectives to be met (i.e., safety, reliability, efficiency, cost reduction).
- The particular application desired (i.e., on-line, day-to-day control of a fleet, or off-line transit management and planning, or both).
- Requirements for the application (i.e., data collection, computation, and display requirements; the data channel from vehicle to base station; interfaces to other subsystems; and integration of the system into dispatch operations).

If AVM appears to be the answer, then management should invest in a system that is tailored to both its needs and the special characteristics of its operations.

Glossary

Algorithm

A set of rules used in mathematical computations.

APTA

American Public Transit Association (U.S. and Canada).

AVL

Automatic vehicle location, a term sometimes used interchangeably with automatic vehicle monitoring.

Broad signpost

In a proximity AVM system, a signpost which radiates a signal in a broad pattern; the vehicle can be located at any point within that pattern.

CAD

Computer-aided dispatch

CTA

Chicago Transit Authority

Dead reckoning

A location technology whereby equipment on the vehicle continuously measures the heading and distance travelled for tracking purposes.

Deadhead miles

Non-revenue producing miles, such as when an empty bus returns to the station or when a taxi cruises in search of business.

Digital communications

Electronic transmitting and receiving of data in a digital form.

EVL

Emergency vehicle location, a limited AVM system used by the Chicago Transit Authority.

Feeder service

A local transportation service which provides connections with a major transit service.

Fixed-route

A regularly scheduled service operating over a set route.

FLAIR

Fleet location and information reporting, an AVM system developed by Boeing and deployed by the St. Louis Police Department.

Headway

The time interval between transit vehicles travelling in the same direction on the same route.

LAPD

Los Angeles Police Department.

LEAA

Law Enforcement Assistance Administration.

LORAN

A long range navigation system in which pulsed signals sent out by two pairs of radio stations are used to determine the geographical position of a ship, airplane, or land vehicle.

Multiuser AVM

An AVM system shared by different groups, such as a transit authority, a police department, and a taxi company, operating within the same general area.

ODCS

On-board data collection system; the prototype system developed by General Motors was first demonstrated in Columbus, Ohio.

Off-line

A term pertaining to equipment, devices, or events which are not under direct control of the computer.

On-Line

A term pertaining to equipment, devices, and events which are in direct communication with the central processing unit and thereby under its control.

Paratransit

Flexible transportation services, operated publicly or privately. Typically, a small scale operation using low capacity vehicles, e.g. dial-a-ride, mini-bus, subscription service, van pools, etc.

Polling

A centrally controlled method of calling a number of points to permit them to transmit information.

Proximity location technology

A technology which locates vehicles according to their nearness to fixed reference points where signposts or sensors have been placed.

Radio frequency (RF) location technology

A location technology utilizing the transmission of RF signals (pulses) between the vehicles and a relatively small number of receivers or transmitters located at known geographic points.

Random-route

A transportation service which follows no set route.

Real-time

A term pertaining to a system which responds to events as they happen for such purposes as monitoring or controlling these events.

SCRTD

Southern California Rapid Transit District.

Sharp signpost

In a proximity AVM system, a signpost which locates vehicles at the particular point where they cross or intercept with a beam, signal transmission, or magnet.

Signpost

In a proximity AVM system, a term used for the low-level radio transmitters attached to stationary objects at intervals along each route.

Time points

Specific locations established by the transit operator or authority for the purpose of checking a bus's progress along a fixed route. Manual or automatic checkers note the time the bus passes each of these points.

TIS

Transit information system; the prototype system developed by General Motors was first demonstrated in Cincinnati, Ohio.

TSC

Transportation Systems Center of the U.S. Department of Transportation.

UMTA

Urban Mass Transportation Administration of the U.S. Department of Transportation.

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Inquiries about the availability or price of reports should be addressed to NTIS, rather than UMTA. The NTIS order desk telephone number is (703) 557-4650. Payment must accompany orders; cash, check, postal money order, GPO coupons, or American Express are acceptable. It is possible to establish an account at NTIS, from which payments are withdrawn when documents are ordered.

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