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AUTOMATIC VEHICLE MONITORING SYSTEMS STUDY

Report of Phase 0. Vol. 1
EXECUTIVE SUMMARY

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Prepared by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

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PREFACE

This document on Automatic Vehicle Monitoring Systems presents the results of work supported by the National Science Foundation. It was sponsored under an interagency agreement with the National Aeronautics and Space Administration through Contract NAS 7-100. Points of view and opinions stated in this document are those of the authors and do not necessarily represent the official position of the sponsoring agency.

FOREWORD

This report was prepared for distribution to public safety planners for the purpose of providing them with a compact source of information regarding improvements in efficiency and cost benefits obtainable with various classes of operational and proposed authomatic vehicle monitoring (AVM) systems. An AVM system can contribute to emergency patrol effectiveness by reducing response times and by enhancing officer safety as well as by providing essential administrative control and public relations information. This complete report and the Executive Summary (Vol. 1) were prepared by the Jet Propulsion Laboratory of the California Institute of Technology using the results of studies sponsored by the National Science Foundation.

Special computer programs are described which can simulate and synthesize AVM systems tailored to the needs of small, medium and large urban areas. These analyses can be applied by state and local law enforcement agencies and by emergency vehicle operators to help decide on what degree and type of automation will best suit their individual performance requirements and also the possible reduction in the number of vehicles needed which could substantially reduce operating expenses.

G. R. Hansen

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G. R. Hansen

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ABSTRACT

A set of planning guidelines is presented to help law enforcement agencies and vehicle fleet operators decide which automatic vehicle monitoring (AVM) system could best meet their performance requirements. Improvements in emergency response times and resultant cost benefits obtainable with various operational and planned AVM systems may be synthesized and simulated by means of special computer programs for model city parameters applicable to small, medium and large urban areas. Design characteristics of various AVM systems and the implementation requirements are illustrated and costed for the vehicles, the fixed sites and the base equipments. Vehicle location accuracies for different RF links and polling intervals are analyzed. Actual applications and coverage data are tabulated for seven cities whose police departments actively cooperated in the JPL study. Volume 1 of this Report is the Executive Summary. Volume 2 contains the results of systems analyses.

G. R. Hansen

AUTOMATIC VEHICLE MONITORING SYSTEMS

George R. Hansen

I. INTRODUCTION

In this report, the results of the first phase of a three-phase program to aggregate existing information on Automatic Vehicle Monitoring (AVM) Systems are presented in terms of performance, urban characteristics, operating modes, and cost in a way that will assist prospective AVM User Agencies to make valid comparisons and selections from among the many competing AVM techniques and AVM Systems. This phase (Phase 0) of the study was performed by the Jet Propulstion Laboratory (JPL) for the National Science Foundation (NSF). As originally conceived by NSF and JPL, the AVM Systems study program would include the following three phases:

Phase 0	Problem Definition and Derivation of AVM System Selection Techniques (in this Report).
Phase I	Critical Research and Verification of the Efficacy of AVM System Selection Techniques Through Computerized System Simulation.
Phase II	Proof of Concept Experiment Demonstrating the Efficacy of Selected AVM Systems in Urban Environments.

In brief, the Phase 0 research was concentrated in three areas: (1) Compilation of a broad information base on AVM technology and urban characteristics, (2) adaptation of computerized analytical techniques needed in the AVM System selection process and in cost benefit trade-offs, and (3) application of AVM System selection process by manual iteration to small, medium and large model cities.

Frequent reference is made in this Report to "AVM techniques" and "AVM Systems". The term "AVM technique" is used to denote the technology required to acquire a fix on a vehicle, while "AVM System" is used to denote the integration of all functional elements required to locate and keep track of vehicles in some automated fashion.

II. SUMMARY OF AVM SYSTEMS STUDY RESULTS

A. WORK ACCOMPLISHED IN PHASE 0

A broad range of information concerning automatic vehicle monitoring (AVM) was compiled from the existing literature, including: (1) Various vehicle location sensing techniques, (2) all functional elements of the total AVM system, and (3) various sized cities with representative geography, topology, demography and urbanology. The information obtained from the literature was supplemented by data obtained directly from police department representatives of seven Southern California cities that participated in the User Group Advisory Committee (UGAC).

Several computerized analytical techniques were developed. City models representative of those characteristics that affect AVM selection were developed for use in the general cost benefit solutions. An analytical technique for predicting vehicle polling rates achievable for the various location sensing techniques in a full AVM system configuration was also developed. Algorithms were developed to estimate the accuracies achievable by a large variety of AVM systems using the probabalistic distributions for three independent variables: (1) vehicle speed, (2) inherent accuracies of location sensing techniques, and (3) vehicle polling intervals.

Preliminary analyses were performed to determine first-order cost estimates for AVM Systems as a function of the various vehicle location sensing techniques when used in small, medium and large cities. Preliminary analyses of the accuracies achievable with various AVM systems were also performed. Various AVM system configuration options were developed, and promising options were examined for possible cost benefits to seven UGAC cities.

B. PRELIMINARY CONCLUSIONS

1. AVM Class should indicate effects on urban environment. From the viewpoint of the prospective AVM system user, the traditional classifications of vehicle locating systems (i.e., piloting, deadreckoning, triangulation, trilateration, and proximity) do not necessarily reflect the impact of an AVM installation on the local urban scene. It is believed that the prospective user's needs would be better met if vehicle monitoring classifications were based on system element types and functions as follows:

Class 0	Manual Monitoring. No AVM
Class I	AVM. No modification to the urban environment. (existing RF links)
Class II	AVM. Autonomous signposts throughout urban area
Class III	AVM. Sparsely distributed special RF sites
Class IV	AVM. Monitored signposts throughout urban area

2. AVM cost benefits obtainable by medium and large cities. The preliminary cost analysis indicates that the cost benefit break-even point occurs for a medium sized city with an area of about 100 km^2 (40 mi^2) and with roughly 50 vehicles. In other words, cities larger in size could expect a positive and increasing benefit with size, up to a certain point. Conversely, cities below this medium size probably would not realize any cost benefit. This conclusion was based on 5-year estimates of AVM system costs and savings.

3. No cost benefits derived from monitored signpost systems. None of the Class IV systems produced a cost benefit for the cities studied, generally because the rental rates on telephone lines raise the equipment costs excessively.

4. AVM System accuracies greater than technique accuracies. In general, the 95% total system accuracy can be expected to be significantly greater than the inherent accuracy of the location sensing technique. Usually the system accuracy is no less than three times the inherent technique accuracy.

5. Vehicle polling intervals determine AVM system accuracies. It appears that the polling interval will dominate system accuracy and that the polling interval can only be shortened at the expense of RF resources dedicated to AVM purposes. Because of the present and predicted future demand on RF resources, this is one area that demands optimization.

6. Critical research required for verification of selection technique. The results of the first phase of the AVM study effort should be used with caution and should not be construed as specific recommendations at this point. The second phase of the analytical work should be completed to verify the results of the first phase.

C. PROGRAM RECOMMENDATIONS

1. It is recommended that the second phase (Phase I) of the AVM Systems study proceed.

2. It is further recommended that mission agencies such as the Law Enforcement Assistance Administration (LEAA) and/or the Department of Transportation (DOT) sponsor the Proof of Concept Experiment, or third phase. The tests presently planned jointly by the city of Los Angeles and DOT could effectively serve this purpose. This could be accomplished by closely coordinating the analytical techniques developed in this study with the Los Angeles Police Department, the Southern California Rapid Transit District, LEAA and DOT and making the analytical tools available to the city for use in the design of the experiment.

III. CLASSES OF AVM SYSTEMS

A. CLASSIFICATION RATIONALE

Traditionally, AVM systems have been classified in the literature according to the method used to locate the vehicle within an urban area. Recognizing that all AVM systems have certain elements in common and that some systems have unique elements, an alternate classification scheme was developed for the purpose of this study. This classification not only implies the type of AVM system but also suggests the physical impact that the system elements and functions will have on the local urban environment. The following groupings of system elements suggested the classification scheme:

Functional Elements Common to All AVM Systems

(1) Existing communications system.
(2) Vehicle polling subsystem.
(3) Landline data links.
(4) Telemetry data/polling handler.
(5) Telemetry link (common to most).
(6) In-vehicle equipment, such as data processor, telemetry data encoder, polling processor, and signpost sensor.
(7) Vehicle location computer.
(8) Information display subsystem.

Functional Elements Unique to Specific AVM Systems

(9) Autonomous signposts; signpost sensor in vehicle (Class II).
(10) Fixed synchronized RF transmitter sites (Class III).
(11) Monitored signposts; vehicle sensor on signpost (Class IV).

A discussion of each of these AVM functional elements follows:

1. Existing communications system. As a practical consideration, AVM systems will probably be integrated with the existing voice communication and vehicle polling RF links, especially for the telemetered location data between the vehicle and the dispatch center.

2. Vehicle polling subsystem. This interrogation device or procedure enables the vehicle location computer (VLC), described in Element 7, to know which vehicle corresponds to which set of location data. Polling may be either an operating procedure or an active element that allows the dispatcher to obtain locations of specific vehicles.

3. Landline data link. This data link is a landline supplying data to the VLC (Element 7). It may either be relatively short, leading from the telemetry data/polling handler (Element 4) to the VLC, or it may be quite extensive, collecting data from monitored signposts throughout the covered urban area, or it may be somewhere in between these in its extent, bringing data from a relatively small number of fixed RF sites.

4. Telemetry data/polling handler. This device is included because AVM systems deal with data that are different (e.g., digital) in character from that used by the dispatcher in voice communication with the vehicles. Furthermore, if the vehicle polling subsystem (Element 2) provides for selective polling, then there are likely to be corresponding additional requirements on the communication system.

5. Telemetry link. Since it is tacitly assumed that the AVM system will not restrict the mobility of the fleet vehicles, some kind of communication-at-a-distance is essential. In some systems, the telemetry link is assumed to share or be in addition to the RF link now used for voice communications. In other systems the telemetry path might be between the vehicles and sparsely distributed synchronized RF sites. In still other AVM systems, the telemetry path may be relatively short, being only from the vehicles to signposts distributed throughout the urban area. In that case, the transmission medium could conceivably be sonic, optical, or even magnetic, instead of radio.

6. In-vehicle equipment. Depending on the AVM system, some or all of the four following devices may be carried in the vehicle:

a. Vehicle data processor. This device receives raw vehicle location data either from the officer or from signpost sensors. It does whatever data processing is done on-board, then adds the vehicle identification data, and passes this information along to the telemetry data encoder, described next.

b. Vehicle telemetry data encoder. This device puts the vehicle location data supplied by the vehicle data processor into the telemetry link (Element 5).

c. Vehicle polling processor. This device enables the vehicle to respond properly when polled, and may range in complexity from a clock to an RF signal decoder.

d. Signpost sensor. Where the densely distributed autonomous signpost concept is used (Class II), the signpost sensor must be carried in the vehicle. This sensor is required to read the signpost ID/location. Location data may be acquired by coded optical, infrared, sonic, or magnetic means besides radio.

7. Vehicle location computer (VLC). This device transforms the vehicle location data into location points or coordinates for use by the information display subsystem (Element 8). It also informs the display subsystem as to the identity of the vehicle to which the location data belongs. The VLC may also interface with the Computer-Aided Dispatch System.

8. Information display subsystem. This device indicates to the dispatcher where the vehicles are currently located (or were when last polled). It may also identify the vehicle's status. As in the case of manual aids used for vehicle location in Class 0, the possible range of complexity and sophistication may range from a simple printer to an elaborate electro-optical device supported by a computer. It should be noted that the display subsystem is virtually independent of the location technique used.

9. Autonomous signposts used in Class II AVM. Each autonomous wayside or buried signpost has a location ID and must be recognizable and readable by the signpost sensor in the vehicle. The signpost telemetry link to the vehicle may be by radio, pulsed light, infrared, sonic, or magnetic means.

10. Fixed synchronized RF transmitter sites used in Class III AVM. These RF sites are a relatively small number of special-purpose transmitters which broadcast synchronized signals that can be used to determine the locations of receivers on vehicles by means of navigation techniques. The characteristics of these signals could be FM phase, pulse, or noise correlation. Some of these sites may also receive retransmitted signals from the monitored vehicles.

11. Monitored signposts used in Class IV AVM. Each monitored wayside or buried signpost requires a vehicle sensor that will transmit the vehicle's ID data received and also identify its own location to the central collection station. These signposts may sense vehicle motion, or they may detect pulsed light, infrared, or ultrasonic signals or receive RF signals through buried antennas.

B. AVM CLASS DESCRIPTIONS

The vehicle location system classes, based on their physical impact on the urban environment, are shown in the following list and are described in greater detail in subsequent paragraphs and accompanying figures. For reference, the traditional vehicle location classifications are noted as indentures.

(1) Class 0 Manual Monitoring. No AVM
  (a) Piloting
(2) Class I AVM. No Modification to Urban Environment (Existing RF Links)
  (a) Officer Update
  (b) Dead Reckoning
  (c) Navigation (Using Existing RF Beacons)
(3) Class II AVM. Autonomous Signposts Throughout Urban Area

(4) Class III AVM. Sparsely Distributed Special RF Sites
  (a) Triangulation
  (b) Trilateration
(5) Class IV AVM. Monitored Signposts Throughout Urban Area
  (a) Vehicle Proximity

1. Class 0 Manual Monitoring; No AVM. This baseline (piloting) class is included in the listing of vehicle location techniques purely for comparative purposes. In Class 0, the location monitoring methods (Figure 1) range from those relying solely on the dispatcher's memory, through manually updated mechanical and visual aids, to keyboard-updated computer displays which keep current each vehicle's location and status based on verbal or digital communications between dispatcher and vehicle.

2. Class I AVM with no modifications to urban environment. All AVM systems require the installation of certain equipment in the command center to accomplish the automation of vehicle monitoring. All AVM systems also require the installation of some device in or on the monitored vehicles. But systems in Class I require nothing further, though they perforce utilize RF resources.

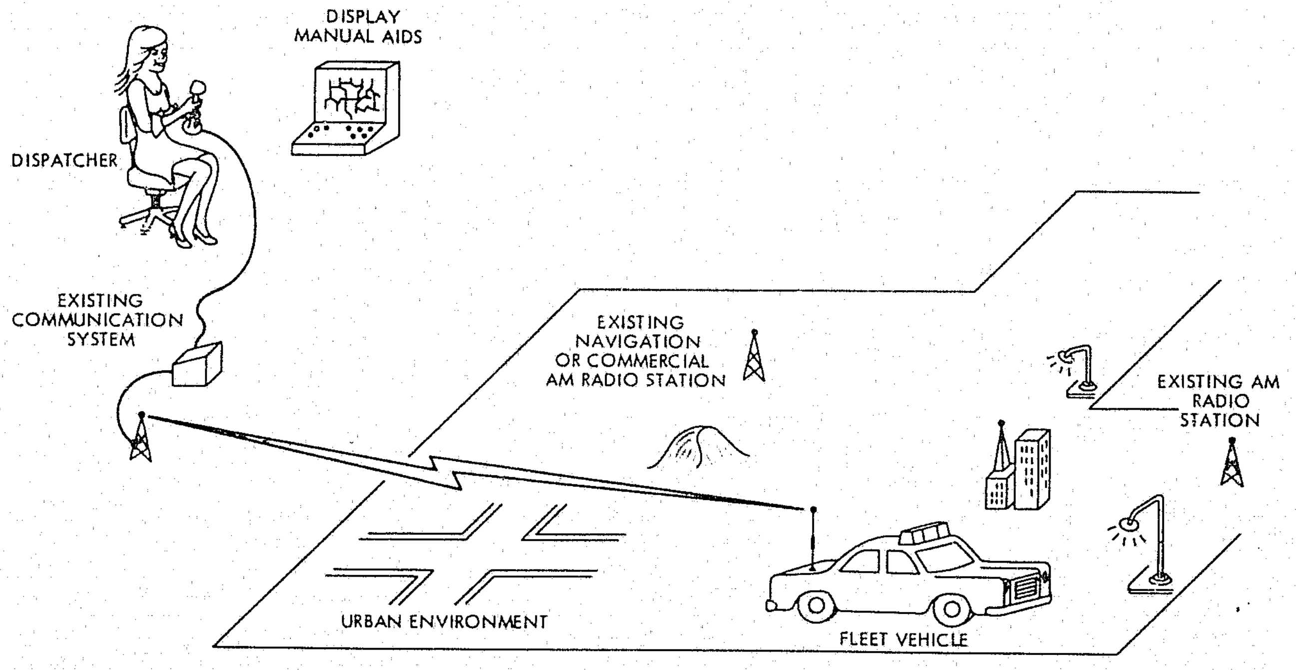

Figure 1. Class 0 Manual Monitoring, No AVM

A typical Class I AVM configuration is shown in Figure 2. Each AVM command center must contain a display subsystem, a vehicle location computer, a vehicle polling subsystem, and a telemetry data/polling handler, which are described in Section IV. Each vehicle requires location sensors, a data processor, a telemetry data encoder, and a polling processor. Class I AVM systems are based upon a variety of location techniques and algorithms which include the following: (a) Officer update techniques, in which the functions of the vehicle's sensors and its data processor are performed by an occupant of the vehicle. (b) Deadreckoning systems are included if the requisite updating does not require the installation of fixed location reference equipment in the environment. (c) If the AVM systems use existing navigation beacons or AM broadcasting stations, they are also included in Class I because the required stations are assumed to be part of the urban environment.

3. Class II AVM with autonomous signposts throughout urban areas. The defining characteristic of Class II AVM systems is the installation of autonomous signposts in strategic wayside or buried locations at intersections throughout the covered urban area. These location reference sites are autonomous in that they communicate their identity only to the vehicles and not to the command center.

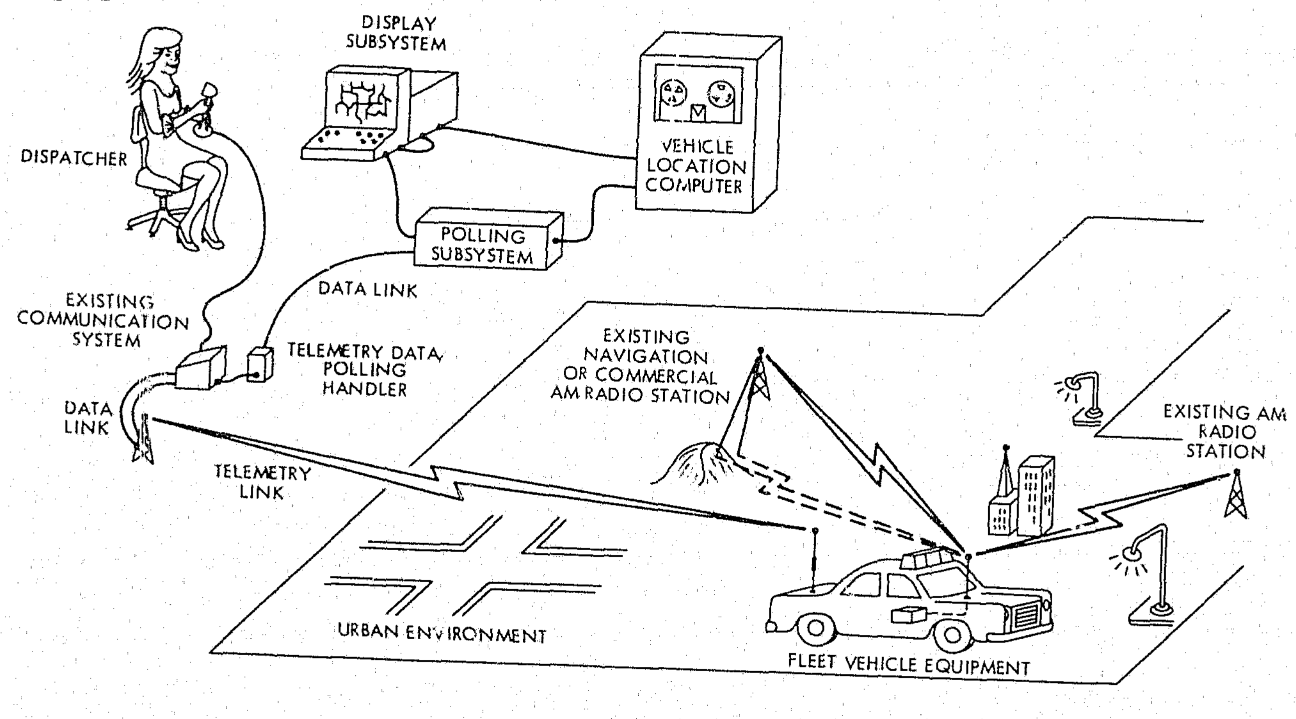

Figure 2. Class I AVM; No Modifications to Urban Physical Environment

The location information provided by the signposts to the vehicle may be either an identification code or the geographic coordinates of the location. Since the vehicle location accuracy provided by systems in Class II is dependent upon signpost spacing, greater accuracy can be achieved in critical areas by locally increasing the signpost density to one per intersection or per lane. A typical Class II system configuration is shown in Figure 3. Signpost systems can be "pure", in that all location information is derived from the fact that a monitored vehicle is (or was) near a signpost; or they can be "hybridized", with the fact of signpost proximity used either to augment, calibrate, or reinitialize the determination of vehicle locations obtained by other means, such as odometers. If a hybrid system does not require a data link in the environment, it is placed in Class II. If the hybrid system requires a data link from the signposts but no special-purpose fixed RF sites, it belongs in Class IV. If it has both a data link in the field and special-purpose fixed sites, it is in Class III.

4. Class III AVM with sparsely distributed special RF sites. This AVM class includes those systems that require the installation of a relatively small number of special purpose fixed RF sites, where a "fixed site" either broadcasts or receives over a relatively large urban area with a radius of 5 to 11 km (3 to 7 miles).

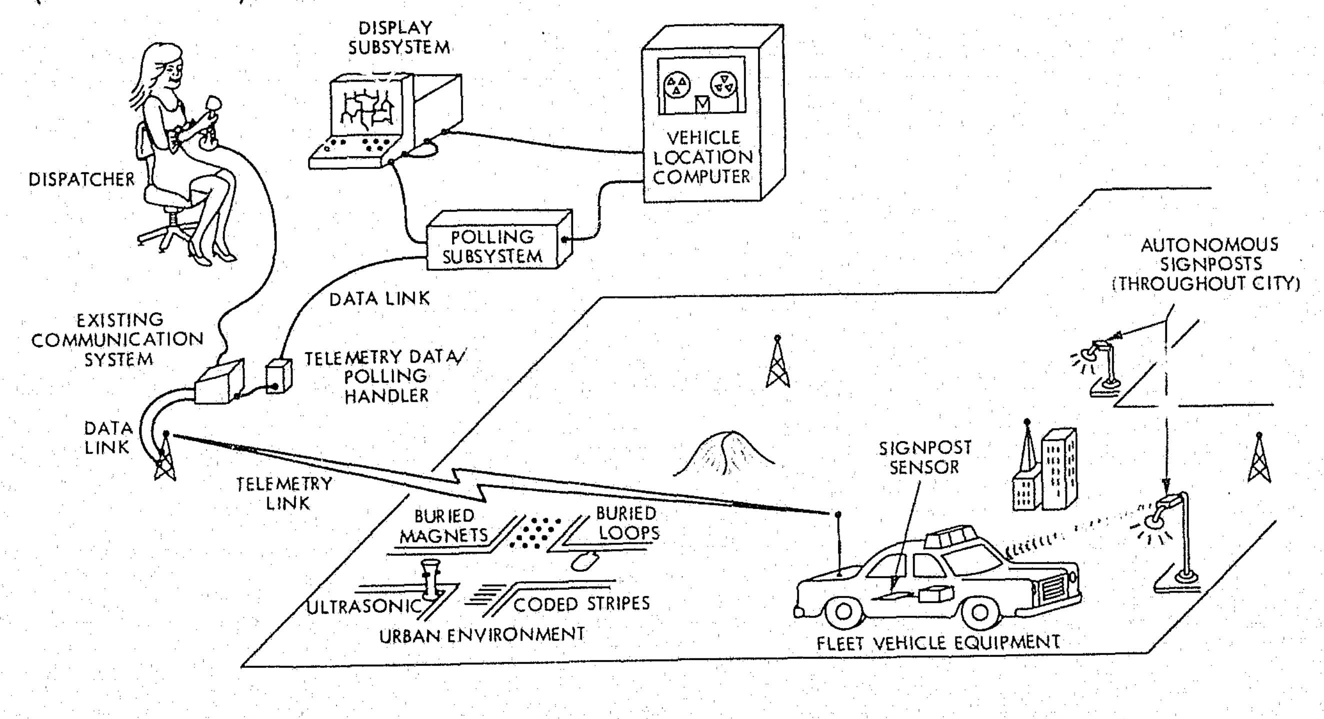

Figure 3. Class II AVM; Autonomous Signposts Throughout Urban Area

Data links in the environment are required to maintain synchronization for triangulation or trilateration purposes. Since the number of fixed sites is relatively small, these data synchronization links could be microwave rather than landline. Figure 4 shows a typical Class III configuration. It is optional only in Class III systems whether the telemetry link from the vehicle be along the existing communication system or through the special-purpose RF sites. In either case, RF resources are utilized for that link.

5. Class IV AVM with monitored signposts throughout urban area. Systems in this class contain monitored signposts installed in strategic wayside or buried locations throughout the covered urban area for the purpose of sensing the proximity and identity of signals transmitted from vehicles. A Class IV data link does not share the use of RF resources with the existing communication system but uses telephone lines, which may make this class of AVM systems very attractive for some applications. A typical Class IV system configuration is shown in Figure 5.

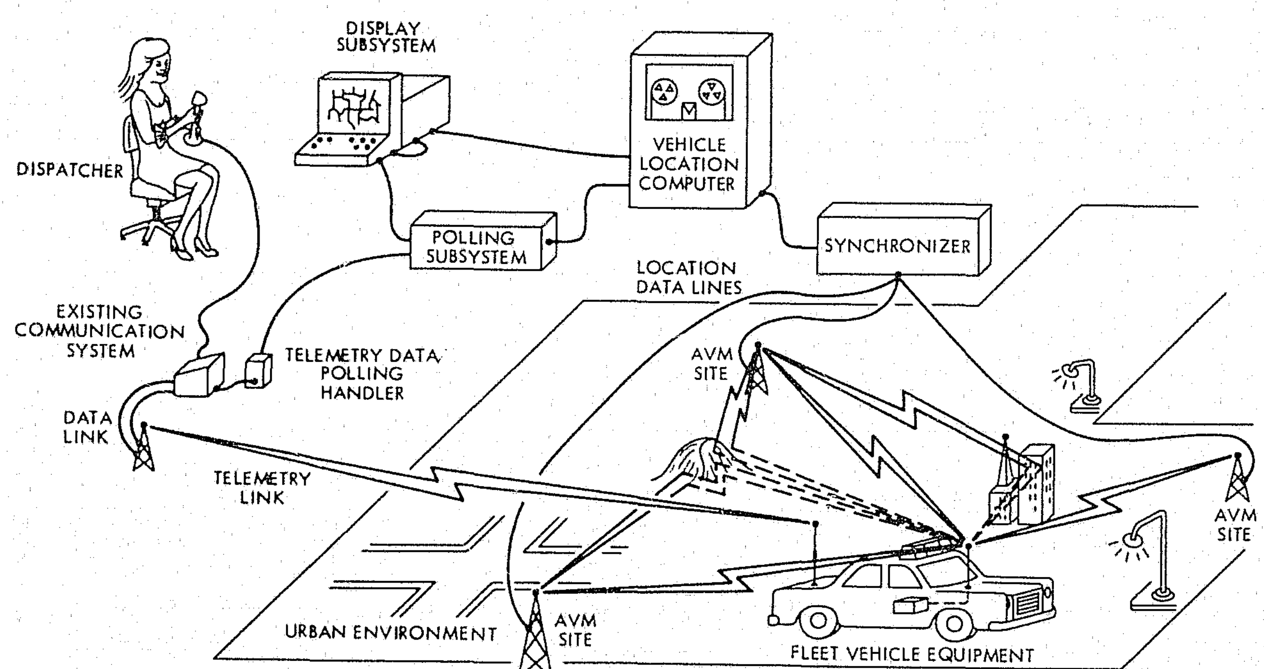

Figure 4. Class III AVM; Sparsely Distributed Special RF Sites

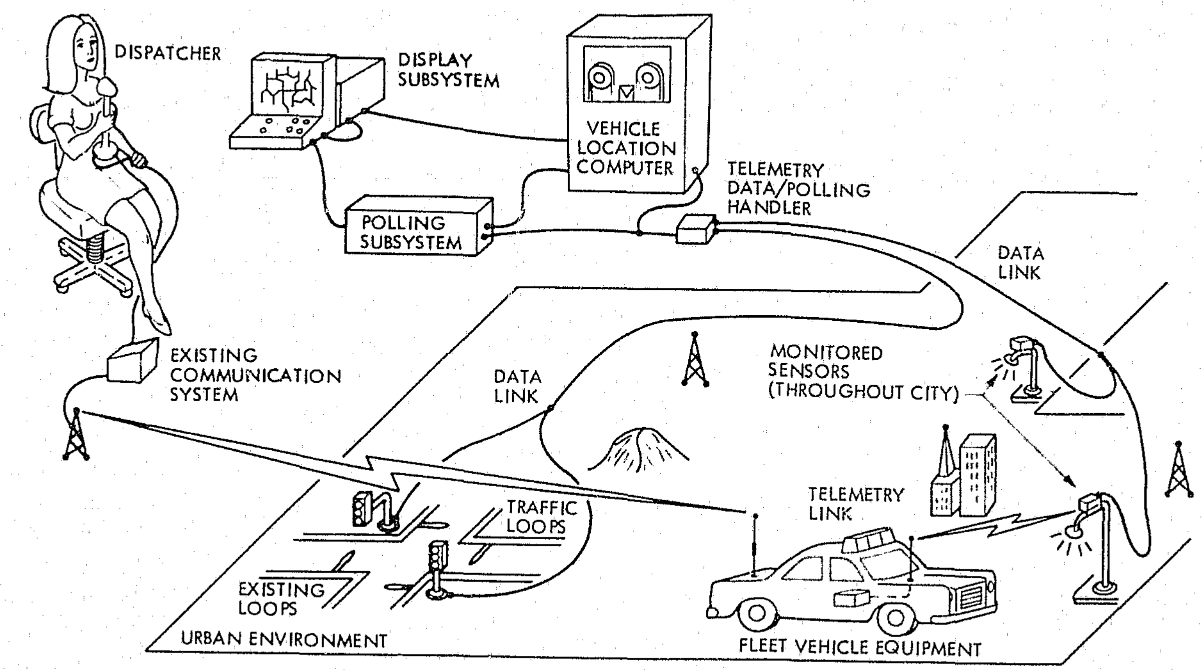

Figure 5. Class IV AVM; Monitored Signposts Throughout Urban Area

IV. VEHICLE LOCATION TECHNOLOGIES AND COSTS

A. PROVED AVM TECHNIQUES

This section contains a narrative description and a compilation of the cost and performance parameters of operational or proved techniques used for automatic vehicle monitoring (AVM). Schemes primarily intended for vehicle identification, such as those used in rail freight or extensions of point-of-sale methods are not included. In this report, the vehicle monitoring techniques are categorized into five broad classes, based on system element types and functions: Class 0, Manual Monitoring, no augmentation of location information; Class I AVM, no additions to the urban environment; Class II AVM, densely distributed autonomous signposts; Class III AVM, sparsely distributed special transmitting/receiving fixed RF sites; and Class IV AVM, densely distributed monitored signposts. In Table 1, the proved vehicle location methods are listed by AVM Class along with estimated costs (as of 1974) for unique system-required equipments installed in each vehicle and at each signpost or special fixed site.

1. Functional diagram correlating various AVM techniques. In order to make equipment and cost comparisons, a functional block diagram combining the elements that make up all of the AVM techniques was generated. This block diagram (Figure 6) demonstrates the equipment and functional commonality among the various techniques. In most techniques, the functional elements can also be physically identical, such as the location/vehicle ID/status register. Variations in costing such elements are due to other factors, such as achievable location precision, fleet size, and amount of status telemetry desired which all affect register length but are technique independent.

Figure 6 illustrates the numerous optional methods available for performing the vehicle location function which make AVM system comparisons difficult. For example, the various Class I techniques can either process the location data on the vehicle or transmit the raw data to the base station. In the Class III techniques, the vehicles may be polled either through the normal 2-way radio or through a special telemetry link used for vehicle location purposes.

Table 1. AVM Classes, Systems and Costs of Functional Elements Installed

AVM Class and System	Element Costs, $	
	Vehicle	Fixed Site
Class 0. Manual Monitoring. No Augmentation of Vehicle Location Information		
Class I. No Modifications to Urban Environment (Existing RF Links)		
(1) Officer update systems	—	—
(a) Keyboard entry	120	0
(b) Stylus map	2535	0
(2) Dead reckoning systems	—	—
(a) Two accelerometers	500	0
(b) Two velocimeters	—	—
Laser, orthogonal	715	0
Laser/compass	805	0
Ultrasonic	485	0
(c) Odometer/compass	—	—
Magnetic compass	285	0
Gyro compass	—	0
(3) Navigation, existing beacons	—	—
(a) OMEGA systems	—	—
Differential	1580	0
Relay OMEGA	455	0
(b) LORAN (A, C, or D)	—	—
Differential	2680	0
Relay LORAN	505	0
(c) DECCA System	1010	0
(d) AM Broadcast stations	365	0

AVM Class and System	Element Costs, $	
	Vehicle	Fixed Site
Class II. Autonomous Signposts Throughout Urban Area		
(1) Active signposts	—	—
(a) Radio beacons	—	—
Low frequency	145	165
Citizen band, VHF	145	145
X-band beacon	160	275
(b) Ultrasonic signposts	170	160
(c) Optical, infrared	170	155
(d) Buried antennas	135	120
(2) Passive signposts	—	—
(a) Buried Magnets	95	110
(b) Reflective patterns	—	—
Coded on signposts	580	85
Coded on roadway	135	125
(c) Buried resonant loops	135	95
Class III. Sparsely Distributed Special RF Sites		
(1) Trilateration systems	—	—
(a) Phase TOA	—	—
Narrow-band	100	5,000
Wide-band	2,965	11,000
(b) Pulse TOA	1,435	14,500
(c) Interferometer, noise	885	9,000
(2) Triangulation systems	—	—
(a) Rotating beams (HONORÉ)	—	—
(b) Direction finding	50	27,500
Class IV. Monitored Signposts Throughout Urban Area		
(1) Radio receivers	—	—
(a) Wayside	135	260
(b) Buried antennas	145	265
(2) Ultrasonic receptors	185	280
(3) Optical, infrared detectors	185	270

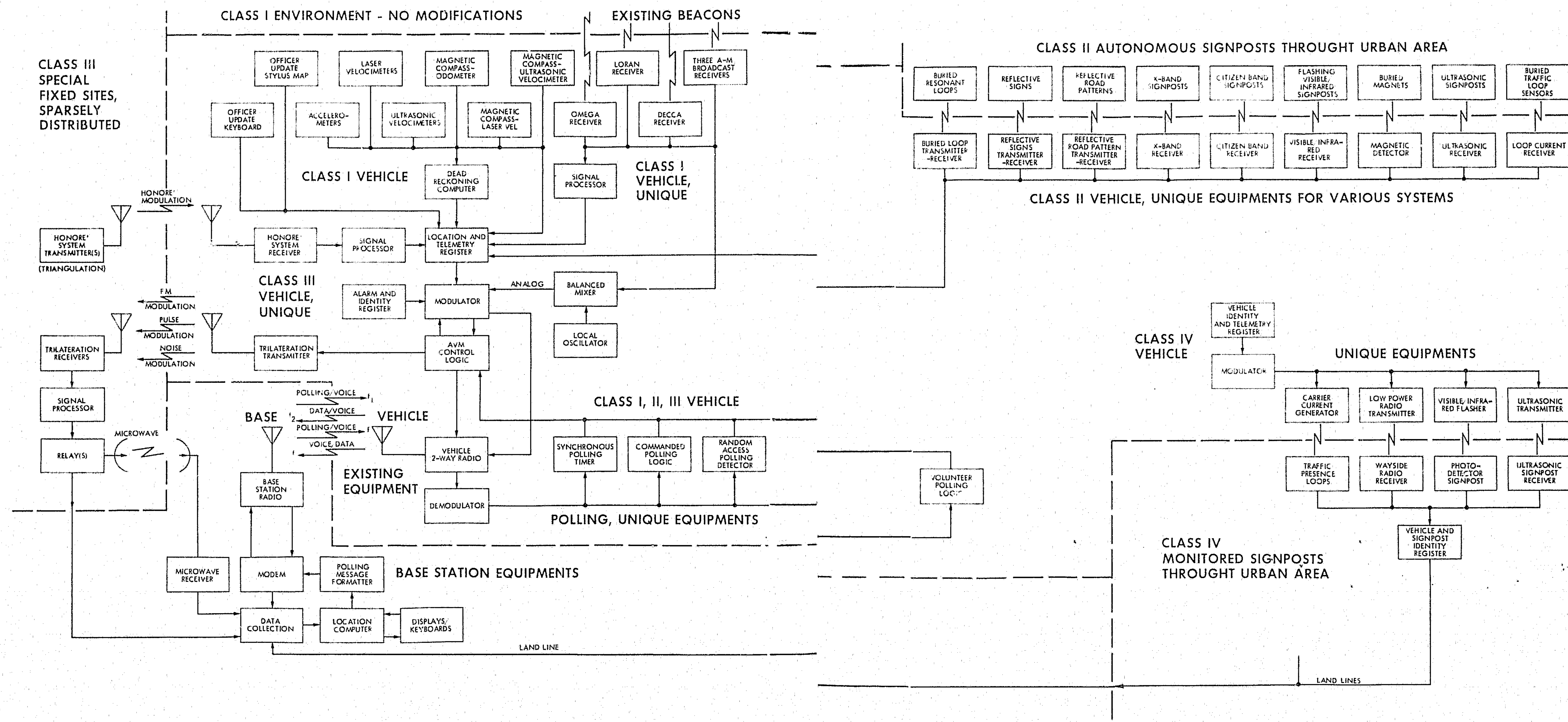

Figure 6. AVM Systems Showing Common and Unique Equipments for Vehicles, Signposts, and Base Stations

Class I, II, and III techniques may use any of the various vehicle polling techniques. Polling does not apply to the Class IV monitored signposts. The consideration of which polling method is to be used may depend heavily on whether or not equipments requiring digitial communication have already been installed.

2. Technical and cost parameters. Virtually every technical performance and cost estimate parameter of a particular vehicle location technique is system-dependent. The AVM system accuracy, the numbers of fixed sites, the message lengths, the data rates, the base station computing, the information displays, software, and RF channel requirements are all functions of the particular application. Some functional elements and performance factors can be determined to a limited extent, such as the cost and coverage radius of the various signposts, RF beacons and traffic presence sensors in Classes II, III, and IV; and also the cost and minimum message requirements of the vehicle sensors and data processors in Class I.

In order that cost estimates could be made for the various AVM techniques, extremely simplified block diagrams of the unique functional elements associated primarily with the vehicle location process were developed. That is, only the vehicle sensor and AVM fixed sites associated with the particular technique were considered. These cost figures accompany each of the descriptions and considerations of the method in the following section.

B. AVM COST CONSIDERATIONS

In addition to the costs associated with the vehicular and fixed site functional elements required for the basic location process, there are the costs of yearly maintenance and vehicular radio additions or modifications for transmitting and receiving AVM signals. Estimates of the vehicular costs (as of 1974) for each class of AVM are presented in Table 2. In this table, the radio cost and the radio modification columns represent optional choices. That is, the radio modification cost is not applicable where a separate radio for AVM signals is selected.

The costs for fixed sites equipment, installation, operational maintenance, data link, and mileage charges per mile per month are summarized in Table 3 for Classes II, III, and IV.

Table 2. Vehicle Equipment Costs* for All AVM Classes and Systems

VEHCOST

AVL COSTS PER VEHICLE IN $

TECHNIQUE	SENSOR	PROC.	RADIO	RAD.MOD	INST	O-M
CLASS I						
KEYBOARD	45	40	1200	50	35	15
STYLUS MAP	2465	35	1200	50	35	25
2-ACCELEROMETERS	400	1000	1200	200	100	100
LASER VELOCIMTR	500	1000	1200	200	135	150
ULTRASONIC VELO	270	300	1200	200	100	150
COMPASS/ODOMETER	265	1000	1200	200	20	40
COMPASS/LASER VEL	655	1000	1200	200	150	30
CMPSS/U-SONIC VEL	385	1000	1200	200	100	30
OMEGA	2500	0	1200	200	30	75
LORAN	2600	0	1200	200	30	75
DECCA	750	0	1200	200	60	75
AM-STATIONS	250	0	1200	200	50	60
DIFF. OMEGA	2500	0	1200	200	30	75
DIFF. LORAN	2600	0	1200	200	30	75
DIFF. AM-STA.	315	0	1200	150	50	60
RELAY OMEGA	375	0	1200	150	40	100
RELAY LORAN	425	0	1200	150	70	100
CLASS II						
BURIED RES. LOOPS	90	0	1200	50	45	15
REFLECTING SIGNS	430	0	1200	50	150	20
REFLECTING ROAD	75	0	1200	50	[illegible]	15
X-BAND POST	120	0	1200	50	40	10
HF, VHF POST	105	0	1200	50	90	10
LF POST	100	0	1200	50	45	15
LIGHT/I-R POST	95	0	1200	50	75	25
BURIED MAGNETS	50	0	1200	50	45	0
ULTRASONIC POST	85	0	1200	50	35	25
TRAFFIC SENSOR	95	0	1200	50	40	10
CLASS III						
NAR-BAND FM PHASE	60	0	1200	165	40	25
WID-BAND FM PHASE	2875	0	0	30	90	25
PULSE T-O-ARRIVAL	2575	0	0	0	150	25
NOISE CORRELATION	785	0	0	0	100	25
DIRECTION FINDER	35	0	0	0	15	0
CLASS IV						
TRAFFIC LOOPS	80	0	0	0	65	10
WAYSIDE RADIO	75	0	0	0	40	10
PHOTO\I-R DETECT	115	0	0	0	70	15
ULTRASONIC DETECT	125	0	0	0	65	15

* Costs as of 1974.

Table 3. Fixed Site Costs* for Class II, III, and IV AVM Systems

FIXEDCOST

TECHNIQUE	AVL COST PER SITE (OR UNIT) IN $ EQUIP	INST	O-M	DATA LINK	LINE RENT
CLASS I					
KEYBOARD	0	0	0	0	0
STYLUS MAP	0	0	0	0	0
2-ACCELEROMETERS	0	0	0	0	0
LASER VELOCIMTR	0	0	0	0	0
ULTRASONIC VELO	0	0	0	0	0
COMPASS/ODOMETER	0	0	0	0	0
COMPASS/LASER VEL	0	0	0	0	0
CMPSS/U-SONIC VEL	0	0	0	0	0
OMEGA	0	0	0	0	0
LORAN	0	0	0	0	0
DECCA	0	0	0	0	0
AM-STATIONS	0	0	0	0	0
DIFF. OMEGA	0	0	0	0	0
DIFF. LORAN	0	0	0	0	0
DIFF. AM-STA.	0	0	0	0	0
RELAY OMEGA	0	0	0	0	0
RELAY LORAN	0	0	0	0	0
CLASS II					
BURIED RES. LOOPS	10	17	0	0	0
REFLECTING SIGNS	55	30	5	0	0
REFLECTING ROAD	5	30	25	0	0
X-BAND POST	230	45	15	0	0
HF, VHF POST	100	45	15	0	0
LF POST	125	45	15	0	0
LIGHT/I-R POST	100	55	25	0	0
BURIED MAGNETS	2	4	0	0	0
ULTRASONIC POST	85	85	10	0	0
TRAFFIC SENSOR	95	40	0	0	0
CLASS III					
NAR-BAND FM PHASE	4500	500	500	25	5
WID-BAND FM PHASE	9500	1500	500	2070	0
PULSE T-O-ARRIVAL	12000	2500	500	2000	0
NOISE CORRELATION	7500	1500	500	2000	0
DIRECTION FINDER	26000	1500	1200	25	5
CLASS IV					
TRAFFIC LOOPS	165	113	10	13	4
WAYSIDE RADIO	160	113	25	13	4
PHOTO/I-R DETECT	170	113	25	13	4
ULTRASONIC DETECT	180	113	25	13	4

* Costs as of 1974.

Additional costs associated with each AVM technique when configured as a system are the base station costs and the vehicle polling system costs, given in Table 4. The base station is assumed to include the vehicle location computer, the peripherals, the dispatcher displays, software, and yearly operational maintenance.

1. Vehicle cost parameters. Vehicle costing for an AVM system is a straightforward multiplicative process of determining the total cost to equip all vehicles in the fleet with the appropriate AVM sensor, data processor, vehicle polling equipment, and radio modification; motorcycles are not considered. If a separate radio link is deemed necessary for AVM purposes, then this additional cost must be added.

If the vehicle fleet has already been equipped with digital message entry devices (DiMED), keyboards, hard-copy printers, gas-plasma or cathode-ray displays, then some of the functional elements required for an AVM system have been established. Prior installation of digital message equipment was not considered in the costing of vehicular equipment.

2. Fixed site costs. Site costs unique to AVM systems are considered only in Classes II, III and IV. In determining the system costs, the number of installed units must first be determined. The design algorithms for fixed sites are dependent on the density distributions of intersections, road segments, and lanes, and on the area to be covered.

Most of the Class II AVM techniques that rely on radio ID signals are configured and costed on the basis of one autonomous signpost per intersection. The exception is the HF signpost which is configured on the basis of one unit for each four intersections because of the greater coverage radius. The reflective pattern signs techniques require two installations for each road segment because of the geometry constraints between vehicle and sign, whereas the traffic presence sensors require one installation for each road segment because of the nature of the normal installation. Buried loops and magnets require an installation per lane in each road segment. In addition, each installation is actually a multiple installation; i.e., there must be sufficient loops or magnets to provide adequate coding for each road segment. The cost estimates for fixed sites were based on an average of 2.4 lanes for each road segment, i.e., about 1 four-lane road for each 6 two-lane roads.

Table 4. Base Station Costs* for All AVM Classes and Systems

BASECOST

AVL BASE STATION COSTS IN THOUSANDS OF $

TECHNIQUE	COMPUTER SML	COMPUTER MED	COMPUTER LGE	INST	O-M	DISP	SOFTWARE SML	SOFTWARE MED	SOFTWARE LGE
CLASS I									
KEYBOARD	30	40	60	10	100	3	10	20	30
STYLUS MAP	30	40	60	10	100	3	10	20	30
2-ACCELEROMETERS	40	60	80	10	100	3	25	25	50
LASER VELOCIMTR	40	60	80	10	100	3	25	35	50
ULTRASONIC VELO	40	60	80	10	100	3	25	35	50
COMPASS/ODOMETER	40	60	80	10	100	3	25	35	50
COMPASS/LASER VEL	40	60	80	10	100	3	25	35	50
CMPSS/U-SONIC VEL	40	60	80	10	100	3	25	35	40
OMEGA	30	50	70	10	100	3	20	30	40
LORAN	30	50	70	10	100	3	20	30	40
DECCA	30	50	70	10	100	3	20	30	40
AM-STATIONS	30	50	70	10	100	3	20	30	40
DIFF. OMEGA	30	50	70	10	100	3	20	30	40
DIFF. LORAN	30	50	70	10	100	3	20	30	40
DIFF. AM-STA.	30	50	70	10	100	3	20	30	40
RELAY OMEGA	30	50	70	10	100	3	20	30	40
RELAY LORAN	30	50	70	10	100	3	20	30	40
CLASS II									
BURIED RES. LOOPS	30	40	60	10	100	3	10	20	30
REFLECTING SIGNS	30	40	60	10	100	3	10	20	30
REFLECTING ROAD	30	40	60	10	100	3	10	20	30
X-BAND POST	30	40	60	10	100	3	10	20	30
HF, VHF POST	30	40	60	10	100	3	10	20	30
LF POST	30	40	60	10	100	3	10	20	30
LIGHT/I-R POST	30	40	60	10	100	3	10	20	30
BURIED MAGNETS	30	40	60	10	100	3	10	20	30
ULTRASONIC POST	30	40	60	10	100	3	10	20	30
TRAFFIC SENSOR	30	40	60	10	100	3	10	20	30
CLASS III									
NAR-BAND FM PHASE	33	80	137	8	100	3	[illegible]	40	60
WID-BAND FM PHASE	40	70	70	10	200	3	25	50	100
PULSE T-O-ARRIVAL	100	250	250	10	175	3	35	70	100
NOISE CORRELATION	100	250	250	10	175	3	35	70	100
DIRECTION FINDER	15	30	60	10	150	3	15	30	60
CLASS IV									
TRAFFIC LOOPS	30	40	60	10	100	3	10	20	30
WAYSIDE RADIO	30	40	60	10	100	3	10	20	30
PHOTO/I-R DETECT	30	40	60	10	100	3	10	20	30
ULTRASONIC DETECT	30	40	60	10	100	3	10	20	30

*Costs as of 1974.

The number of loops at each lane segment was that sufficient to provide a unique base-2 code for each road segment. The number of magnets used is half this value since spaces can be used to provide approximately half the coding bits (magnet for "one", space for "zero").

Since the Class III synchronized RF sites are more sparsely distributed, their numbers are estimated on the basis of urban area for the selected phase and pulse time-of-arrival techniques. The radius of coverage for narrow-band and pulse systems, based on prior tests and experiments, is set at 5 km (3 miles). In addition, the requirement that, wherever possible, four or more antennas should cover the given area is imposed. This procedure provides data for least-squares computation as opposed to the analytic "flat earth" solution of vehicle location. The wide-band antenna coverage radius is set at 11 km (7 miles), based on prior tests. Design algorithms were established from the rectangular model cities data as follows:

$$\text{Number of narrow-band and pulse sites} = 6 + \frac{\text{area in km}^2}{10}$$

$$\text{Number of wide-band sites} = 4 + \frac{\text{area in km}^2}{40}$$

The number of fixed sites in the southern California UGAC cities was determined from geometrical gridlined overlays superposed on outline maps of the cities. The outline and site locations for the cities are depicted in figures that accompany Part 2 of this Report. A minimum number of fixed sites for noise correlation and direction finding was established, recognizing that this number is probably insufficient for all but the smallest cities.

Class IV monitored signposts were configured and costed on the same basis as the equivalent Class II devices. Telephone line rental is, however, included in the site costs where applicable as the line should be considered an equipment cost as opposed to an operation cost.

3. Base station costs. Base station equipment costs were estimated on the basis of both urban area coverage and fleet size. The station's computer costs were estimated on the basis of area, and the software costs were based on fleet size. This separation of cost elements is only partially defensible. It is assumed that a minicomputer is usually used to support the AVM function with varying amounts of bulk storage (disc) to accommodate the city map for output display.

Exceptions are in the Class III time-of-arrival (TOA) methods, where larger machines are assumed. The pulse and noise-correlation techniques also require a larger computer with more speed and versatility than can be provided by a minicomputer because of the inherent capability of servicing many more vehicles per unit time and the need to accommodate a large number of inputs in real time. The software estimate based on fleet size is also difficult to justify totally. Much reliance was placed on prior work estimates and on the judgements of svstems analysts.

Three estimates each of base station computer and software costs were made based on model city parameters for small, medium and large cities. For the UGAC cities, the costs were determined based on the urban areas and the total fleet size, excluding motorcycles, using linear interpolation.

Display equipment costs are included in the base station costs on the basis of the actual number of dispatchers in the case of UGAC cities. For the model cities, the costs are estimated on the basis of 1 display console for each 50 vehicles or less.

4. Installation costs. Equipment installation costs were obtained by multiplying the cost per unit vehicle and the cost per fixed site installation by the appropriate number of units. Toegether with the base station installation cost, they make up the tabulated total cost. A constant cost value is assumed for the base station, which is a rounded average value of prior estimates made in conjunction with AVM deomonstration tests.

5. Operation and maintenance costs. The estimates of O - M costs for equipment installed in vehicles, at fixed sites, and the base station are based on experience values for both mobile and fixed equipments. In the base station, the principal cost element is for operation and maintenance personnel. Three persons (one per shift) were assumed in all AVM techniques to provide software support or equipment service. Although this assumption may not be justifiable, it was believed that AVM is a comparitively new technology which will probably interface with computer-aided dispatching and digital message systems and that additional service personnel would be required for a substantial time period after the initial installation.

V. VEHICLE POLLING AND LOCATION PERFORMANCE

Four classes of vehicle polling are considered for AVM Systems: (1) Synchronous, (2) Commanded or random access, (3) Synchronous with Command capability, and (4) Volunteer or contention. All four techniques are generally applicable to Class I and II AVM Systems. Synchronous polling and synchronous with command are used mainly in Class III Systems. For the Class IV monitored signpost systems, which use land lines, polling by radio is not applicable in the context used in this description.

All polling techniques are suitable for half-duplex (base station and vehicle on the same frequency), but when the base station relays all vehicle transmissions or when each vehicle monitors all other vehicles, then the Volunteer technique can only be used on full-duplex (base and vehicle on different frequencies).

1. Synchronous polling. In this technique, each vehicle transmits location data at a preselected time within the fleet polling sequence. Equipment on the vehicle keeps track of the start of the sequence and internally determines when its time to respond occurs. The cost of the vehicle polling equipment installed (as of 1974) is about $270.

2. Synchronous with command capability. This polling technique allows the base station to modify the position of each vehicle in the polling sequence. The cost of the vehicle equipment installed is about $365.

3. Commanded or random access polling. In this technique, the base station sends a request to each vehicle whenever location data is required. This technique is the most flexible but requires more use of available RF time.

4. Volunteer polling. This contention method requires that each vehicle determine whether the channel is "clear" before transmitting. The cost of vehicle equipment installed is about $170.

These vehicle polling techniques were evaluated with both a simple one-time radio message transmission and with redundant transmissions where every message is sent twice. The digital message rate is set at 1500 bps. Where equivalent RF channels are assumed, a channel spacing of 25 kHz is used. Message lengths are about 20 bits, or occupy about 15 millisec transmission time. Delays due to equipment turn-on times reduce the achievable polling rate.

NASA — JPL — Coml., L.A., Calif.

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

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