UM-HSRI-78-44-2

APPLICABILITY OF DIGITAL DATA COMMUNICATION FEATURES IN PUBLIC TRANSIT SYSTEMS: TECHNOLOGY ASSESSMENT

September, 1978

BY

TAPAN K. DATTA
BRIAN L. BOWMAN
MICHAEL J. CYNECKI

The opinions, findings, and conclusions expressed in this document are those of the authors and not necessarily those of the Michigan Transportation Research Program, The University of Michigan, and the Michigan State Highways Commission.

41331

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UM-HSRI-78-44-2		

4. Title and Subtitle	5. Report Date
Digital Data Communication Features in Public Transit Systems: Technology Assessment	October, 1978
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
T. Datta, B. Bowman and M. Cynecki	UM-HSRI-78-44-2
9. Performing Organization Name and Address Wayne State University Department of Civil Engineering 667 Merrick Detroit, Michigan 48202	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Michigan State Highway Commission State Highways Building P.O. Box 30050 Lansing, Michigan 48909	13. Type of Report and Period Covered Final Task Report 14. Sponsoring Agency Code

15. Supplementary Notes
This study was conducted for the Michigan Transportation Research Program(MTRP). Highways Safety Research Institute, The University of Michigan, Ann Arbor, Michigan, 48109. MTRP is sponsored by the Michigan State Highway Commission.

16. Abstract

A survey was conducted of the state of the art of automatic vehicle monitoring (AVM) systems and their use in public transit, taxi, and police operations. The systems identified are applicable to improving operational efficiency and quality of service. The various system elements related to AVM systems were reviewed. Those elements included vehicle location, vehicle identification, vehicle monitoring, computer scheduling, computer dispatch, silent alarms, security alarms, mechanical alarms, on-board readout, real-time display, passenger counting, management reporting, and digital data hardware.

17. Key Words	18. Distribution Statement
Automatic Vehicle Monitoring (AVM) Public Transit Mobile Communications	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. PREFACE

This report stems from a request by Mr. Charles Uray, Jr., Chief Deputy Director, Michigan Department of State Highways and Transportation, to the Michigan Transportation Research Program to carry out a technology assessment on specific transit features of Automatic Vehicle Monitoring Systems (AVM).

In recent years, digital data communication techniques have been combined with mobile radio communication systems to provide an expeditious and expansive information transfer between vehicles and control centers. Numerous systems are currently operative and planned for installation in the United States for operations involving law enforcement, transit operations, and to a lesser degree taxi operations.

The emphasis of this paper is on AVM systems applicable to improving the operational efficiency and quality of service of transit operations.

Due to the size and scope of this project, the issue of applicability of digital data communication systems in public transit industry addressed by using the present state-of-the-art information as available through technical papers, journals, magazines, and published reports of projects that have been implemented across the country. This technical report forms the basis of the conclusions and recommendations arrived at by the authors on the basis of the review of the literature.

II. INTRODUCTION

The need to attract auto users to public transit is more evident today than in the past. The problem of congested highways has been aggravated over the past few years by the auto's growing contribution to urban air pollution. In recent years the fuel embargo, coupled with growing environmental concerns and the skyrocketing costs of new autos, has emphasized the need to create greater public confidence in the public transportation system. To develop this confidence, public transit systems must substantially increase their current performance levels.[1]

This contention is substantiated by the University of Maryland study of the perceptions of public transportation and auto users in Philadelphia and Baltimore with respect to the attributes of their respective urban transportation systems.[2] From a list of 35 attributes for the Philadelphia study and 44 for the Baltimore study, the attributes "arrive at intended time" and "passenger safety" were considered most important by the people surveyed in the two cities. Further analysis found that a greater percentage of auto users than transit users considered "arrive at intended time" very important, and that the auto user was much less satisfied with his ability to arrive at work on time when using public transit than when using his own car. This finding suggests that both the reliability and safety of public transit systems must be improved to capture a larger proportion of the traveling public.

---

1. Dein, T.B. "Mass Transportation Research: The Basic Issues," Highway Research Record #318, 1970, pp. 1-11.

2. Paine, F.T., et. al., "Consumer Conceived Attributes of Transportation: An Attitude Study", Department of Business Administration, University of Maryland, College Park, M.D., June, 1967.

Automatic Vehicle Monitoring Systems (AVM) offer the potential for increasing transit reliability and passenger safety by providing vehicle status and location information based on real time. While indicators of system performance and status utilized in AVM systems, such as headway and schedule adherence, passenger counts, etc., are not new, the integration of electronic hardware, computer software programs and digital data communication systems necessary to monitor the appropriate parameters in real time is relatively new.

This report is an attempt to bring together the literature available on the subject to determine if AVM systems are operationally and financially feasible for public transit systems as they exist today. The report stratifies an AVM system into its various elements and analyzes each one individually. These elements include:

- vehicle location
- vehicle identification
- vehicle monitoring
- computer scheduling
- computer dispatch
- silent alarm
- security alarms
- mechanical alarms
- on-board readout
- real-time displays
- passenger counting
- management reporting
- digital data hardware
- mobile communication hardware

III. CONCEPT OF AVM

The energy crisis and recent concerns pertaining to environmental quality have emphasized the need for improved urban mobility. Automatic Vehicle Monitoring Systems (AVM) is an evolving technology that offers considerable potential in the near future for improving levels of service and, at the same time, reducing operating costs in bus-transit systems. A good explanation of AVM is given by Blood and Kleim[1] (1977):

> "... AVM is a terminology for a class of electronic systems that, through automatic position-tracking and status-monitoring, provide the information as well as the means for central control of individual vehicles in a fleet dispersed over an operating area. Such systems are considered to be comprised of three functional elements: a location subsystem to provide continuous position tracking of each vehicle; a communications subsystem to monitor vehicle status and to return control commands to the vehicle; and a computer sybsystem to manage the information flow, process incoming data, generate displays to a dispatcher and prepare records for subsequent analysis."

Past experience has demonstrated that electronic vehicle monitoring can improve the service and efficiency of transportation systems above that possible by conventional means. Conventional techniques for performing this function - human monitors posted along the route or reports by the operator using voice radio-are wasteful of time, manpower, and radio frequency spectrum.[2] Moreover, human error or lack of cooperation often

---

1. Blood, Bernard E. and Kliem Bernd W., "Experiments on Four Different Techniques for Automatically Locating Land Vehicles", U.S. Department of Transportation, Report No. UMTA-MA-06-0041-77-2, 1977.

2. Goldsmith, Arthur, "Department of Transportation National Plan for Navigation," U.S. Department of Transportation, Report No. DOT-TST-78-4, 1977.

renders these techniques ineffective. In addition the conventional techniques cannot provide the real time data and information necessary to maintain today's level of service, much less improve it. To be effective, AVM systems must address three types of information:[1]

- <u>background information</u> which forms the requirements for the provision of transit services. This includes service specifications (routes, headways), run schedules for vehicle trips, vehicle assignments to these trips, driver schedules for the runs, and maintenance schedules for the vehicles in service. All of this information dictates the nature and extent of the service that is to be provided at any given moment.

- <u>control information</u>, which establishes the constraints on the service while in operation. This includes daily dispatching information on the actual vehicles and drivers that have reported for work, running and loading conditions at any given moment, information on schedule reliability, emergency situations, mechanical condition of the buses etc., and information concerning the various assistance requests received throughout the day from drivers and passengers. All of this information dictates the nature and extent of the service that can be provided at any given moment, given various operating constraints.

---

1. Catton, F. D., "Bus Transit Automatic Vehicle Monitoring Systems" Telimove Automated Vehicle Monitoring Conference Proceedings, 1976.

- reporting information which results from the production of the service. This includes exception reports (schedule disruptions, missed runs, etc.), event logs (emergency situations, accidents, etc.), passenger complaints, vehicle mileage and pay hour reports, information on passengers carried,etc. This information demonstrates the performance of the service and its effectiveness, and is used to revise the background plans as appropriate.

Three additional concepts are very important in the application of measurement, communication, and control to urban transportation and essential services.[1]

- information must be as comprehensive, accurate, and timely as required, and the system must have the ability to display, log, store, retrieve, and summarize this information as required for most effective response by all parts of the system and the organization.
- feedback mechanisms are required to ensure that error-free messages are transmitted, that they are directed to the proper recipient(s), that messages have been received, that appropriate actions have been taken, and that the triggering events/ perturbations have been taken care of.

These criteria require that the proper AVM hardware components be integrated in such a manner as to encourage the use and cooperation of of system users. To be effective,therefore, the monitoring system should not be complicated to operate and be of obvious value.

---

1. Irwin, Neal A., "Concepts for Improved Communications and Informative Systems in Urban Transportation," Telimove Automated Vehicle Monitoring Conference Proceedings, 1976.

Figure 1 places the information flow into perspective as an integral component of the transit operating process.

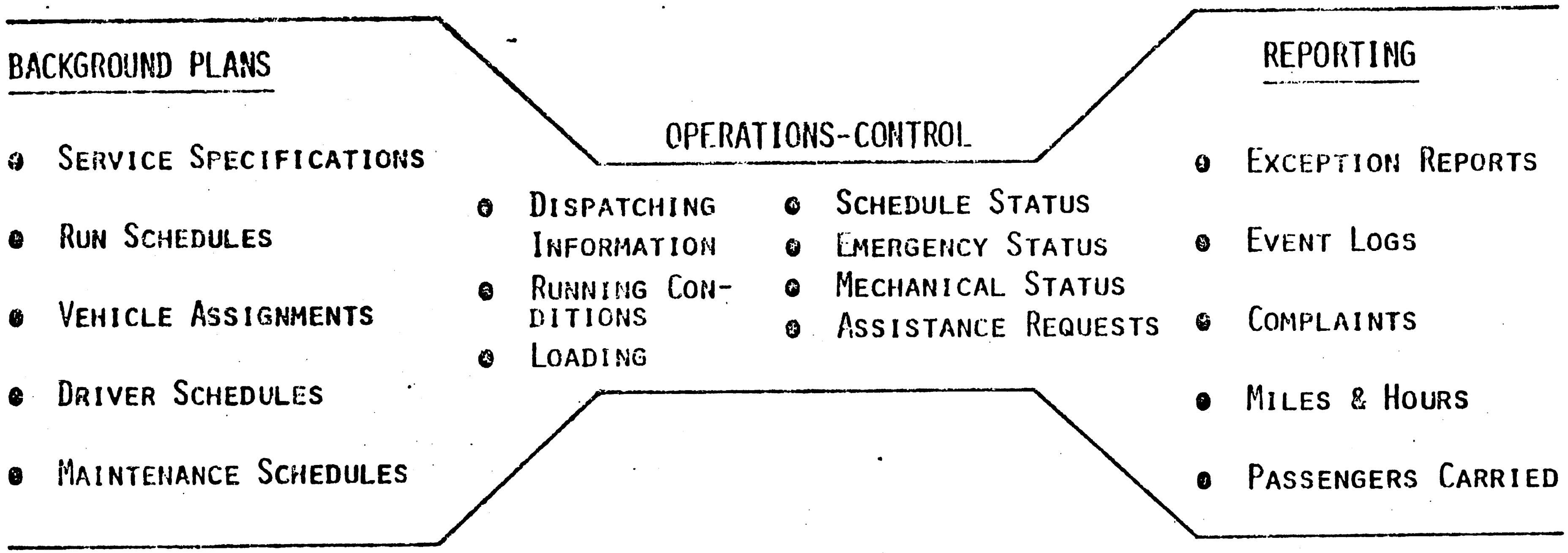


Figure 1 - The Transit Operating Process

Source: Catton, F. D., "Bus Transit Automatic Vehicle Monitoring Systems' Telimove Automated Vehicle Monitoring Conference Proceedings, 1976.

IV. CLASSIFICATION OF TRANSIT CONTROL SYSTEMS

Automation of transit vehicle monitoring functions has been evolving over the past 40 years, with the greatest technological advances occurring within the last decade. While many methods have been devised, they can all be categorized into two general groups, based on their transmission method. In this respect, information can be automtaically transmitted by land lines or by radio communications. Thus, automatic vehicle monitoring is categorized as non-radio and radio-based control systems.

Radio-based control systems or hybrid systems are currently favored by transit authorities because of the increased versatility they afford over non-radio systems alone.

● First-Generation Radio Control Systems

First-generation control systems, which began to emerge in the sixties, are voice-radio communications used in the transit control process. Generally this consists of a transmitter and receiver, a microphone and a loudspeaker on each bus to allow the bus driver to talk to and to receive instructions from central control. Many transit properties in the United States, Canada, and Europe have equipped their fleets with voice-radio communications primarily because of the need to be in closer contact with the drivers because of an increase in emergency situations.

While it is possible to monitor a small fleet of vehicles using only voice-radio transmissions, the information will be accurate only for the most recently contacted vehicles if it is not integrated with an automatic vehicle locating device. The difficulty with voice-only transmissions, for both vehicle monitoring and location placement, is given by Symes[1] (1976).

> Assuming even a low average vehicle speed of 10 mi/h (14.66 ft/s), the vehicle contacted only 60 s ago could be 880 ft from its last reported position or could be stopped at a traffic signal. Thus, a voice transmission of location data is not really a feasible alternative for accurate position locating. Additionally, voice channels are already congested with routing communication, and continuous transmission of location information would be impossible for a large fleet.

Thus, conventional methods employing field checkers must supplement voice-only transmissions for the majority of the control activities.

● Second-Generation Radio Control Systems

The proglems encountered with voice-only communication prompted the development of second-generation radio control systems. This generation of control eliminated some of the radio channel and message efficiency restrictions by supplementing the voice radio with one-way digital communications. The system was given the capability of automatically transmitting routine data such as vehicle location, passenger counts, vehicle identification, etc., from the vehicle to central control.

Most of these systems utilized some type of dead reckoning concept. This concept involves the use of the vehicle odometer to measure dis-

---

1. Symes, Denis J., "Multiuser Area-Coverage Automatic Vehicle Monitoring Program" IEEE Transactions on Vehicular Technology Vol. UT-26, No. 2 May 1977.

tance. Since these devices tend to produce cumulative rather than random errors, the positional inaccuracy of the vehicle increases as the distance traveled increases, and becomes unacceptable after 10 miles or less. For example, a one percent error in the distance measurement will produce a 250-foot error after five miles.[1] These inherent inaccuracies make it necessary to periodically correct the odometer.

In addition to bus location, second generation radio control systems can transmit vehicle identification, route and run number, passenger counts, emergency alarms, mechanical status, etc. This is because the digital communications capability releases the operator from using the voice radio for these purposes.

The second generation control system is subject to many of the pitfalls of first generation control. Channel and efficiency limitations of voice radio makes them effective for emergency handling but only partially effective for most other control functions.

- Third-Generation Radio Control System

This system significantly improved the information handling potential of the communications system by introducing two-way digital communications capability.

Recorded messages can be sent to the driver, by means of precoded messages, without having to summon him to the voice radio. Although the voice radio is present, it becomes a subsystem in this generation of radio control. The main difference between third and second generation

---

1. Goldsmith, Arthur (Editor) "Development of Transportation National Plan for Navigation" DOT-TST-78-4, November, 1977.

control is that display logic is used so that precoded messages can be given to the driver. This capability also makes it possible to use variable message techniques to communicate with random route transit vehicles, police units, emergency response units, etc. This allows the maximum utilization of the data transmission capability and of voice radios, giving the driver more free time for his other duties.

- Fourth-Generation Radio Control Systems

Fourth generation control is similar to third generation control with the following major differences:[1]

- firstly, control is exercised in a much more interactive way than with previous systems,with computers assisting both the drivers and the controllers in the formulation of control actions.
- secondly, the information base on which the transit operation is structured becomes an integral part of the control system, both in the way it is used as input to the control process and in the way it is updated by the control process staff.

This is made possible by the use of powerful hardware/software systems at central control, electronic processors,and various data sensing devices.

The full capacity of two-way digital communications allows a greater degree of driver self-regulation and more effective control actions by the controllers. The controllers can exert effective and continuous control en route by employing software programs that can be an aid in determining what corrective actions are appropriate to retain schedule adherence. These cor-

---

1. Catton, F. D., "Bus Transit Automatic Vehicle Monitoring Systems", Telimove Automatic Vehicle Monitoring Conference Proceedings, September, 1976.

rective actions, such as short turn, skip stop, wait for transfer connection, etc., can be relayed to the individual vehicles by the use of on-board pre-coded indicator lights. Electronic processors allow for flexible sophisticated control procedures that can be implemented without the restrictions of fixed-logic packages, at what has been proven to be lower cost than third-generation systems.

Transit personnel who are responsible for the planning, control, and operation must have access to a vast amount of information. While this information is available with third-generation systems, the handling of this information can be a tedious and time-consuming job subject to many uncertainties. The transit controllers must have available to them various schedules, such as run guides, vehicle registers, and driver schedules, that describe the service to be provided, while at the same time they must assimilate information on the actual vehicles/manpower available and the various operating conditions that affect service. By using all of this information the controller decides when, where, and how he must make the adjustments to provide the required service. When this background information is combined with the real-time data available from the AVM systems, the data can become so voluminous that the effectiveness of the control process can be severely downgraded.

This potential problem is resolved in fourth-generation control systems by storing the transit information base in the central control computer and by using the computer to compare real-time information against the stored information. The computer can then provide assistance information to the drivers and exception reports to the controllers. This makes the fourth-generation control, because of its interactive nature and feedback mechanism, the most potentially effective of all control systems. It requires only an interface with a transit scheduling program and an interface with a computerized traffic signal control system to make transit control truly automatic.

Effectiveness of AVM Systems

The foregoing discussion on the different types of information transmission concepts serves to illustrate how diversified the AVM hardware can become. AVM technology has undergone radical evolutionary changes since it was introduced 30 or 40 years ago. These changes were dictated by the need to have better information on which to base control actions. Experience has shown that, except for situations where a transit property is small enough that it can use only voice communication in its control activities, it is difficult to justify first-generation voice-only radio communication over other techniques.

Figure 2 illustrates that many second-or third-generation control systems on the market are limited in their ability to control bus operations because of limited information-handling capabilities, and because message structures, transmission rates, and response times are in many cases inappropriate for the effective operation of transit services. To fortify this view Catton[1] (1976) states:

---

1. Catton, F.D., "Bus Transit Automatic Vehicle Monitoring Systems," Telimove Automatic Vehicle Monitoring Conference Proceedings, September, 1976.

OPERATING FUNCTIONS	NON - RADIO CONTROL SYSTEMS	FIRST - GENERATION RADIO CONTROL SYSTEMS	SECOND - GENERATION RADIO CONTROL SYSTEMS	THIRD - GENERATION RADIO CONTROL SYSTEMS	FOURTH - GENERATION RADIO CONTROL SYSTEMS
PLANNING			Medium	Medium	High
SCHEDULING	Low		Low	Low	Medium
DISPATCHING			Low	Low	Medium
ROUTE SUPERVISION	Low	Low	Low	Medium	High
EMERGENCY HANDLING		Medium	Medium	High	High
PUBLIC RELATIONS			Medium	Medium	Medium
MAINTENANCE			Low	Low	Medium
REPORTING	Low		Medium	Medium	High

Level of Effectiveness

LOW

MEDIUM

HIGH

Figure 2 - Effectiveness of AVM Systems in Transit Operations

Source: Catton, F. D., "Bus Transit Automatic Vehicle Monitoring Systems," Telimove Automatic Vehicle Monitoring Conference

"To be truly effective, we believe that an automated control system must be able to handle all of the day-to-day operating activities of a bus service including such real-time control activities as dispatching, route and schedule supervision, emergency handling, passenger loading, mechanical monitoring, traffic priorities, etc., and such off-line activities as event logging and management reporting, and the very important scheduling process itself which dictates the structure of the service. A two-way digital communications system, which is the fourth generation control system discussed above, seems to be the only practical way to achieve this.
The capital costs of implementing this fully automated fourth generation system is about double the cost of implementing a purely voice radio first generation system. Our studies have shown, however, that these capital costs can be recovered in about one to two years after implementation because of the savings in operating costs and the improvements in service that result, whereas it is very difficult to achieve any cost savings using purely voice first generation or partially automated second generation communications systems. Thus once the decision is made to introduce communications in the transit operation, then the transit operator might as well go all the way and completely automate the system for greater cost-effectiveness.

This is the approach that is being followed by most of the transit properties in Germany and Switzerland, and that is being currently implemented by the Toronto Transit Commission."

Since fourth generation control systems are the most responsive, cost effective, and advantageous for the majority of urban areas, the remainder of this report focuses on them.

V. VEHICLE ALARMS/SECURITY PROCEDURES

The concept of safety alarm systems for air and marine vehicles has existed for years. In contrast, the safety aspects of surveillance on land do not relate primarily to the avoidance of fixed hazards and other vehicles. Rather, they are related to the mobilization, management, and coordination of response resources, protection of vehicle occupants, and the provision of emergency treatment to accident victims. In general, three characteristics are required of systems that can perform these functions:[1]

- An alarm that can be operated when needed (covertly and silently on a vehicle) to alert central station personnel to the emergency.
- Sufficiently accurate information about the location of each vehicle or other entity that is part of the system.
- A communication link between the incident and the center responsible for response.

Vehicle alarms are of three basic types:[2]

1) a concealed emergency alarm to be triggered surreptitiously to warn of any criminal or hazardous situation.

2) a security alarm to indicate any intrusion or equipment tampering that will indicate any mischievous activity while the bus is unmanned, particularly at night.

3) a set of mechanical malfunction alarms.

---

1. Goldsmith, Arthur "Department of Transportation National Plan for Navigation," U.S. Dept. of Transportation, Report No DOT-TST-78-4, 1977.

2. "Specifications for Bus Radio/Management Information System," Massachusetts Bay Transportation Authority, October, 1976.

● Emergency Alarms

The increasing rate of crime and violence on transit vehicles is sufficiently high to raise serious doubts in passengers' minds concerning the ultimate safety of public transportation. Incidents involving assults, robberies, vandalism, threats to drivers and passengers, etc. are substantially reduced by an effective silent alarm system.

Experience has shown that the effectiveness of any security effort is directly proportional to response time. Police records indicate that if the enforcement units can arrive on the scene within five minutes from the time of the alarm the arrest rate increases sharply.[1] Any alarm system should therefore be designed to minimize the following factors involved in response time.

1. Time until the silent alarm is detected by the controller.
2. Additional time until the police call is initiated.
3. Time to complete the police call.
4. Police dispatch delays.
5. Police field force response time.

The first two factors are under the direct control of the transit authority. The third factor is a composite control shared by the transit authority and the police agency. Since the last two items cannot be influenced by the alarm system,it is imperative that the emergency alarm function complete functions 1, 2, and 3 in a time interval that is small compared to five minutes (i.e.,in the order of 30 seconds). This objective must be met even when there are simultaneous silent alarms.

---

1. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

This places several significant requirements on the system. The sequence of events and several specific requirements can best be described as follows:

Step a. A silent alarm is initiated by the driver.

Step b. The controller receives an audible and visual alarm and initiates a call to the police dispatcher.

Step c. The controller is given information on the vehicle I.D., location,and estimated passenger load.

Step d. The pertinent information is given to the police dispatcher.

To achieve the 30-second objective a study team engaged by the Chicago Transit Authority (CTA) arrived at the conclusion that step b must occur within 10 seconds after step a. Step c can take longer but should occur within 25 seconds.[1]

The reliability of the emergency alarms is also dependent upon the rate of false alarms and system failures. The study team in Chicago determined that the majority of false alarms resulted from the drivers' inadvertently setting it off. This indicates that a better human factors design should be considered in lieu of a simple foot switch for the actual alarm.

Figure 3 displays the driver's discrete foot switch that was used for the silent alarm in Chicago. While it was easily accessable to the driver it was deficient with respect to inadvertent tripping caused by the movement of the operator, vehicle vibration,or the placement of articles on the switch. This switch location also suffers from the difficulty encountered in insulating it from water during bus cleaning and other environmental hazards.

---

1. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

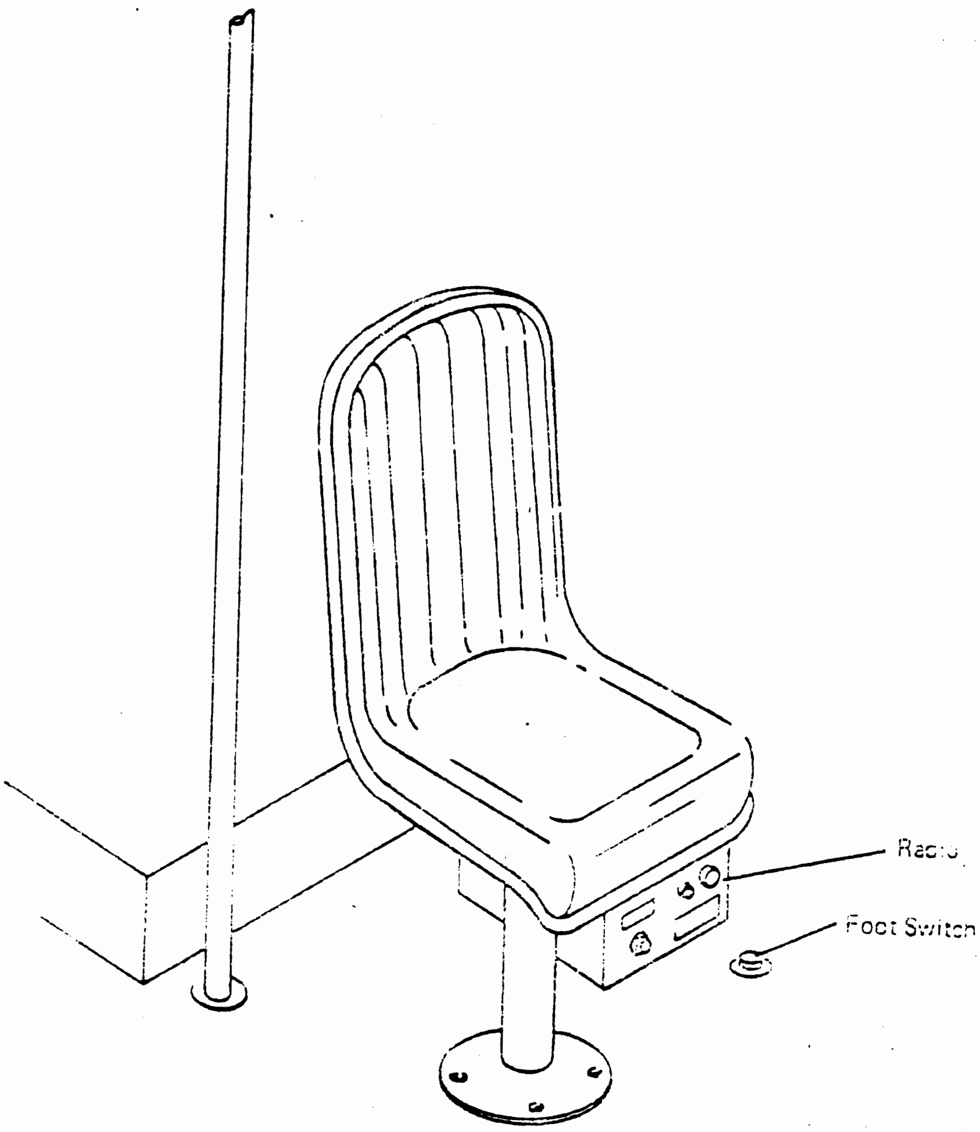


Figure 3 - Floorboard Switch for Silent Alarm

Source: "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974., p. 3-14.

Another concept for the actual alarm switch is shown in Figure 4. This concept requires only an assembly type design by mounting a ring switch beneath the drivers seat. The driver can activate the alarm by moving his leg and deflecting the ring, thereby activating the alarm. This affords greater movement to the driver and a reduction in accidental tripping.

Figure 4 also displays another concept that employs a device similar in appearance to a bell surrounding the pedestal of the drivers seat. This concept also has the advantage of reducing accidental tripping and at the same time it raises the switch above dirt and water. In addition it reduces the number of false alarms due to vibration, since the driver's seat is fastened to rigid frame members of the vehicle. The switch is so constructed that movement of the housing in any direction activates the alarm.

A third concept consists of the bell and ring used in conjunction with one another. A movement of the driver's leg toward the bell brings the calf of his leg into contact with the ring switch. When both the ring and bell switches complete the circuit simultaneously, the alarm is activated. The simultaneous closure of both switches by any event other than an intentional action is highly unlikely, yet the complexity of action demanded of the driver is not greatly increased over that required by the floorboard foot switcl

Additional concepts on the location of the switch, such as a button on the steering column or dashboard, suffer from the disadvantage of being too conspicuous. Switches positoned so that they can be depressed with the driver's knee have advantages, but their reliability is dependent upon the physical configuration of the driver's compartment of the vehicle under consideration. Whatever concept is employed it is considered as being

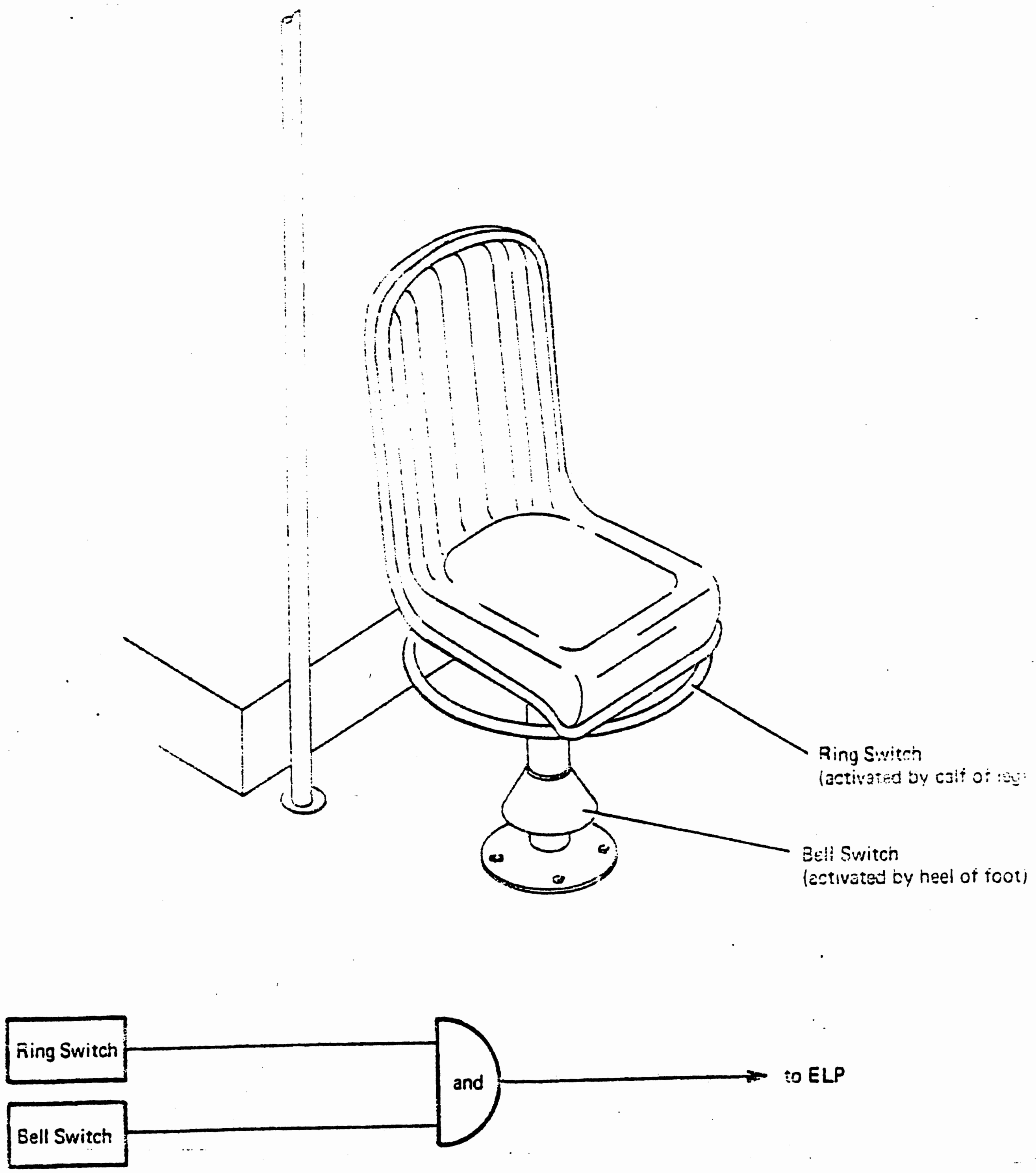


Figure 4 - Silent Alarm Concepts - Ring and Bell Switches

Source: "Schedule Control and Management Information System Study", IBM Federal Systems Division, November, 1974, p. 3-15.

advantageous to make the false alarm rate less than 10 percent of the average alarm rate.[1] A high false alarm rate can create contempt for the system by the responding police units, thereby increasing the average response time.

Whichever concept for the type and location of the alarm switch is chosen, it should possess the following functional requirements:

a) Switch location considerations
   - easy access by driver
   - located to minimize inadvertent tripping
   - driver movement for switch access should be minimal and blend with natural posture.

b) Alarm features - the alarm should automatically continue its transmission, giving the vehicle I.D. for an extended period of time or until the controller turns it off.

c) Priority - the silent alarm should have priority over all other com munication and be designed in such a manner that it cannot go unnoticed.

In an AVM system employed in Sudbury, Canada, the alarm format, once activated, is transmitted in a cyclical fashion, 1.5 seconds on and 6 seconds off, until acknowledgement is received.[2] Transmission in this cyclical manner overcomes such problems as channel in-use or R.F. (radio frequency) propagation 'fades'. As soon as it is received by central control, a signal is sent to the alarming vehicle to turn off the mobile transmitter alarm cycle. This prevents the channel from being tied up and opens it immediately for other communications.

1. "Schedule Control Management Information System Study," IBM Federal Systems Division, November, 1974.
2. Kedar, M., "Manual Centralized Fixed Route Fleet Monitoring and Control (Sudbury Transit Control Systems)," Telimove Automated Vehicle Monitoring Conf. Proceedings, Sept., 1976.

Problems with a system failure can be reduced by using hardware redundancy and by specifying equipment capable of withstanding the environmental conditions prevalent at the situ locations.

To avoid police search problems the vehicle location information provided with the silent alarm should position the bus to within one city block. The system should also possess a self-test feature to periodically test its operating status.

- Security Alarms

The overall purpose of the security alarm is to prevent the loss of fares and damage to equipment as a result of unauthorized entry into the fare box. This entry can occur while the vehicle is in service,but the primary advantage of the alarm is that it affords protection to the vehicle while it is unattended, particularily during storage. The experience of transit authorities indicates that pilferage has ranged in technique from very subtle substitution of bogus parts for later entry, skillful timing of entry, and direct techniques.

To function correctly it is necessary for the farebox alarm to satisfy the following requirements.[1]

- detect when the farebox is opened on a particular vehicle,
- detect if an open condition is legitimate or illegal,
- be as immune as possible from false activation by noise, vibration, etc.,
- be as immune as possible from intentional disablement (power loss, radio loss, loss of mechanical or electrical integrity),

1. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

- be as invulnerable as possible from system deception techniques (e.g.,external magnets applied to an internal relay to hold it in an open condition or power down),
- be coordinated with other data from vehicle sensors,
- be rapid in the presentation of an alarm,
- provide a high degree of reliability with a low amount of maintenance.

Although the concept of this alarm is similar to that of the silent alarm, it is not practical to recognize the alarm whenever the farebox is opened. This is because the authorized farebox collections can number in the thousands every day for the entire transit fleet. It is possible to design the system to ignore alarms that come from authorized collection points by using special vehicle location sensors. The alarm is ignored whenever it is sent from the proximity of the farebox pulling island or garage during the regular collection hours.

- <u>Mechanical Alarms</u>

The purpose of the vehicle mechanical alarms is to detect an equipment malfunction before physical damage or vehicle failure en route can occur. The specific parameters that need to be monitored are those that:

- have a sufficiently high rate of occurrence;
- are inexpensive to repair if detected early;
- are expensive to repair if the vehicle is allowed to continue operating;
- can be reliabily and inexpensively instrumented.

Those parameters that may warrant consideration for instrumentation are briefly discussed in an NTIS publication, which states:[1]

- "Engine Coolant Temperature Sensor - The engine coolant is water, or a water and ethylene glycol mixture. Normally, the temperature sensor is in the water jacket or engine block. The temperature sensed is indicative of overall engine temperature (if coolant level is normal), or of block temperature if coolant is low. Both responses are desired. Conditions such as poor radiator cooling, excessive engine heat development (from excessive load, combustion problems, etc.) broken water pump, or circulation system leak cause a response.

- Engine Coolant Level - If the engine coolant level is below a certain fairly low level, a noticeable rise in engine temperature will be observable. If the level goes too low, it goes beneath the pick-up level of the water pump and temperature rises very rapidly.

- Engine Head Temperature - Direct measurement of head temperature, perhaps near the exhaust valves, provides a very sensitive indication of engine problems. The heat-sensitive switch can be designed to threshold at a small tolerance, for example, at a 30° rise above normal.

- Oil Pressure - Measured by means of a pressure-sensitive switch. The oil pressure sensing point should be in a high volume flow point of the circulation system, such as a series, as opposed to a bypass, filter point. Possible stagnation points should be avoided to minimize contaminant problems with the gauge or oil lines to the gauge.

- Oil Temperature - Measured by means of a high reliability heat sensor. Sensor shall be placed in the engine case nearest the oil circulation point reaching the highest average oil temperature. This may be some point near the exhaust valve guides. The location depends very much upon the particular engine design and its oil circulation system.

---

1. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

A high oil temperature is indicative of a severe wear problem, or an oil problem (such as dangerously reduced viscosity). Any of these conditions requires a maintenance check before any further long duration operation of the bus occurs.

- Transmission Fluid Level - A correct fluid level in the automatic transmission is important. A low level can result in fluid overheating; however, reserve capacity is usually built into the unit to partially compensate for some fluid loss. Standard bus check-out procedure at the garage is to frequently and periodically check fluid level. Prolonged operation of the transmission at low fluid levels causes fluid heating, thinning, further heating, chemical breakdown of the fluid, malfunctioning of the internal mechanism of the transmission, and perhaps more fluid loss. All symptoms are progressive. Normally, when the fluid is checked for level, a competent mechanic can determine if the fluid has experienced overheating.

- Generator Output Sensor - The bus has several important electrical systems onboard which are very important to safety and comfort of bus and passengers. They include:

    1. Bus headlights, rear lights, interior lighting;
    2. Bus radio and other alarms;
    3. Other sensors;
    4. Some controls and small power devices (fans, etc.).

  The bus generator, of course, is designed to maintain an adequate charge in the storage battery through the action of the voltage regulator and together with the battery to supply power to the entire electrical system.

- Battery Condition Sensor Generator Output Sensor - A low battery will render the entire sensor and communication system inoperative. Therefore, it may be desirable to send an alarm to the Operations Control Center if the bus has been inadvertently left inoperative for several days.

- Air Conditioning Operating Status - Quality passenger service includes factors related to health and comfort. A comfortable temperature within the bus is one of those factors. There is air conditioning equipment aboard some of the buses and it is required that it be operating when conditions so warrant. Frequently, in hot summer weather and when frequent passenger boarding and alighting occur it may be difficult to maintain a comfortable onboard temperature. The training and duty of the operator should be to keep the air conditioning turned on in warm seasons.

- Fuel Level - The number of buses which run out of fuel while en route each month sometimes exceeds one hundred. The consequences incurred are passenger inconvenience, expense of road calls, schedule disruption, and other inconveniences. One solution is the placement of a fuel level sensor onboard the bus for telemetry of fuel level back to Central Control. The data will be machine monitored and indication given to the dispatcher if the operator has not attended to fuel replenishment before the fuel level sensor has reached the alarm condition. The dispatcher, taking into account the remaining work for the operator, will arrange for the bus to be refueled in a timely manner.

  A second solution is for the Operations Control Center to keep track of the bus odometer readings and their most recent refuelings (indexed to odometer reading at fuel station). From knowledge of average fuel mileage, Central Control can estimate fuel level.

- Vehicle Speed - The vehicle odometer reading is telemetered to the Operations Control Center. It is possible to determine average speed from these readings. Speed checks, as from an onboard speedomoter, are related to speed limit violations.

- Vehicle Air Pressure Sensor - Accidents with various transit companies and also other road vehicles have occurred because of loss of braking due to low air pressure. However, CTA has a mandatory warm-up period which its operators are trained to observe before even moving the bus at the beginning of a run. If pressure should be lost suddenly during a run, it is doubtful if more could be done over immediate actions which the operator now takes.

- Engine Running Status - Engine running/not running data was considered when some of the details of interpreting various other sensor alarms were considered. For example, when the bus is garaged at end of its work (the radio is required to remain turned on and in contact with the Operations Control Center), the oil pressure alarm will be triggered, unless other means of inhibit are provided. Other sensor outputs could be similarly affected."

The number of parameters monitored is dependent upon the sophistication and subsequent cost of the monitoring equipment. Those functions which can be directly correlated to equipment reliability, such as, engine temperature and oil pressure, should be given primary consideration. Engine head temperature is considered to be the most sensitive and reliable indicator of most temperature-related engine damage problems. When the temperature safe guard is employed with oil pressure sensors, an effective early warning is given for most engine failures. The engine manufacturer should define the best location for these sensors.

CONCLUSIONS

Silent Alarms

The silent alarm function is generally considered to be a significant benefit to any transit property. Silent alarms have been so effective in present applications that their use and development is strongly encouraged by UMTA.[1] Drivers appreciate this aspect of AVM more than any other single feature. It gives them an increased sense of security especially during times of darkness and off-peak passenger loadings.

Benefits to be derived from the system include a reduction in crime rate, reduction in property loss, increased passenger confidence, and an increase in operating revenues. The increase in operating revenues stems directly from an increase in ridership attributable to the increased passenger confidence. The ridership increase is particularly evident during hours of darkness, when the operating costs per passenger mile are at their highest.

Another side benefit to the silent alarm system is that it can act as a deterrent to criminal activities occurring outside of the bus system. By utilizing the mobile communications equipment to report criminal activities the vehicle driver can be an immense aid to law enforcement agencies in the quick apprehension of criminals. This would be a societal benefit of an AVM system that would be difficult to quantify. There have, however, been similar side benefits from the increased popularity of CB radios. This experience has demonstrated that this type of surveillance can be effective if a proper description of the incident and location is given.

1. "Specifications for Bus Radio/Management Information System," Massachusetts Bay Transportation Authority, October, 1976.

● Mechanical Alarms

The purpose of the mechanical alarms is to telemeter back information that is designed to reduce the cost of road service and the related maintenance operations. These objectives, in turn, should result in a reduction of operating expenses and an increase in the quality of service and passenger revenue. Experience of the Chicago Transit Authority indicated that sensors to signify engine failures caused by temperature/pressure problems and out of fuel conditions maximized the benefits for the capital investment required.[1] This choice was based on a history of prior road calls. Approximately 1400 calls of the 56,000 road calls were coded as engine failures. Of these engine failures, it was estimated that approximately 500 calls were related to temperature/pressure failures. Minor repairs were often all that were required to correct the problem when the vehicle operator noticed the on board warning light. Major and subsequently costly repairs were required when the operator failed to heed the warning indicator. Since the engine failure sensors associated with an AVM system supplement rather than replace the on board indicators, it has a large potential for reducing the number of major overhaul tasks caused by failing to heed the on-board warning.

Actual experience of the Central Arkansas Transit Authority (CAT) resulted in twelve failures being detected by the AVM sensors before the vehicle operators noticed them. The CAT experience with the AVM engine failure sensors can be summarized as follows:

- The system recognized temperature/pressure related failures in sufficient time to prevent the occurrence any major engine damage.

---

1. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

- Approximately 50 percent of the failures were detected by the vehicle operators.
- There were no false alarms.

The valve of the fuel sensors will vary from one transit authority to another. An estimate of the monetary savings to be realized by their installation can be obtained by investigating the maintenance records to determine the number of road calls made for out of fuel conditions and the cost of each call. This cost can be surprisingly high when the expense of equipment, labor, passenger inconvenience, and lost operating revenues are taken into account. The sensors themselves are relatively inexpensive to purchase and install.

There are two principal causes of a transit vehicle running out of fuel, and each cause requires a different sensor. In one case the vehicle exceeds its operating range, thereby depleting its full complement of fuel. This problem can be solved by attaching the sensor in conjunction with the odometer. It can compare the miles logged with the maximum running capacity of the fuel tank and forward an alarm in ample time for remedial action. The other case for fuel outage is when the fuel tank is not "topped off" during replenishment. This problem, as well as the first, can be remedied by a detector which detects a low fuel condition. These sensors can be inexpensively installed in new vehicle purchases but are often impractical to install in existing equipment.

- <u>Farebox Alarm</u>

Since the farebox of most transit vehicles can carry as much as $500, it is a prime target for thieves. A tamper-proof farebox alarm in accordance with expeditious fare collection techniques can thwart any nefarious activities. The associated violence and intimidation employed by thieves can also be avoided if a notice of the alarm is posted in a conspicuous location.

VI. VEHICLE LOCATION, MONITORING, AND IDENTIFICATION

Of the four major subsystems (location, communication, data processing, display) that comprise an AVM system, the location subsystem is the most vital. System performance and cost depends most heavily on the location subsystem (which will be the most expensive element of an AVM system).

Fundamentally, there are two basic applications of AVM systems: fixed-route or random-route (area coverage) systems. Major bus transit operations are a primary example of a fixed-route system, while the dial-a-ride bus, taxi, and police operations typify random-route applications. Although the principal concept of both these applications is to locate and track a single vehicle or group of vehicles, the technology of these systems varies with their use. In Table 1, Symes[1] has attempted to match the potential AVM uses to the type of coverage required.

Table 1 - Potential Use of Fixed-Route/Random-Route Systems

Potential Use	System Required
Large Fleet Management	
● Transit	
- Fixed-route service	Fixed-route coverage
- Random-route service	Random-route coverage
● Paratransit	Random-route coverage
● Police	Random-route coverage
● Utilities	Random-route coverage
● Delivery & Repair Services	Ransom-route coverage
● Postal Services	Fixed-route coverage
Emergency Medical Services	Random-route coverage

A multi-user AVM system, which is designed to serve many users with an integrated system, has many advantages.

1. Symes, Denis J., "Multiuser Area - Coverage Automatic Vehicle Monitoring Program," IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 2, May, 1977.

The primary advantages of this system are the significant reduction in cost for both equipment and operation of the system by each individual user. Other advantages include; a) an interface of several operations for better control and, b) expansion of the market by making AVM available to users other than those with fleets large enough to justify a separate private AVM system.

- <u>Equipment</u>

There are three basic AVM location techniques:

1. Signpost or proximity
2. Radio frequency
3. Dead reckoning

Each of these types has unique economic and performance attributes in different deployments, and within each type, subtypes exist.

The different location subsystems are described in the following paragraphs (see Figure 5).

- <u>Signposts</u>

Signposts can either be passive or active. With passive (vehicle) signposts, the signpost continually broadcasts its street address (in a special numerical code). When a particular vehicle passes near the signpost, it picks up the signal and relays it by radio to the control center.[3] In the active (vehicle) system, the vehicle continually broadcasts its identity.

---

1. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically Locating Land Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977.
2. Symes, Denis J., "Multiuser Area - Coverage Automatic Vehicle Monitoring Program," IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 2, May, 1977.
3. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

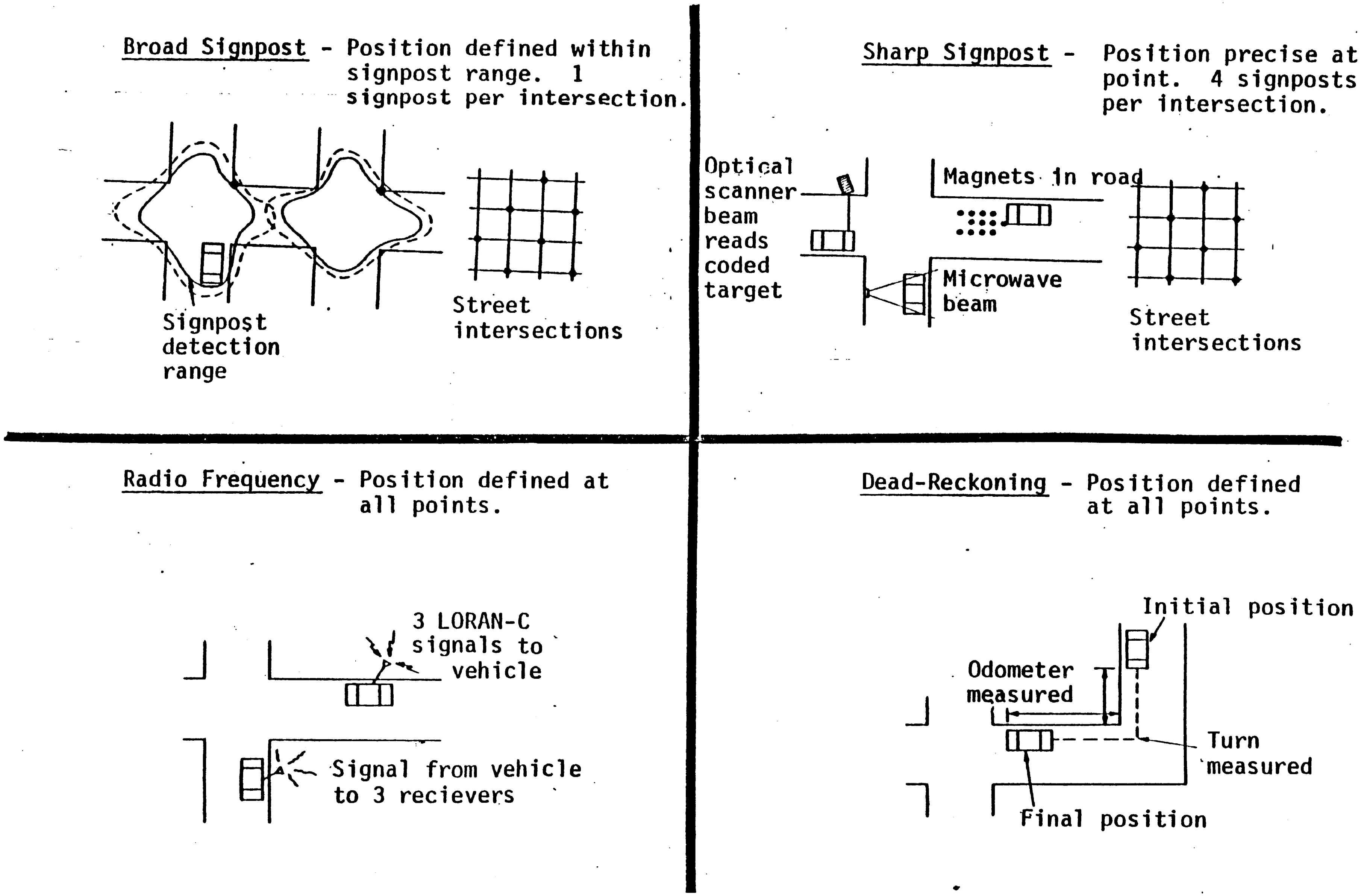


Figure 5 - AVM Location Subsystem Technologies

Source: Reed, David H., et. al, "A Study of the Costs and Benefits Associated

The signpost picks up the signal from the passing vehicles and relays it by a communication line to the control center. The main advantages of the passive system over the active system are:

1) The signposts do not require communication lines to the control center. Where battery power is used, the installation is not limited by physical connection (except support systems) to any external system.
2) The signpost does not require a receiver and vehicle ID decoder, but only a low-power transmitter, and therefore is lower in cost and smaller in size.

Other advantages of the passive electronic signpost include:

1) passive systems tend to be lower in cost;
2) they conserve the radio frequency spectrum;
3) they can be integrated with regular vehicular radio equipment;
4) they are potentially very accurate.

The principal disadvantage of the passive signpost is that the bus must carry a signpost receiver, signpost ID decoder, and transmitter for transmittal of location data back to the control center. However, since the bus carries a data communication package for additional purposes such as voice, the extra cost is low and is basically a one-time capital expense.

Signposts can also be classified into two major categories: broad or sharp. The radio broad-field type gives a precision of 100-600 feet whereas a sharp signpost (as in an optical scanner) will give a precision up to a few inches. The distinction between broad and sharp signpost systems is important in the area of system performance and costs.

"For random-route vehicle tracking, signposts would need to be installed at least at every other intersection (assuming an ideal rectangular street pattern). At these intersections, one broad-field signpost would be needed, whereas up to four of the sharp-field signposts would be needed to cover the possible vehicle manuevers (i.e., turns). Since vehicle position is known only at the signpost and yet it is desirable to use the minimum number of installations (i.e., at every other intersection),most proximity AVM concepts include the use of an odometer to provide incremental distance measurement between signpost installations and thereby achieve accuracy specifications (e.g., ± 300 feet). In one unique broad-field signpost system, the use of the odometer is obviated by adjusting the radiation fields of adjacent signposts to overlap. By measurement of relative field strengths, position between the signposts is obtained. Field strength decreases approximately linearly with distance from the signpost."[1]

The following section describes a number of signposts concepts summarized in a study for the Chicago Transit Authority in 1971.[2]

- Magnetic Signposts - In this technique small magnets are embedded in the roadway in a vertical position. The vehicle picks up the magnetic fields as it travels over them. A row of magnets is embedded for each location point, oriented in the direction of vehicle travel. A code corresponding to the intersection, or checkpoint, is developed in the pickup circuitry because of the polarity orientation of each magnet as it is embedded. Magnets are required for each roadway lane and test results indicate very good accuracy.
- Lasar Scanner/Passive Beacon - A small, low-power laser beam continuously scans in a vertical plane laterally to the vehicle from a part in the near curb side of the vehicle. A passive beacon, consisting of horizontal

1. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically Locating Land Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977

2. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

strips of reflective material (tape, paint, foil, etc.) placed in a vertically oriented code pattern, reflects the laser beam back to a sensor on the vehicle. The sensor digitizer, the returned light pulses, and the digitized code, which is the ID of the beacon or intersection, is transmitted over the vehicle radio to the control center. The system is potentially capable of measuring range of vehicles-to-beacon. This and other possible design features are usable in determining exact arrival of a vehicle at a particular point.

- Radio Scanner/Transponder - A low-power transmitter, operating at any UHF or VHF frequency, periodically radiates a signal from the near-curb side of the vehicle. A beacon is mounted to a post on the curb, such as at a passenger stop or street intersection. It consists of a receiver which stores the received power by means of a special RD power supply circuit. The received signal carries an interrogation signal which the receiver also demodulates and uses internally to trigger an ID code generator which in turn re-modulates a very low power transmitter (at a second VHF or UHF carrier frequency) which transmits the ID code of the beacon back to the vehicle. The power for the code generator and transponder is obtained from the special RF power supply circuit.

- Optical Scanner/Passive Beacon - A wayside scanner reads a vehicle identification number that is coded either digitally, or by special type style numbers placed on the near-curb side of the vehicle when it passes. The code is then relayed back to the Control Center. This system, while limited in many respects, has been in use in American railway systems and London bus systems for several decades.

- Inductively Coupled Data Link - A small battery-powered transponder onboard the vehicle responds to a buried loop interrogator as the vehicle passes over it. The interrogation is composed of a decoder and transmitter-receiver. Besides identifying the passing vehicles, the interrogator can receive and decode some operational messages. Messages are returned to the control center via phone lines or radio link.

- VHF Wayside Beacon/Electronic Signpost - This signpost continually repeats a coded signal corresponding to the local street address or street intersection. The passing vehicle picks up the signal and relays it back via radio link to the Control Center. The signpost normally operates in the VHF radio spectrum with output power in the milliwatt range.

- Radio Frequency

Many radio navigation concepts utilize time-of-arrival or phase differences of synchronized radio frequency (RF) signals from (or to) three or more transmitters (or receivers) located at known geographic points. With assumption of straight-line transmission paths, these time or phase differences are used to calculate position by trilateration. Examples of radio frequency techniques that are particularly applicable to land vehicles are described below.

- Loran-C - The Long Range Navigation Grid maintained by the U.S. Coast Guard is used for navigation of ships in the coastal confluence. By 1978 most coastal regions of the U.S. will be covered by this grid; and it is anticipated, with the addition of a few necessary transmitters, all of the continental U.S. can be covered in the next few years. Loran-C provides position of a ship, aircraft, or land vehicle by transmitting pulsed 100 KHz carriers from three geographically separated transmitters. Two of the transmitters are time-slaved to the third so that the time differences of pulse arrivals can be used to locate the vehicle.

  Theoretically, constant time difference of pulse arrivals from any pair of stations defines a hyperbola on the surface of the earth. The crossing of two such hyperbolas gives the position fix. For ships, hyperbolas of constant time differences are overlaid on navigation charts. On land, however, variations in conductivity over transmission paths from the transmitters may not permit the construction of geometrically true hyperbolas. It is empirically known that measured time-differences are stable (i.e., continuously the same at a given location); however, the grid needs to be calibrated for land use. The more the distortion in the hyperbolas, the more or denser the calibration points needed to provide a given accuracy.

- Pulse Trilateration - A network of receiving stations, separated by a distance determined by power levels and other factors, receive sharp rise-time pulses on high frequency carrier signals from tracked vehicles. Each vehicle emits its pulse followed by a message code in an assigned time slot. The times of pulse-arrival at the receiving sites are established and then relayed by wire link to a 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 that vehicle's position. The selection of the three receivers is based on a priori knowledge of a particular vehicle's operational area or knowledge of its last position. At carrier frequencies of 1000 MHz, it is estimated that the average separation of the receiver sites will be six miles in urban areas. This is a significant parameter in the system cost equation and its empirical determination is quite important."[2]

In the hyperbolic trilateration technique, the location is dependent upon the angle at which the lines of position interact. As this angle becomes more acute, the location error increases. Location errors in RF systems also result from atmospheric noise, external man-made noise, and receiver noise (which blocks out the signal). Other problems such as high rise buildings, tunnels, and bridges can also cause errors in RF systems by blocking the signal.

1. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically Locating Land Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977.

● Dead Reckoning

"A dead-reckoning location technique is generally characterized by providing position information without reference to external signals. This location system utilizes a magnetic heading indicator and an odometer to track vehicle position. In dead-reckoning schemes, position errors are cumulative and an auxiliary method must be utilized to provide the positio of a starting point and other reference points thereafter at frequent inte vals to keep the error within specification. For the starting position, t vehicle operator transmits his position to a central computer; thereafter, the tracking is accomplished automatically by transmitting heading and distance-increments to the central computer at very frequent intervals. These data are used to update the vehicle position on a very accurate "map stored in the computer memory. When the compass indicates that a turn has been made, the computer automatically "places" the vehicle on the nearest street location compatible with the change in heading. By "placing" the vehicle on the nearest new street, any accumulated position error is automatically zeroed. The scheme works best for a vehicle that makes frequent turns."[1]

The principal advantages of this location technique are; 1) the possibility of position location accuracy to within a few feet after a long trip and 2) random location of vehicles is very easily accomplished and is adaptable to all types of purposes including fixed route. The main problems of dead reckoning include; 1) while the odometer part of this location subsystem has very good accuracy, the compass part of the subsystem (at the present time) has cost, operational, and performance problems; 2) errors on this system are cumulative, not random; 3) this location subsystem is not the best suited for bus systems (fixed route).

1. Blood, Bernard E., Klien, Bernd, W.A., "Experiments of Four Different Techniques for Automatically Located Land Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977.

- System Reliability Requirements

System reliability is a key requirement in any location subsystem in an AVM program. Strict reliability requirements are needed to insure the system will not be hindered by frequent breakdowns or lack of data from vehicles. For the tests in Philadelphia[1] UMTA requested that the system should have a mean time between failure (MTBF) of no less than 1000 hours with a design goal of 2000 hours. UMTA defined MTBF as "total operating time divided by the total numbers of failures." A failure is defined as occurring (1) when 5% or more of the vehicle cannot be located within the accuracy requirements, or (2) whenever location, schedule, or headway data of these vehicles cannot be displayed or printed.

- AVM Location Accuracy Requirements

The location accuracy requirements for an AVM system are dependent upon the use of the system (i.e. transit, police, taxi). In most police operations, a location accuracy of 933 feet was found necessary by Larsen[2], based on a analytical model developed in St. Louis. For other police operations, such as sealing off a block, coordinating a chase, or quickly locating an officer in trouble, an accuracy of about 220 feet is required (based on the average size of a city block in St. Louis).

Bus operations, on the other hand, are usually based on vehicle headway. Accuracy is measured in time and later converted into a distance.

---

1. Symes, Denis J., "Multiuser Area - Coverage Automatic Vehicle Monitoring Program," IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 2, May, 1977.

2. Larson, R.C., et al., "Evaluation of a Police Implemented AVM System, Phase I, with Recommendation for Other Cities," to be published by LEAA, prepared by Public Systems Evaluation Inc., 1977.

Therefore, timepoints are used to measure time-of-passage of transit vehicles. In Chicago[1], where the average headway would be five minutes (at rush period), a maximum of 10% error of timepoint location precision was required. This translates to roughly 30 seconds time-of-passage error. To further increase accuracy in location measurement, 24 seconds was recommended. This is about 150 feet at an average minimum route speed of 5 mph. The precision accuracy, measured in feet, would of course differ with varing vehicle headways and speeds.

Based on a lengthy state-of-the-art literature review in both the requirements of an AVM system and the range of competitive location subsystem technologies, the following was required by UMTA in Philadelphia (1975)[2]:

1. Performance specification of 300 feet (with 95th percentile certainty) for accuracy on both fixed and random routes.
2. Performance specification of 15 seconds (with 95th percentile certainty) for time-of-passage accuracy on fixed routes.

The 95th percentile specification of accuracy within 300 feet is not only to insure proper accuracy but to reduce the possibility of any large errors. It is felt that if location errors are large (even though they may be few in number), considerable question in system reliability will result.

---

1. Symes, Denis J., "Multiuser Area - Coverage Automatic Vehicle Monitoring Program," IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 2, May, 1977.

2. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically Locating Land Vehicles: A Summary of Results," USDOT Report # UMTA-MA-06-0041-77-2, TSC, November, 1977.

The following is an excerpt from the "Multiuser Automatic Vehicle Monitor System: Request for proposal (TSC-432-0017-RN)," issued by the Transportation Systems Center in 1975. This specification was the official standard of performance for the four location subsystems tested in Philadelphia.

"3.2 AVM Accuracy

Location accuracy is specified at two AVM system levels:

1. Location Subsystem - The L.S., independent of other system elements, shall satisfy the accuracy requirements in 3.2.1.
2. AVM System - Vehicle position indications and time-of-passage determinations shall satisfy the accuracy requirements in 3.2.2.1, 3.2.2.2 and 3.2.2.3 below.

3.2.1 <u>Location Subsystem (L.S.) Accuracy Specification</u>

For a single AVM-equipped vehicle at any given instant, L.S. error is the radial distance between the true position and the L.S.-measured position. The L.S. error shall be

Less than 300 feet for 95% of all possible true vehicle-locations
Less than 450 feet for 99.5% of all possible true vehicle-locations

and in addition for the L.S. measurements of true locations on any 0.1 mile segment of any possible travelway, the average of the corresponding L.S. errors shall not exceed 450 feet. The above specifications are applicable under the following conditions:

Possible true locations comprise all geographic points on all travelways in the specified area of AVM coverage as well as on any separately specified routes of AVM coverage.

The vehicle is operating at any speed in the range 0 to 100 mph.

Environmental conditions are within the specified range.

The telemetry (e.g., from vehicle to central) is "perfect," i.e., all L.S. data gathered on the vehicle (and/or at auxiliary receiving sites) are transferred without alteration to the point of processing.

3.2.2 <u>AVM System Accuracy Specification</u>

3.2.2.1 <u>Fixed-Route Vehicles</u> - For all AVM-equipped vehicles operating "on fixed routes during any statistically significant period of time (i.e., at least the length of one full operational day for the system), at least 95% of all such position indications (or updates) of all fixed route vehicles shall be in error by less than 300 feet, and at least 99.5% of all such position indications shall be in error by less than 450 feet. This fixed-route system error is the straight-line distance between the true position of a vehicle at a given time and system-indicated position (for the same time) as presented to the dispatcher or stored for subsequent off-line use. Note that the system-level error includes effects (e.g., polling procedures) which degrade the inherent accuracy of the L.S. measurements, but also includes effects (e.g., position extrapolation) which enhance the accuracy or compensate for the effects of error sources.

This specification is applicable under the following conditions

Vehicles are operating on all of the routes specified

Vehicles are operating at speeds in the normal range experienced in urban bus transit

Environmental conditions are within the specified range.

3.2.2.2 Random-Route Vehicles - For all AVM-equipped vehicles operating on random routes in the AVM-coverage area during any statistically significant period (i.e., at least the length of one operational day for the system), at least 95% of all position indications of all random-route vehicles shall be in error by less than 300 feet, and at least 99.5% of all such position indication shall be in error by less than 450 feet. The random-route system error is the radial distance between the true position of a vehicle at a given time and the system-indicated position (for the same time) as presented to the dispatcher or stored for subsequent off-line use. Note that the system-level error includes system effects which degrade the inherent accuracy of the L.S. measurements as well as system capabilities that enhance the accuracy of compensate for the effect of error sources.

This specification is applicable under the following conditions:

Vehicles are operating on any travelway in the specified area;

Vehicles are operating at speeds in the normal range experienced in urban traffic;

Environemntal conditions are within the specified range.

3.2.2.3 Fixed-Route Schedule Monitoring (Time-of-Passage) Accuracy - For fixed-route transit vehicles the AVM system shall have the capability for the determination of

schedule deviations;

running times;

differences between schedules and actual start times for runs;

differences between schedules and actual layover times.

For all designated time points on all specified routes, the times of bus passage, as determined by the AVM system, shall be accurate to ± 15 seconds for 95% of all such determinations and ± 60 seconds for 99.5% of all such determinations (considering a statistically significant period of time -- at least one full operational day for the system). Derived times and time periods (those identified above and others), as presented to the dispatcher or stored for off-line use, shall be fully consistent with the times of passage specification; e.g., indicated shcedule deviations shall be accurate to ± 15 seconds for 95% of all such indications. As this is a system-level specification, all applicable sources of error and data enhancements are included.

The above specification is applicable under the following conditions:

All AVM-equipped buses are operating on all specified routes.

Bus trajectories (i.e., detailed time/position histories) are those typical of urban transit bus operation on fixed routes.

Time points are established piror to system operation, but may be located at any points along the routes.

Time-of-passage knowledge also implies time of departure knowledge for those events at which the bus has stopped at a time point."[1]

1. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically locating Land Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977.

The performance specifications given for the 1976/77 test in Philadelphia were used because it was felt that they had the potential for giving significant benefits in AVM applications.[1] The following is a list of major AVM functions which can result in improvements for transit operations, and therefore is a basis for performance specifications in transit operations:

Reduction of headway variance on short-headway routes (10 minutes or less) by use of the central-control capabilities of AVM systems. Reduced headway variances will cause higher levels of service in transit operations, or routes can be maintained at the same level of service with fewer vehicles.

Maintenance of schedules on long-headway routes (more than 10 minutes) by utilizing the automatic indication of actual position verses scheduled position at every point along the route. This feature will improve the reliability of service and make certain buses would not arrive early or late.

Automatic collection of fleet-operational performance data, such as accurate and complete measurements of running times (as a function of time, passenger loading, etc.) between major stops or "time points" on transit routes. This data is extremely difficult and expensive to obtain in a usable form. However, this data is essential for making schedules that optimize efficiency in service and the allocation of the available transit vehicles and drivers.

Improvement of driver security and passenger safety by using a priority "silent alarm" signal with the communications subsystem. When the alarm is actuated, emergency aid can be dispatched to the exact location of the vehicle.

- <u>AVM Experience</u>

AVM Systems have been tested by both U.S. and foreign governments over the past decade. Table 2 lists the different agencies influenced by AVM and

1. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically locating Land Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977.

a list of tests of different AVM locations systems.[1]

Table 2 - AVM Background Experience

U.S. Government

Department of Transportation

- Chicago Transit AVM Pilot Project .. 1971 (Signpost)
- 1971 Field Tests in Philadelphia
- 1976/1977 Field Tests in Philadelphia
- 1977 AVM Cost/Benefit Study

Four Location Subsystems Used:

- Signpost and Dead Reckoning
- Pulse Radio Frequency, Signpost and Dead Reckoning
- Signpost and Odometer
- LORAN Radio Frequency, Signpost and Dead Reckoning

Department of Justice

- Funded Police AVM Systems in the following cities:
  Montclair, CA .... 1971 (Signposts)
  St. Louis, MO .... 1974 (Dead Reckoning)
  Huntington Beach, CA .... 1975 (Signpost)
  Dallas, TX .... 1976 (Radio Location)
- Development and Field test of a Cargo Security System for Trucks in Los Angeles ... 1976/1977 (Signposts/Radio Location)

Federal Communication Systems

- Issued Rule and Order Related to AVM Frequencies

Foreign

Paris - Experimental System on one transit route.

Zurich - 1/3 of Transit fleet Equipped. Used electronic signposts to reset odometer for location.

Hamburg - Signpost and Odometer on 160 buses.

London - Optical System on all routes since 1959. Manually reset odometer system on one route since 1973.

1. "Transportation and Automatic Vehicle Monitoring," Gould, 1978.

The major evaluation of AVM location subsystem testing has been undertaken by the U.S. Department of Transportation/Urban Mass Transportation Administration (USDOT/UMTA) in developing a system for both-fixed and random-route users. This experimental undertaking was programmed in two phases.

Phase I consisted of testing four vehicle location concepts in Philadelphia while Phase II contemplates selecting one of the four systems to develop, fabricate, install, and test a completely functional system that can be shared by users with diverse requirements. The results of the tests (Phase I), conducted in Philadelphia during the winter of 1976-77, have been thoroughly analyzed and documented in several reports and papers.[1,2,3,4,5] The program details and the results are briefly summarized below. Phase I of the UMTA program consisted of testing AVM equipment of four manufacturers, 1) Fairchild Space and Electronics Company 2) Hazeltine Corporation, 3) Hoffman Electronics Corporation and, 4) Teledyne Systems Company. The raw data measured was corroboratively processed by Ludwick of MITRE Corporation.[4] The testing was performed at the system (AVM) level and at the subsystem (AVL)

---

1. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically Locating Land Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977.
2. Symes, Denis J., "Multiuser Area - Coverage Automatic Vehicle Monitoring Program," IEEE Transactions on Vehicular Technology, Vo. VT-26, No. 2, May, 1977.
3. Bordelli, A. and Sklar, S. "An Integrated Approach to Automatic Vehicle Monitoring and Mobile Digital Communication," Conference Board of 28th, IEEE Vehicular Technology Conference, March, 1978.
4. Ludwick, S., John, Jr., "Analysis of Test Data from an Automatic Vehicle Monitoring (AVM) Test," Conference Record of 28th IEEE Vehicular Technology Conference, March, 1978.
5. Gruver, G.W., "Philadelphia Field Tests of an Overlapping Sign Post AVM System During the UMTA Multi-User AVM Program." Conference Record of 28th IEEE Vehicular Technology Conference, March, 1978.

level against the specification data stipulated by UMTA . System-level performance included errors introduced by the communication system (particularly errors resulting from finite polling intervals) but also corrective measures such as error corrective coding as well as extrapolation of position and other data smoothing techniques. For the location subsystem, data sufficient for complete position fixes and time-of-passage was checked against the specifications. The testing encompassed both fixed-route and random-route configurations. In addition, the AVM systems tested were also expected to monitor the fixed-route schedules by recording the schedule deviations, running times, differences between scheduled and actual times for runs, and the differences between scheduled and actual layover times.

Special tests were conducted to demonstrate the ability of the AVM system to function under conditions of 1) extreme temperature, 2) urban RF environment, 3) urban EMI, 4) vehicle speeds to 100 mph, 5) a variety of sign post mounting conditions, 6) tunnels, covered roadways, narrow streets, wide boulevards, etc.

Each of the systems was evaluated for its ability to locate the vehicles accurately. The performance specifications drawn by the entire AVM system are shown in Table 3.

The overall accuracy statistics of each of the four individual systems are shown in Table 4. The table does not include the results of Fairchild and Hazeltine tests for fixed route configuration. In the former case, all of the data were to be manually calculated, and the raw data showed that their results are very accurate in this regard. No efforts were made to calculate.

Table 3 - AVM System-Level Performance Specification

Item	Fixed-Route Operation	Random-Route Operation
95% of all location indications (or updates)	Error < 300 feet	Error < 300 feet
99.5% of all location indications (or updates)	Error < 450 feet	Error < 450 feet
99% of all time-of-passage determinations	Error < $\pm$ 15 seconds	----------
99.5% of all time-of-passage determinations	Error < $\pm$ 60 seconds	----------

Source: Blood, E., Bernard, Kliem, W.A., Bernd, "Experiments on Four Different Techniques for Automatically Locating Land Vehicles - A Summary of Results," TSC, UMTA, November, 1977.

	Fixed-Route Time Point Accuracy (Seconds)					Random-Route Location Accuracy (Feet)				
	Required	Fairchild	Hazeltine	Hoffman	Teledyne	Required	Fairchild	Hazeltine	Hoffman	Teledyne
Number of data points	450	-	-	426	341	450	844	434	999	463
95%	15	-	-	10	34	300	250	1650	275	925
99.5%	60	-	-	23	50	450	425	3550	475	1650

Table 4 - Overall Accuracy Stastistics

Source: Ludwick, S. John, Jr., "Analysis of Test Data From an Automatic Vehicle Monitoring (AVM) Test," Conference Record of the 28th IEEE Vehicular Technology Conference, March, 1978.

the data. In the Hazeltine tests, the reported results were not representative of the true situation because of some hardware problems, and hence they were not recorded. As a result of Phase I testing in the area of location accuracy performance and economics the Hoffman Electronics Corporation (now Gould Corporation), system was awarded the UMTA multi-user AVM contract for Phase II testing in Los Angeles.

It is important to realize that the Philadelphia tests occurred in 1976-77 and, due to rapid advances happening in AVM technologies, the test results may now be obsolete. Systems using a particular technology that have performed poorly may have had rapid advances since that time,and new and different devices (or technologies) may have been developed or perfected.

The technical details, objectives,and achievements of some of the other major applications are summarized below.

- Huntington Beach Automatic Vehicle Monitoring System Utilizing Overlapping RF Signposts

The AVM System jointly developed by Hoffman/Gould and the Huntington Beach Police Department has been operating for over a year in Huntington Beach, California. The components of the system are 1) an AVL system, 2) color graphic displays for two dispatchers, 3) an existing UHF voice channel, 4) computer aided dispatch system. The entire system services 56 police vehicles with the information obtainable from H83 Sign Posts over an area of twenty-nine square miles. The AVL system was installed in 1976 and became operational in 1977. Operational improvements are being continually accomplished since the beginning of its operation.

The System has operational flexibility; any of five different modes of operation can be chosen by the dispatcher as per the needs of the situation.

A brief description of the modes of operation follows:

- Automatic Mode: when a car is selected in this mode, all of the operations of vehicle location, identification, vehicle assignment, best route selection, and the display of maps are all carried over by a computer.
- Unit Emergency Mode: This is similar to Automatic Mode except that this mode is selected by a vehicle unit.
- Vehicle Status Mode: The vehicle status mode shows any AVM-equipped vehicle, selected by the dispatcher at its current location.
- Reporting District Mode: In this mode, all vehicles and case location information within a selected area is displayed.
- Tracking Mode: At the choice of the dispatcher, any particular vehicle movement can be tracked down and displayed.

For more details of the system components and their functions, see paper by Gruver and Reichard.[1] In summary, the observations of this Program are: 1) failure of a few sign posts has no major effect on the operation of the system, 2) theft and vandalism of sign posts have posed a minor problem, 3) a location accuracy of ± 300 feet on major streets and ± 600 feet on minor streets was achieved with the 483 sign posts, 4) the measured location accuracy of ± 300 feet at the 70th percentile was achieved against the design specification of ± 350 feet at 50 percentile.

---

1. Gruver, W. George and Reichardt, A. Otto, The Huntington Beach Automatic Vehicle Monitoring System Utilizing Overlapping RF Sign Posts," Conference Record of Paper Presented at the Twenty-Eighth Annual Conference, March, 1978.

- Hazeltine's AVM System Testing in Dallas:

The AVM system of Hazeltine Corporation has been tested in Dallas in addition to Philadelphia under a contract with differing sponsoring agencies. The description and details of the test conducted in Philadelphia is given in an earlier section. The details of the testing in Dallas follow:

The AVM Systems of Hazeltine Corporation has been subjected to testing in the operations of the Dallas Police Departments Southwest Patrol District in 1976. The area under surveillance of the system covers approximately 100 square miles providing location and digital status communication for 43 vehicles. In addition it provides an interface with the City of Dallas Police Computer-Aided Disptach System. The general operational features of this system are somewhat similar to that of the Huntington Beach Police Department.

The special features of this system are the ability to provide: 1) two-way extended-length message transmission between the dispatcher and vehicle operator, and 2) direct access by the vehicle operator to remote computer data files using a data terminal in the vehicle. The system proved to have good base-to-mobile communication links well beyond 25 miles (40 km). An average location accuracy of 270 ft. for 95% of the time was observed. Additional details of the elements of Hazeltine's AVM system in Dallas can be found in a paper by Borelli and Sklar.[1]

---

1. Bordelli et. al., "An Integrated Approach to Automatic Vehicle Monitoring (AVM) Test," March 1978.

- AVM Experience in European Countries

The importance of AVM Controlled Operationas has been realized by at least four European Countries: France, Switzerland, Germany, and England. In all of these four countries, the application of AVM Systems was solely intended for improving transit operations in the cities of Paris, Zurich, Hamburg, and London, respectively. The experiences of AVM in these countries will be of immense value for adopting AVM systems to the transit industry of the United States. The details of the systems and problems faced by the agencies are thoroughly investigated and summarized by Kleim.[1] Summary of some of the operational details are provided below.

- AVM in Paris:

An AVM System was initiated and made operational in January 1975 for monitoring 35 transit vehicles in a fleet of 3700 buses operated by Regie Autonome des Transports Parisiens. The objective of this program was to increase the level of service, while the cost of operation was not a main concern. The general observations made under the program were as follows:

1. The AVM system was not effective when the buses were operating in heavy traffic.
2. The drivers of vehicles under AVM had no prior training, which reduced the system effectiveness. Training of drivers was considered imperative for future operations.
3. Installation of equipment on vehicles was found to be more complex than what was previously envisioned.
4. Because of door-closing problems on the vehicle, the passenger counting mechanism did not function properly.

---

1. Kliem, W. A. Bernd, "Investigation of European AVM Experience," Report I UM711-PM-76-13, December 1978 of Transportation Systems Center, USDOT.

In this program, AVM is planned for expansion to other vehicles in the fleet.

- AVM in Zurich:

Verkehnsbetriebe der stadt Zurich, the public transit authority operating streetcars, electric buses, and motor buses, has initiated AVM to alleviate the problems encountered in controlling the vehicles. The major objective was to provide a better communication link between the vehicle and the Central Control System. The system was first installed in 1971 for select routes, and subsequently the program was expanded to other routes. The significant points of this program are summarized below:

1) Off-line data such as passenger boardings was found to be of great help in scheduling.
2) The accumulated data on vehicle movements enabled the operator to develop techniques to predict the arrival times at next stops.
3) The dispatcher was well trained to use the equipment with special simulators for training
4) Several hardware problems were later solved by modifications to the system.

- AVM in Hamburg:

Hamburger verkehriverbund, the public transit authority, initiated the AVM program for its bus fleet in 1965. The AVM system was intended to provide position and passenger counts to a central dispatch point for use in the control of vehicles. The observations made in this program are:

1) Passenger counts on the vehicles were found to be very useful for scheduling and to dynamically route the buses.

2) Deviation in headway on the AVM Controlled routes have been significantly reduced.

3) The spare vehicles required to substitute the disabled vehicles have been cut down.

4) The number of dispatchers employed has been reduced.

5) Passenger wait time has been reduced.

- AVM in London:

Greater London Council, in 1959, has initiated AVM System to overcome the limitations of radio channel communications and to provide a more cost-effective control system. The system was made operational on seven of the routes as a starting point. Some of the relevant experiences are:

1) It was found useful to obtain a continuous location system over a discreet location system.

2) The control equipment was not operated efficiently. This was a result of insufficient training of the dispatcher.

3) Several problems in the software were left unresolved.

4) Some modifications were done to alleviate hardware problems.

- <u>Cost Benefit Analysis</u>

This section is a result of the study of the cost and benefits associated with AVM, based on the field tests in Philadelphia in 1976, which was the first major cost-benefit analysis done on AVM.[1] This test covered the three basic location techniques: signpost (both broad signposts and sharp signposts), radio frequency, and dead reckoning for both fixed and random route operations. The study focused on B-C ratios of bus, police, taxis, and multi-user vehicle fleets. Because of many

---

1. Reed, H.D., et al, "A Study of the Costs and Benefits Associated with AVM," Report #UMTA-MA-06-0041-77-1, DOT/TSC, 1977.

uncontrollable variables and uncertainties the results were presented in a high and low range of potential B-C ratios (Figure 6). The high range was based upon reasonably optimistic projections, while the low range was based on a conservative projection. The actual B-C ratio for an AVM system will most likely be within the ranges of Figure 6 and depend upon such variables as 1) type of urban/rural environment, 2) type of location subsystem used, 3) the ability to properly manage the AVM system.

Some of the major conclusions of the B-C analysis are listed below: [2]

- AVM installations to date have not assigned importance to formalized cost-benefit related data gathering or analysis.
- Police cost savings are the most significant. Due primarily to the high cost of staffing patrol cars, even small reductions in required vehicles account for large payroll savings.
- Bus savings are considered positive. However, approximately half of the total savings are made possible by replacing personnel who made manual passenger counts with automatic passenger counters. AVM bus savings vary widely between cities due to extreme differences in operation cost factors such as insurance, O & M, number of checkers and service operating characteristics of transit properties.
- Sharing costs among a mix of users does not provide significant savings. Only a portion of AVM costs are eligible for sharing between users. The benefits of shared costs are diluted when participants compromise otherwise lower individualized technology costs.
- Costs and benefits are highly dependent upon site and fleet characteristics. Implementation planning must consider the changes in location system costs associated with changes in fleet size, mix or utilization, and operating areas.

2. Reed, et. al., "A Study of the Costs and Benefits Associated with AVM," U.S. DOT, UMTA, February, 1977.

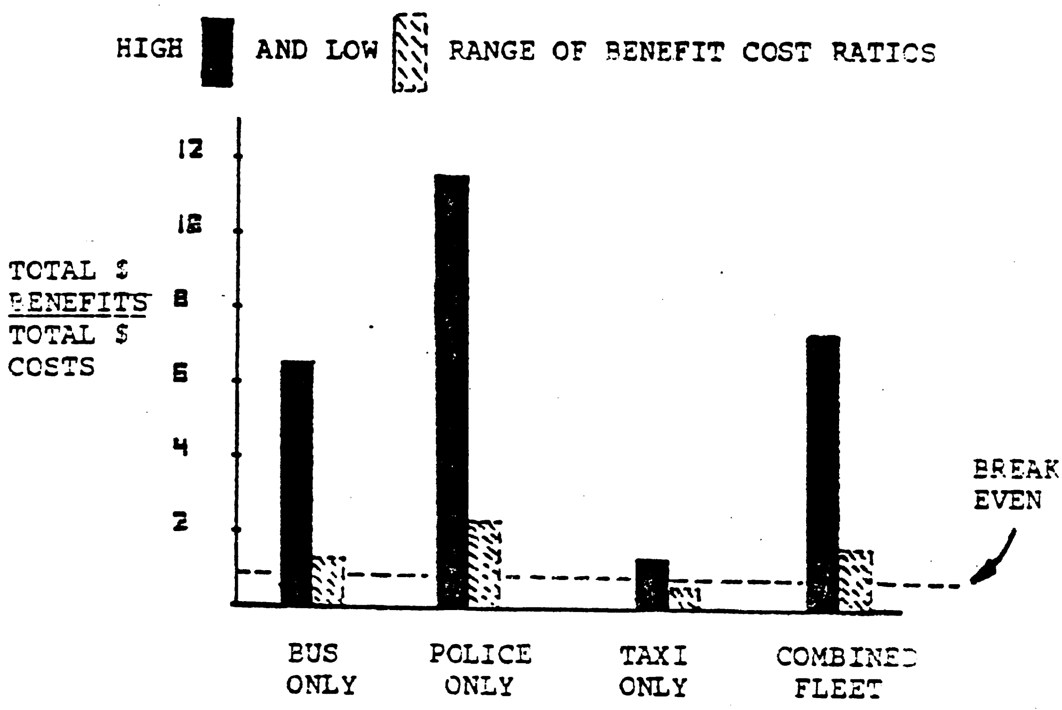


Figure 6 - Benefit-Cost Ratios for AVM Fleet Operations

Source: Reed, H.D., et al., "A Study of the Costs and Benefits Associated with AVM, Report #UMTA-MA-06-0041-77-1, DOT/TSC, February 1977.

- Security benefits of the silent alarm are important. No dollar value has been assigned to these benefits, but they appear to provide sufficient reason to proceed with an AVM implementation which might be marginal in terms of dollar benefits.
- Usually careful planning and management are required to exploit AVM's potential benefits. The high and low assumptions used in this study illustrate that the extent of savings can vary greatly with slight changes in AVM utilization.
- Different location systems are the most economical for fixed- and random-route users.

The vehicle location subsystem is the most revolutionary element of AVM, hence the location subsystem creates the opportunities for more efficient and productive utilization of equipment and personnel. In the judgement of the project manager, the estimates were realistic and the cost variations were also identified with each generic AVM system, which is shown in Table 5.

Sharp Signpost	± 20%
Broad Signpost	± 5%
Radio Frequency	± 18%
Dead Reckoning	± 6.5%

Source: Reed, David H., et. al, "A Study of the Costs and Benefits Associated with AVM," U.S. DOT, UMTA, February, 1977.

Table 5 - Total System Cost Variations in Generic AVM Systems

The location subsystems were analyzed (for the AVM life cycle cost) showing the effects of the number of vehicles and land area on the system costs. Figure 7 illustrates the effect of fleet size on system costs (for fixed-route systems) showing that broad signposts are the most cost effective location subsystem. However, it was discovered that for random route operations radio frequency location subsystems were advantageous, based on cost (Figure 8).

Figure 9 displays the effect of land area on AVM life cycle costs for the different location subsystems. This figure shows the size of land area does not affect the cost of radio frequency or dead reckoning systems.

Table 6 further illustrates the ranges of B-C ratios of bus, police, taxi, and multiuser systems using the different location techniques. This table shows the following:

- Police systems show the highest investment payoffs (using radio frequency location systems).
- Transit fixed-route systems would benefit best by using the broad signpost location concept.
- Multi-user systems do not fully show the significant savings (that were expected) over separate AVM systems.

The cost curves in Figures 7, 8, and 9 are represented as straight lines, but this may not be the actual case in real life. Actual curves may be non-linear with abrupt jumps, but they are not appropriate for this particular analysis. Figures 7 thru 9 are meant to illustrate the cost differences due to the particular location subsystem technologies used, and the cost relationship between AVM systems using the different location subsystem technologies.

It must be realized that the numbers in Figures 7, 8, and 9 and Table 6 not only represent costs as of 1976, but reflect the technologies present

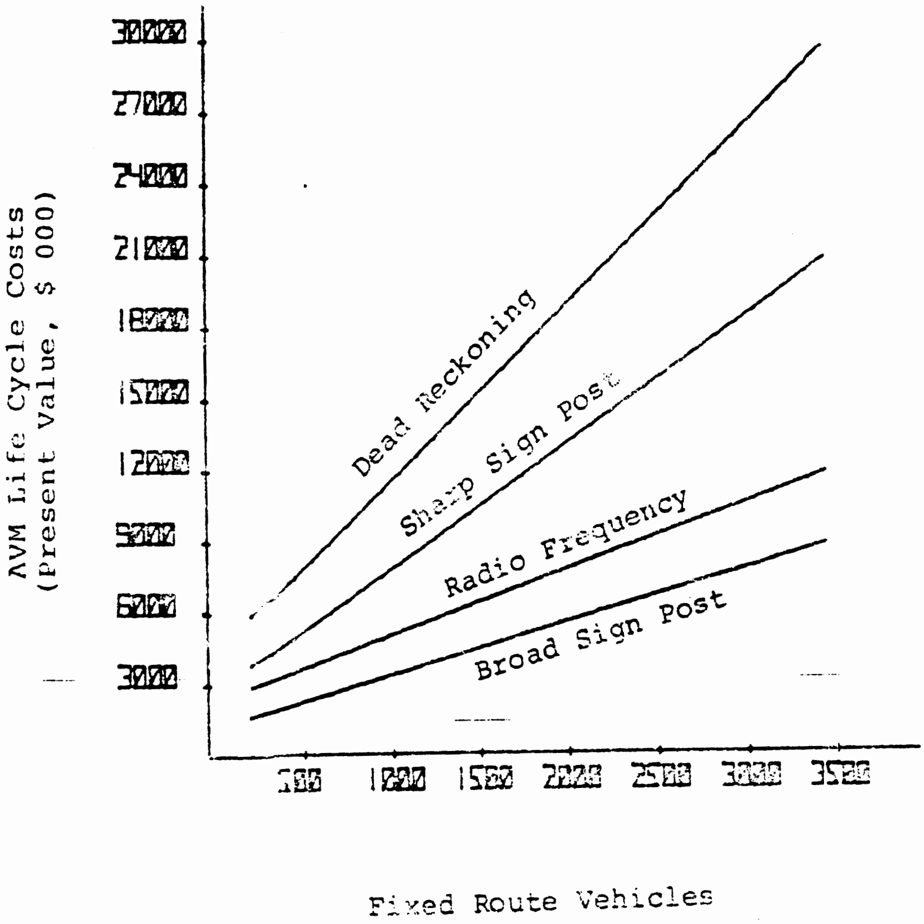


FIGURE 7 LOCATION SYSTEM COST AS A FUNCTION OF FIXED-ROUTE FLEET SIZE*

*Within Constraints of Base Case Except for Fleet Size

Source: Reed, H.D., et al.,"A Study of the Costs and Benefits Associated with AVM,"Report #UMTA-MA-06-0041-77-1, DOT/TSC, February 1977.

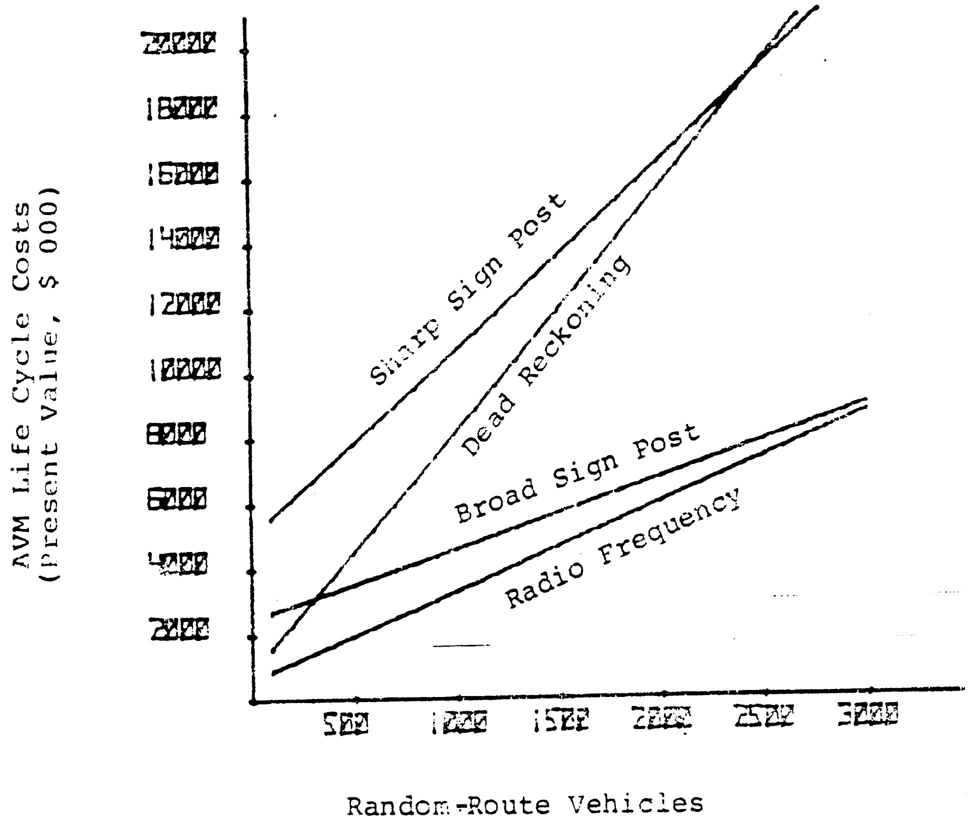


FIGURE 8

LOCATION SYSTEM COST AS A FUNCTION OF RANDOM ROUTE FLEET SIZE*

*Within Constraints of Base Case Except for Fleet Size.

Source: Reed, H.D., et al.,"A Study of the Costs and Benefits Associated with AVM, Report #UMTA-MA-06-0041-77-1, DOT/TSC, February 1977.

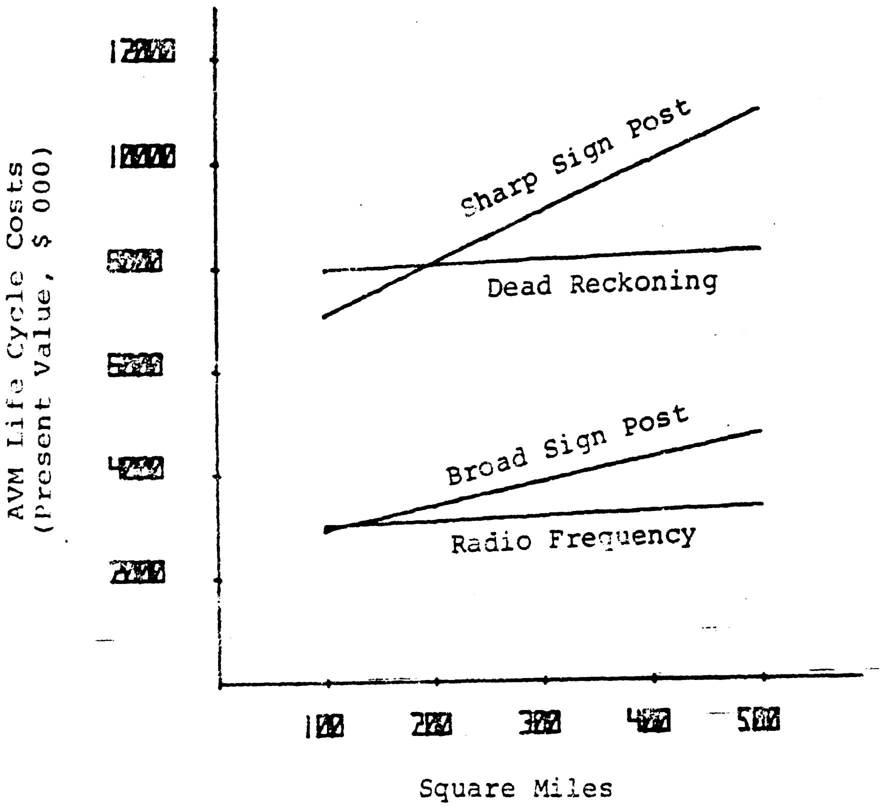


FIGURE 9

LOCATION SYSTEM COST AS A FUNCTION
OF OPERATING AREA*

*For 1,000 Random-Route Vehicles
Within Constraints of
Base Case.

Source: Reed, H.D., et. al., "A Study of the Costs and Benefits Associated with AVM," Report #UMTA-MA-06-0041-77-1, DOT/TSC, February 1977.

at that time. There may have been significant advances in one or all of the technologies since then as well as changes in costs involved.

	Broad Signpost		Radio Frequency		Sharp Signpost		Dead Reckoning	
Benefit Estimate:	Low	High	Low	High	Low	High	Low	High
Bus Alone	1.36	6.50	0.98	4.69	0.58	2.76	0.40	1.92
Bus Shared	1.37	6.52	*	*	*	*	*	*
Police Alone	1.89	9.21	2.39	11.65	0.80	3.89	0.95	4.63
Police Shared	2.41	11.76	*	*	*	*	*	*
Taxi Alone	0.49	0.98	0.74	1.48	0.22	0.43	0.31	0.61
Taxi Shared	0.82	1.63	*	*	*	*	*	*
TOTAL MULTIPLE	1.59	7.25	1.44	6.54	0.65	2.99	0.55	2.51

*Not available.

Table 6 - AVM Investments Payoffs (Benefit/Cost Ratios)

Source: Reed, H.D., et. al.,"A Study of the Costs and Benefits Associated with AVM," Report #UMTA-MA-06-0041-77-1, DOT/TSC, February 1977.

● CONCLUSION

There are two basic applications of AVM systems: fixed route or random route. Fixed-route systems would include transit operations, while taxi, police, and delivery service would typify random-route operations. Although the concept of these applications in AVM is the same, the technological requirements differ as to their use.

There were three main types of location technologies developed for locating and tracking vehicles in AVM systems. These concepts are as follows:

1) Signposts (both sharp and broad)

2) Radio Frequency

3) Dead-Reckoning.

Signposts can either be passive or active. In this technique, detecting devices (signposts) are located along a route and when a vehicle comes within the range of the signpost, a message is sent to the control center by the vehicle or by the signpost. Vehicle location between signposts is accomplished by a distance measuring device (odometer). Sharp signposts have an accuracy of up to a few inches but more signposts are needed to track vehicle movements especially in random route operations. Broad signposts have less accuracy, but only one signpost is needed per intersection, as opposed to 4 sharp signpost needed per intersection. The odometer and other devices provide the additional location accuracy. One of the major costs in AVM signpost systems is related to the number of signposts used.

Radio frequency concepts utilize the time-of-arrival or phase differences of synchronized radio frequency signals from (or to) three or more transmitters or receivers located at known geographic points. The time or phase differences are used to calculate position by trilateration. The two major radio frequency techniques used so far are Loran-C and pulse trilateration. There are a few problems with their systems that have yet to be solved. These problems concern noise (atmospheric, man-made, and receiver noise) blocking out the signal thus causing errors or buildings, tunnels and bridges blocking out the signals.

Dead-Reckoning is the third type of location and monitoring technique. In this method the vehicle continually tracks all of its movements with an odometer and compass. Other devices supplement this method to increase its accuracy. Although the odometer part of this system can be very accurate, all of the literature reviewed thus far has indicated there are severe cost and operational problems associated with the compass mechanism which greatly reduces the accuracy of vehicle location.

- Location Accuracy

The location accuracy requirements is based on the use of the system (i.e. transit, police, taxi, etc.). For some police operation, accuracy may depend on the size of a city block when coordinating a chase or locating an officer in trouble). For transit operations, accuracy is dependent upon headway, measured in time, and is later converted into a distance. The UMTA tests in Philadelphia based its accuracy requirements upon a state-of-the-art literature review in both the requirements of an AVM system and the range of competitive location subsystem technologies, giving the following requirements:

1. Performance specification of 300 feet with 95th percentile accuracy on both fixed-and random-route systems.
2. Performance specification of 15 seconds with 95th percentile for time-of-passage accuracy on fixed routes.

The following is a list of major AVM functions which can result in improvements in transit operations and is therefore a basis for performance specifications in transit operations.

Reduction of headway variance on short-headway routes (10 minutes or less) by use of the central-control capabilities of AVM systems. Reduced headway variances will cause higher levels of service in transit operations, or routes can be maintained at the same level of service with fewer vehicles.

Maintenance of schedules on long-headway routes (more than 10 minutes) by utilizing the automatic indication of actual position versus scheduled position at every point along the route. This feature will improve the reliability of service and ensure that transit does not arrive early or late.

Automatic collection of fleet-operational performance data, such as accurate and complete measurements of running times (as a function of time, passenger loading, etc.) between major stops or "time points" on transit routes. This data is extremely difficult and expensive to obtain in a usable form. However, this data is essential for making schedules that optimize efficiency in service and the allocation of the available transit vehicles and drivers.

Improvement of driver security and passenger safety by using a priority "silent alarm" signal with the communications subsystem. When the alarm is actuated, emergency aid can be dispatched to the exact location of the vehicle.

● <u>AVM Experience</u>

AVM Systems, utilizing different location concepts and technologies, have undergone testing and implementation in both the United States and foreign countries. The tested systems involved varying degrees of AVM utilization and different purposes (i.e. transit, police etc.). One of the most comprehensive tests was a program sponsored by DOT/UMTA to develop an AVM system to accommodate both fixed-route and random-route users. The program involved two phases. Phase I involved the testing of four location subsystems in Philadelphia--1976-77. In Phase II, which will be conducted in Los Angeles, the most successful competitor of phase I will be selected to develop, fabricate, install,and test a completely functional system that can be shared by users with diverse requirements.

The results of the Huntington Beach AVM test, which utilized a signpost location technology with a random-route system, included the following:

a. Failure of a few signposts had no major effect on the system operation.

b. Theft and vandalism of signposts posed only a minor problem.

c. Location accuracy of ± 300 feet on major streets and ± 600 feet on minor streets was achieved.

d. The measured location accuracy of ± 300 feet at 70th percentile was achieved against a design specification of ± feet at 50th percentile.

Results of the Hazeltine AVM system in Dallas for police operations indicated that an average location accuracy of 270 feet with 95% certainty was achieved. In foreign AVM experiences, one of the major conclusions was that drivers and operators should be well trained in the use of the AVM system to achieve the full range of possible benefits.

● Cost-Benefit Analysis

The state of the art of the costs and benefits associated with AVM systems and operations is rather limited. The most comprehensive cost-benefit analysis was based on field tests in Philadelphia in 1976-77 under DOT/UMTA sponsorship. This test dealt with four different location techniques (broad signpost, sharp signpost, radio frequency, and dead-reckoning) with regard to transit, police, taxi and multiuser fleet operations. Some of the major conclusions are listed below:

a. AVM systems tested or installed previously, have not assigned importance to formalized cost-benefit related data gathering or analysis.

b. Police cost savings are the most significant due to the high cost of staffing patrol cars.

c. Bus savings are considered positive. However, a sizable portion of the total savings were made possible by replacing personnel who made manual passenger counts with automatic passenger counters. AVM bus savings vary widely between cities due to extreme differences in operation cost factors such as insurance, O & M, number of checkers, and service operating characteristics of transit properties.

d. Sharing costs among a mix of users does not provide significant savings because only a portion of AVM costs are eligible for sharing between users. The benefits of shared cost are diluted when participants compromise otherwise lower individualized technology costs.

e. Costs and benefits are highly dependent upon site and fleet characteristics. Implementation planning must consider the changes in location system costs associated with changes in fleet size, mix or utilization, and operating areas.

f. Security benefits of the silent alarm are important. No dollar value has been assigned to these benefits, but they appear to provide sufficient reason to proceed with an AVM implementation which might otherwise be marginal in terms of dollar benefits.

g. Usually careful planning and management are required to exploit AVM's potential benefits. The extent of savings can vary greatly with slight changes in AVM utilization.

h. Different location systems are the most economical for fixed and random route fleets.

It is important to note that this test was based on four particular AVM technologies in 1976 and 1977. Since that time, innovations that may have occurred in one or all of those AVM technologies may, therefore, invalidate some of the results of the Philadelphia cost-benefit analysis.

VII. PASSANGER COUNTING/MANAGEMENT REPORTING

One of the real advantages to a comprehensive AMV system is that it supplies a vast amount of information. If this information is judiciously selected and handled correctly it can be beneficial in increasing the level of transit service and operational efficiency. Therefore it requires a well selected software package to efficiently handle the data management.

The passenger counting and reporting elements of AVM Systems consist of on board data collection and on and off-line reporting. The digital communication technologies have been applied for this part of the AVM system quite effectively. The following provides a summary of the state of the art related to passenger counting and management reporting.

- Passenger Load

The information that can be gained from a history of passenger loadings at specified locations for each route during peak and non-peak operating periods can be one of the most important pieces of information obtained. It can be used to modify and/or change routes and headways to increase the level of service. Software programs are used to retrieve, summarize, and either print or display the results,giving a history of seasonal, daily and hourly fluctuations on designated routes, route segments,and the entire system. Some software used to date also have a selective retrieval capability that can be used to limit the data analyzed using time, location,-and route as search parameters.

This data retrieval capability of the software programs is used to measure ridership patterns and trends on the transit routes. The data can be used to formulate schedules that are responsive to the demand.

It is advantageous to have the system accumulate and compute the standard deviation and mean of passenger arrivals and departures for specified time intervals on specified routes. When this data is kept on file then the system produces routine recurring tabular reports comparing the passenger load for periods such as the current calendar quarter and the preceding calendar quarter or any other quarter.

For the passenger information to be accurate it is necessary to count both boarding and alighting passengers. This concept necessitates the installation of sensors on both the front and rear doors of the vehicle. Accuracy also requires that the sensors count passengers bi-directionally, that is, both boarders and alighters. Passenger load is obtained by computing the difference between the two and telemetered to the control center during the regular polling cycle. The following concepts were considered by the Chicago Transit Authority.

a. Interruptable Light Beam. The basic idea of this concept is to project a pair of light beams horizontally across the entrance and exit points of the vehicle. The beams are placed in such a manner that they are interrupted sequentially by boarding or alighting passengers. After the second beam is interrupted a count is registered.

b. Reflective Light Beam. This concept is posed as a solution to closely packed passengers. It eliminates the problems encountered with the interruptable light beam when both beams are interrupted simultaneously by crowded passenger conditions. In this detection method a light beam is directed downward into the step well where it experiences separation by the upper torsos of the passengers.

c. Treadle Sensors. This type of sensor consists of pressure sensitive elements placed in or under the step panel. A number of these switches can be placed on a single step well to differentiate between egressing and ingressing movement.

d. Sonic Beam Sensor. This concept is dependent upon the passengers interrupting a signal beam similar to the interruptable light beam sensors. In place of light as the transversing medium it uses sound energy. This sound energy is created by an acoustic oscillator generating a tone of approximately 50 KHz. The receiver switch is also driven by air pressure and sends a signal to a barometric type switch when the sonic signal is interrupted. It has the advantage of being unaffected by electrical disturbances. Air pressure reliability is good since the vehicle cannot be operated without the proper operation of its air brakes.

e. Sonic Proximity Sensor. This device emits an acoustic signal similar to the sonic beam sensor but it can be delivered non-directionally. When an object enters its sonic field the signal is reflected to its source.

f. Seat Switch Sensor. This sensor is not practical since it is subjected to error caused by passenger movement while seated. It also suffers from the disadvantages of not being able to count standing passengers.

g. Bus Weight Sensors. A simple approach to estimating the number of passengers is to weigh the bus. Weight sensors can be interposed between the vehicle frame and suspension components to sense the total bus load. The precise number of passengers is ambiguous. The number is estimated by dividing the total passenger weight by the weight of the average adult.

h. Turnstile Passenger Counter. This type of sensor requires a large amount of space and can inhibit passenger movement during peak conditions.

i. Porcupine Passenger Counter. This device is placed in the passage way of each door on the vehicle. This device requires that only boarders use the front door and alighters use the rear. This requirement is impractical under crowded conditions when standing passengers may inhibit free passenger movement.

j. Fare Type. Both manual and automatic concepts of passenger counting by fare type have serious disadvantages. The manual method requires the vehicle operator to enter the fare type into a keyboard mounted on the farebox and places an extra workload on the driver. Automatic methods utilizing tokens, passes, exact change etc., require expensive and bulky equipment.

A summary of the parameters for consideration in the comparison of various sensors is given in Table 7.

The object of the management reporting system is to provide timely information, derived from data gathered during operation, so that both management and technical personnel can better plan and direct transit activities. The information necessary should include data such as driver performance, passenger load, schedule deviation,and information about the performance and utilization of system hardware.

Concept	Data Sensed: Bdrs	Data Sensed: Altrs	Data Sensed: Load	Data Sensed: Fare Type	Data Computable from Sensed Data: Bdrs	Data Computable from Sensed Data: Altrs	Data Computable from Sensed Data: Load	Data Computable from Sensed Data: Fare Type	Data Computable from Sensed Data: OD	Data Computable from Sensed Data: Rdrs	Pot. Error	Relative Reliability	Relative Complexity	Pot. Cost	Adaptabilit to Bus Environment
Interruptible Light Beam	X	X					X		X	X	15% to 5%	good	average	aver.	fair
Fare Key Counter	X			X							5% to 1%	good	average	low	good
Inter. Light Beam, Fare Key Counter Combination	XX	X		X			X	X	X	X	15% to 5%	good	above average	above aver.	good
Auto. Fare Type Passenger Counter	X			X						X	5% to 1%	fair	high	high	good
Reflective Lt. Beam	X	X					X		X	X	15% to 5%	good	average	aver.	fair
Treadle	X	X					X		X	X	5% to 1%	fair	average	above aver.	good
Turnstile	X	X					X		X	X	5% to 1%	good	low	below aver.	poor
Porcupine	X	X					X		X	X	5% to 1%	excel.	low	low	poor
Sonic Beam	X	X					X		X	X	15% to 5%	good	average	aver.	good
Sonic Prox.	X	X					X		X	X	15% to 5%	good	average	aver.	good
Seat Switch			X							X	15%	good	above average	above aver.	good
Bus Weight			X							X	15%	fair	average	high	good
Passenger Weight			X							X	15%	fair	above average	high	good

Table 7. Comparison of Passenger Data Sensors

urce:
"Schedule Control and Management Information System Study," IBM

● Master Schedule File

The system can be capable of creating and maintaining a Master Schedule File. The purpose of this file to define a schedule for every run on each route, giving the running time between successive timepoints that are designated to regulate the bus movements over the route. Consideration should be paid to the schedules required to monitor other functions such as odometer calibration, passenger count, engine alarms, emergency alarms,etc., so that routing interrogation during the polling process can be initiated, processed,and output under computer control.

The primary content of the Master Schedule is the bus schedule,which is defined in terms of the route, run, trip,and running times. It should also contain a program for sampling schedule adherence, headway adherence, and passenger load. The capability to add, change, or delete entries is required to maintain the file.

● Driver Performance

The software system can be utilized to provide a representative cross section of schedule adherence and incident occurrences by selected routes designated drivers. This information can be formed by those programs and files which utilize data from the surveillance system pertaining to the transit operating standards. The principal measure available is schedule adherence. In addition, the number of incidents in which a driver is involved provides valuable information.

The summary data files provide the mean and standard deviation of the difference between actual and scheduled arrival times for specified points along the route. From this data it is possible to construct frequency distributions of schedule deviations for each route to which particular drivers have been assigned. By accumulating a history of all the driver's performance on a particular route the system output can be used to tailor the standards of each route. This will allow the system to compare the performance of each driver with the standard and to flag those individuals who are consistantly out of the norm. Those drivers whose profiles show consistant deviations from the norm can be given remedial instruction or disciplinary action.

An added advantage of this analysis is that since traffic conditions, heavy passenger load, environmental conditions, dispatcher commands,and incidents affect travel time,it will be possible to associate a specific incident with an expected delay time. This will allow the system to correlate schedule adherence with a record of delay occurrences and operating conditions which affect travel time, including particulars as to time and duration of occurrence and corrective action taken.

● Fare Type

For those transit authorities that have a stratified fare structure-for example,zonal fare differentiations-this output can provide valuable information. The program can be used to calculate the total revenue resulting from each fare type and to show any unusual passenger counts.

The system should be capable of summarizing and displaying the history of passengers and revenue by route, route segment, time of day, and fiscal period. This information will be useful to management in establishing origin and destination information for particular routes as an aid in increasing the level of transit service and in establishing express service.

● Incident and Delay Record Analysis

The system can be capable of recording records of incidents and delays in addition to that used in the individual driver analysis programs. Summaries of delay records, accident reports, and unusual occurrences will provide data concerning transit service, safety, and community relations.

Included in this program are the details of all such incidents, including location, vehicle number, driver identification, garage number, route number, time, origin, direction, and length of delay. In addition, the system can be capable of recording additional information required for various categories of unusual occurrences such as incidents involving accidents, alarms, fire, illness, larceny, and equipment failure. It is beneficial to have the capability of retrieving this information for specific routes or areas based on time, category, length of delay, origin, route, garage, run, driver or vehicle identification, direction of travel, action taken, and reference number

- Equipment Analysis

An equipment analysis program can be constructed that analyzes and summarizes the telemetered data from the equipment sensors. This data can be useful in revising the scheduled maintenance procedures, assessing equipment performance, and evaluating the maintenance activities of specific garages. The system can be capable of calculating the rate of failure, mean time required to repair a unit, and number of defective units. It can also produce an itinerary of maintenance activity by vehicle identification. This program c be useful in providing the capability of tuning the system for optimum performa

- Driver Profile

An advantage of having the driver's profile on a computer file is that it expedites the completion of accident and incident reports. Pertinent information to have on file is the employee's name, identification number, assigned garage, operator registration, and any other information essential to completing the appropriate reports. The system can be programmed so that this information is inserted automatically merely by the controller issuing the type of report to be completed and the operator identification.

- Road Service Call

A record of vehicle identification, cause of vehicle failure, driver identification, garage, route, run number, vehicle location, and type of service needed can be initiated by a computer program. This program can not only initiate the road service but can summarize the remedial actions by time period. This report will be a supplement to the equipment analysis report in that it will help to figure the longevity of equipment components as well as the work load on respective garages.

- Accident Report

The accident report can be event driven and triggered by the preparation of an accident entry in the incident file. The report can generate additional memos to the claims, finance, or payroll departments. It can be utilized to pinpoint accident-prone drivers, accident locations, and point of emphasis in defensive driver programs.

- CONCLUSIONS

The management information system offers significant benefits in the form of increased fiscal efficiency and customer satisfaction. Some of these benefits can be described in the following categories:

- Driver Performance
- Fare Type Analysis
- Incidental Analysis
- Ridership Statistics

The major benefit of driver performance records is the ability to maintain long term performance statistics on individual drivers that can be used for motivation and discipline. When used in conjunction with schedule performance analysis, these records can be used to detect and evaluate service inefficiencies that are driver related. In addition,computer compiled driver performance reports can make a significant savings in personnel time. It is not unusual for supervisors to spend up to 20% of their time filling out forms on driver's performance where the task is presently being performed manually.

The fare type analysis is beneficial from its ability to more accurately calculate the weighted average fare. For those authorities that utilize a weighted fare system, this information can provide an important marketing impact for experimenting with different fare structures.

Incident reports can be made for all incidents that result in a significant delay for the system. Currently they are usually recorded manually by dispatchers and supervisors. The computer compilation of these reports will eliminate a significant proportion of this manual effort. This will improve the accuracy, extend analysis capability,and reduce the hand work over time.

Good measures of ridership statistics ensure that some routes are not over served nor others inadequately served. In addition, some metropolitan areas use measures of passenger demand to measure public transit deficiencies Many transit authorities employ checkers to collect ridership information. These checkers often ride the vehicles and record times and numbers of passengers by stop. The location-oriented ridership information available from AVM systems provides the time and place aspects of this manually gathered information. The addition of passenger counting facilities to the AVM digital data link makes it possible to eliminate the manual efforts of counting passengers,thereby saving the labor costs associated with the checkers. In addition to this monetary savings, automating the data collection will improve the quality of the input data and significantly reduce the cost of data reduction.

While the following list of suppliers is not complete,it represents companies that produces passenger counters:

- Automatic Passenger Counting Systems, Inc.
- Dynamic Controls, Inc.
- Honeywell, Inc.
- International Prodata Systems Corporation
- Scope Electronics, Inc.

An estimate of the savings that can be realized by implementing these reports and functions was performed by the Chicago Transit Authority study team. These estimates are shown in Table 8 . It must be recognized that the costs represented in this table are based on:

Function	Annual Quantifiable Tangible Benefits	Non-Quantifiable and Intangible Benefits
Driver Performance	20% of mobile supervisor time $400,000	Reduce operating expense, improve service
Ridership Statistics	34 clerks $600,000	Improved schedules
Fare Type Analysis	3 key punch operators $50,000	
Incident Analysis	1 dispatcher $20,000	

Table 8. Estimated Benefits from Management Information System

Source: "Schedule Control and Management Information Study," National Technical Information Service, Springfield, VA. Nov. 1974.

VIII. COMPUTER SCHEDULING & DISPATCH

The transit routes and scheduling programs are part of the Master Schedule File. This file should specify normal events which can be defined in advance. The primary purpose of this file is the transit vehicle schedule which is defined in terms of the route, run, trip,and running times which characterize the schedule. It should also contain the detailed instructions for sampling schedule adherence, headway adherence, passenger load,and fare type. The capability to add, change, or delete entries is required to maintain the file and the desired level of service.

The AVM system will provide a wealth of route data to the dispatcher in both graphic and alphanumeric formats that will enable him to see not only a portion of the route but complete routes as well. It also provides information on the effectiveness of current dispatch and service restoration techniques.

In addition, the system can provide the dispatcher with such diverse support status information as availability of extra vehicles by assigned terminal, availability of extra drivers, the location and availability of mobile supervisior by district, en route conditions of vehicles, schedule requirements, etc. This information lends a high degree of confidence in the appropriateness of actions taken to maintain the desired level of service.

To be efficient and responsive to passenger demands,dispatch systems and the resultant timetables must be dynamic. The changing timetables are often improved to reflect changing demands that occur with seasonal variations. Examples of this change are the fluctuations in student ridership commensurate with the beginning and end of the school year, vacation schedules, holiday schedules,etc. Software programs that can acheive these timetables result in a faster turnabout time and drastically reduces costs.

The savings to be gained from computerized dispatch systems can be better understood when current manual timetable processes are reviewed. The manual preparation of initial timetables often requires a lead time of at least three months prior to the date on which they become operational. Selection or picking of the runs by operators at the rating stations can take five to six weeks. This, added to the time necessary to build the runs, easily uses up a lead time of three months.

The preparation of the vehicle schedules is the first step toward the posting of new timetables. In the manual system, information supplied by supervisors (detailed documented passenger counts and time checks taken by field personnel and observations from schedule specialists), determines the vehicles and headways required for each route. Once the desired level of service is established, the vehicle assignments are then finalized.

Upon the finalization of the vehicle assignments, the schedule maker takes over and builds or constructs the runs that make up the completed timetables. The difficulty in this task stems from the necessity to construct the timetables in the most economical manner while adhering to the many constraints and practices imposed by labor agreements and other institutional barriers.

When converting to computerized scheduling techniques, it is often advisable to use one route for testing and debugging. After this initial trial proves successful, computerized vehicle timetables can be prepared for all routes and stored in the Master Schedule File.

Another software program can be devised to work in conjunction with the Master Schedule File to provide valuable management information on the cost of the runs based on current expenses. The following cost information can be made available:

- cost for a route by time of day
- costs of the non-revenue trip to place the vehicle in service and to remove it from service
- cost of replacing an operator on a vehicle already in service
- overtime
- travel time
- cost per mile
- costs to the community for the level of service required
- mileage to the community for the level of service required.

The following programs can be used as a direct aid in analyzing and making modifications, both real time and scheduled changes, to the master schedule file.

- <u>Scheduled Trip File</u>

The computerized schedule can be placed into records corresponding to individual bus trips. Each record can include such information trip-associated times, run and terminal identification,and other information considered pertinent. Included in this file can be the separate schedules for weekdays, Sunday, Saturday,and holidays for each route.

- <u>Vehicle Inventory File</u>

This program gives the dispatcher an accurate account of equipment status. The program can be designed to yield the following information which will both support all bus related radio communications and aid in the approximate positional location of any individual bus.

- Vehicle Identification Number. This number should be unique for each individual vehicle.

- Vehicle Type. This information can indicate the various distinguishing physical characteristics of each vehicle. It can be used to indicate those vehicles that are equipped with data collection equipment if certain parameters are not monitored uniformly throughout the fleet.
- Terminal. This information can be used to indicate to what garage the vehicle is assigned. It can be useful when deciding which vehicle to use for special or replacement runs.
- Current Status. This information describes the operational condition of the vehicle, such as whether it is currently active, idle in a repair facility, or contains defective communication equipment.
- Maintenance History. This information can include the type of work and date of all maintenance performed on the vehicle.
- AVM equipment. The type of communication equipment and vehicle sensors aboard the vehicle can be recorded for use in preventive maintenance programs.
- Run number. This information can be updated by entering the vehicle-run assignment data from the terminal at the time the vehicle pulls out. It can designate the run to which the vehicle is assigned and can provide the link enabling the determination of the schedule location of any active vehicle.
- Run completion time. This information can indicate the time at which the scheduled run will terminate, which normally will correspond to the time at which the vehicle is scheduled to return to the garage. To remain accurate this data must be updated for any changes which occur en route, such as vehicle or driver replacements.

- <u>Bus/Driver Assignment</u>

This program will assign drivers to vehicles as a routine part of the check in procedure before the start of the first trip. This system would require that the vehicle number, installed sensor equipment, service restrictions, if any, and name, identification number, and experience of the driver be used. If another run is substituted, the alternative run and driver profile should be substituted to keep the system updated. This approach also has the advantage of knowing where specific drivers are located in case they must be contacted for any reason.

- <u>Replacement Request</u>

This program is supplementary to the Bus/Driver Assignment program. It further defines the reason for replacement for an in service vehicle. If it is a replacement for an in-service vehicle, additional information may be desired as to the cause for the action, etc.

- <u>CONCLUSIONS</u>

The AVM system can establish a closed-loop information flow that permits a dispatcher to know the disposition of his vehicles and enables him to control their deployment. This information is beneficial in applications of both fixed route and random-route systems. This information can be used to ensure that vehicle schedules are met and that only the nearest vehicle is used in response to system demands. The following benefits could be realized from this segment of the AVM system.

- Reduction of average response times to service and emergency calls.
- The number of deadhead miles can be reduced in random-route applications.
- Increased on-time service with vehicles, adhering to established schedules.

- More uniform headway adherence.
- More even distribution of passengers between vehicles.
- Reduced layover time due to stricter schedule adherence and reduced uncertainty of total travel time.
- Fewer personnel required to establish, check, and control timetable and schedule adherences.

IX. SCHEDULE ADHERENCE

Schedule adherence files are programs that should be updated at regular intervals to maintain a timely record of measured driver performance against the established schedules. The system should maintain a history of the deviations from scheduled arrivals at timepoints on each route for both peak and off-peak operations. It should possess the capability to retrieve, summarize and display the results, giving a chronological history of the fluctuations in running times. It should also have a retrieval capability that can selectively give summaries of the information desired. This capability will provide a means of detecting trends, while the files can be reviewed for more data about specific information for particular route segments. Changes can be made in the transit schedules, based on this information, that will be responsive to the changing transit demand and traffic characteristics.

In addition to the offline decisions pertaining to route scheduling and establishing appropriate headways, the AVM system provides management the ability to be responsive to immediate service disruptions. In handling specific service disruptions, management must take into consideration not only the specific incident but passenger considerations, environmental conditions, time of day, relationship between the delay and recovery time, and the possible effects on other routes by the remedial action taken. Decisions taken in this manner require the availability of the current status of all transit vehicles on the route. Many of the decisions that are involved can be made with the aid of computers. The necessary information flow and the trade-off effects of the proposed remedial actions are areas where computer assistance will be beneficial in expediting the best course of action.

● <u>Headway Deviation</u>

Headway Deviation files complement the Schedule Adherence files. They give an indication of the degree to which scheduled headways are not met by showing the mean deviation from scheduled spacing between transit vehicles. The data can be investigated to determine where schedule changes must occur to obtain the desired schedule.

While the main purpose of these files is long-range planning, the information available here can act as the standard of performance for on line decisions necessary to counteract any service disruptions. The following paragraphs outline some of the on-line service restoration techniques available to the dispatcher with the information flow and communications capability of an AUM system.

● <u>Adjustments to existing headways</u>

a. Hold Back. This technique is employed when there exists a gap in the headway. This action can be initiated by the dispatcher when the recovery time does not exceed the delay time either during the analysis time interval or after initiating the delaying of an en route vehicle. This action involves telling the late vehicles and their leaders to close up the gap. The duration of this action can be either until the gap is closed or the end of the run.

b. Move Up. This technique is used to compensate for a malfunctioning vehicle that can safety reach a maintenance point. The malfunction will be detected by the vehicle operator or by the vehicle sensors. This action affects the defective vehicle and its followers until the malfunctioning vehicle reaches a replacement vehicle at the maintenance point.

c. Reschedule. This technique can be initiated when external conditions cause highly irregular service gaps. One cause for this action, for example, can be the forecast of severe weather conditions. Based on the severity of the condition, the dispatcher can adjust the departure time of vehicles from the terminal to equalize the route headways. For missing vehicle runs, such as problems with the driver or a malfunctioning vehicle within the terminal area, the dispatchers can make limited time adjustments. These adjustments would be in effect until another driver or vehicle can be obtained, or, if the passenger loading is light, until the last scheduled departure. For adverse environmental conditions, the action can be in effect until the weather clears and the streets are safe for normal speeds.

● Put Followers Ahead

This technique is effective for unusually heavy passenger loads. These loads usually cause an increase in headway, with the heaviest loaded vehicl following at the greatest headway. This condition can be caused by a sudden influx of passengers from special events, such as spectators at sports games or the simultaneous release of workers from large employment centers. The controller will become aware of the situation via communication with the driver or through the AVM system. This technique requires that followers to a vehicle that is spending an unusually long time loading passengers pass up the delayed vehicle. This technique is usually used in conjunction with the hold-back action to try and retain the specified headway. An extra action of sending an extra vehicle to compensate for the heavy loading is an additional tactic that can be used when it is known that special events or heavy demand will be present on a particular route.

- Fill In

This technique can be beneficial when an excessively large gap in service occurs during peak hours. It is an action that is usually reserved for headway variances of 200 percent or more. It varies from the hold-back technique, in that to slow down the leaders would cause a detrimental effect on the quality of service and cause the run to exceed recovery time. A severe gap such as this can be caused by traffic obstructions or by a defective vehicle. This action can be accomplished by diverting a vehicle from the same route that is heading in the opposite or off-peak direction or by diverting a vehicle from a foreign route. When diverting a vehicle from a foreign route, care must be exercised to minimize the potential impact on the loaner route until the vehicle can be returned. This action will last until the passenger destination obligations are met and the vehicle will then be released to meets its original obligations.

- Reroute Around Problem

At times it may be advantageous to reroute the transit vehicle around bottlenecks that may be caused by calamities or emergency situations. One instance of this may be a large fire, when the emergency equipment and gawkers render a route impassable. This type of strategy requires adequate on-the-scene information to properly select the correct alternative route. The type of information required will often necessitate the dispatching of a mobile supervisor to the scene. The duration of the action is as long as the disturbance exists.

● Troubleshoot

This action is necessitated by the notification to the controller of an engine alarm either by the vehicle operator or by the automatic engine sensors of the AVM system. The alarm can be analyzed by the service coordinator to determine if the vehicle can safely make it to a maintenance point or if a service crew should be dispatched to the defective vehicle.

● Inoperative Vehicle

If the preceding action determines that the defective vehicle will not be returned to service for a considerable period of time, then additional actions are necessary to remove the vehicle and to deliver the passengers to their intended destination. This action can take two primary directions. The first action is to change the defective vehicle with one that is already in the field. This can be accomplished by changing with a vehicle that is on the same route but scheduled to finish its regularly scheduled run, or by ordering up a replacement vehicle from the terminal. If the first option is chosen, care must be exercised to ensure that adequate reserves of fuel are available on the replacement vehicle. This action eliminates the need for an extra bus and eliminates the attendant delivery labor. The second option requires additional labor to deliver the replacement bus from the terminal to the meeting point. Often, the driver of the replacement is from the maintenance staff,which is detrimental to the maintenance system. Duration of these actions will normally last until the end of the run.

● Extra Trip

This action can be necessitated by several conditions, such as the failure of a relief driver to meet his assignment. Notification of this condition will need to be forwarded to the controller by means of voice communication.

● Nonstop Trip

This is a technique that can be used to compensate for a long delay that is beyond the control of the transit authority. This action requires that the vehicle be run nonstop or preferably to switch to an express route to reinsert the run in its proper position.

● CONCLUSIONS

The assumption that improved service regularity will increase patronage and operating revenues is basically sound. Regular users of transit service adapt their behavior to the quality of service and shun, when possible, those systems that have poor schedule adherence. They learn the schedule and develop a level of confidence in the service that is commensurate with past experience. If the schedules are dependable, the passengers can plan their activities so as to lose less time on both trip ends. If the arrival times of transit vehicles are subject to wide variations, with vehicles typically early or late, passengers tend to arrive earlier to reduce the risk of missing their ride, thus extending their average waiting time.

Since AVM technology enables the transit authority to improve the schedule adherence and reliability, benefits can be gained by lengthening the perceived passenger waiting time. The increased headway reduces the equipment and driver assets invested in the route and can increase the average load factor on each vehicle. The increase in the average load factor is a direct result of reducing vehicle bunching. The magnitude of this increase is directly dependent upon the type of service delivered prior to the system improvement. A route that typical offered good schedule adherence and reliability with little bunching will not experience any significant load changes or vehicle savings. A route with a prio history of poor headway adherence and significant bunching may reap significant benefits if all vehicles are not loaded to capacity. The increase in average load factors due to the increased headways can result in a reduction of revenue runs while actually increasing the level of service and ridership.

Another benefit to be derived from improved schedule adherence is a reduction in layover time. Layover savings can be realized by reducing the unnecessary idle time at the ends of the revenue runs. Part of the time allowed for layover at the end of the revenue run is for driver rest breaks and the rest is a cushion to absorb late arrivals at the end of one run and still permit the next run to begin on time. The latter portion of layover is a form of insurance against the pyramiding and self-perpetuating increases in late vehicles. In some instances, transit operators rush through their run, intentionally getting ahead of schedule so that their layover and subsequent rest time is increased. Layover time, therefore, can become an expensive proposition in terms of idle equipment and personnel.

Layover time is a factor which can be drastically reduced by AVM systems. The exact vehicle location information for an entire route or set of routes that is possible with AUM systems enables the controller to implement operational strategies and control methods which can minimize disruptions in service and maximize schedule adherence. These measures can reduce the variation in running time, thereby cutting the required layover time. The reduction in layover time immediately increases the productivity of vehicles and drivers. If the overall productivity increases, it will be possible to offer the same level of service and headways with fewer vehicles.

X. ONBOARD READOUT, DISPATCH SYSTEMS

Onboard digital readout and communication capabilities afforded by an AVM system are a key element to increasing the level of transit service. Messages can be reciprocated between the vehicle operator and central control pertaining to schedule adherence, emergency situations, vehicle failure etc., that serve to increase transit efficiency and cost-effectiveness. The availability of alphanumeric displays and function keys substantially increases the equipment utility by relieving the vehicle operator from the task of manually removing the handset for voice communication. This not only increases the transmission rate and reduces channel congestion but releases the driver to perform his main function of piloting the vehicle. When an unusual situation occurs or additional information is needed the handset can be used for vocal communication. These diverse functions are just part of the operational requirements that need to be performed by the mobile vehicle terminal.

It is necessary for the vehicle terminal to monitor the receiver output of its associated mobile radio transceiver, recognize and receive digital messages addressed to that vehicle, perform error detection (and error correction if the transmission format includes that function), accept only error-free messages for presentation to the vehicle operator or the operation of indicators, and make an automatic acknowledgement transmission for each accepted digital message. It also provides function keys that when depressed by the vehicle operator automatically cause a transmission of the corresponding preset function-code messages as soon as the vehicle-to-base radio channel is clear, and performs all communication protocol functions necessary to verify error-free receipt of such transmissions by the dispatch center communications controller. Suitable indicators are provided so that the vehicle operator can determine whether or not function-key transmission has been acknowledged by the dispatch center communication controller.

The vehicle terminal is capable of accepting and storing a dispatch message which is commensurate with the type of operation. On fixed-route systems this may merely require an indicator, either visual or audio, that a message is to be received over the handset. On random-route systems, police applications, fire and emergency-response or fixed-route systems employing CRT equipment, the equipment should be capable of accepting or storing a message containing from one (1) to eight (8) or more 32-character text lines.

Prior experience with a demand responsive transit sytem in Rochester, New York, showed that their system needed to be capable of displaying, in a manner clearly legible to the vehicle operator in his normal driving position, at least four 32-character text lines of aphanumeric characters.[1] When the four-text-line display was used it was beneficial that the displayed lines were selectable by the vehicle operator from any four contiguoug lines of the eight lines stored in memory. The display started automatically with the first four text lines of each newly received message.

1. Ward, John E., "Radio and Digital Mobile Terminal Equipment for an Expanded PERT (Dial-a-Ride) Service in Rochester, N.Y." Report #ESL-R-635, MIT, July, 1973.

In a study performed for the Massachusetts Bay Transportation Authority,the equipment that was recommended utilized both voice and data transmission normally transmitted on separate channels[2]. The vehicle radios have a four-channel minimum, equipped for operation on two channels and remotely switchable between two channels by a dispatcher. The channel primarily relied on is a data channel,but it can be remotely switched to a voice channel, the choice of which is determined by their permanent rating station assignment. Both channels are capable of carrying both voice and data transmissions in order to provide for the required system features. The vehicle radios include both a handset as an integral part of the control head and an external speaker. The digital transmission scheme provides for external vehicle monitoring inputs in addition to the radio control requirements.

Under normal idle-state conditions, the radio is logically set to a data channel with an indicator light signifying that the unit is on. When the vehicle operator requires conversation with the dispatcher he will activate a switch that is marked as a "request-to-talk" switch and the lamp will be extinguished. This action is recognized by the logic circuitry and when the channel is free it will send the first of a possible number of transmissions indicating that the "request-to-talk" function has been selected. Once the radio and logic has received a digital acknowledgement from the central equipment,the indicator light will be reilluminated. The digital message can then be routed to the appropriate dispatcher. The dis-

---

2. "Specifications for Bus Radio/Management Information System," Mass. Bay Transportation Authority, October, 1976.

patcher then selects the bus identification and causes a voice-enable digital message to be transmitted to the appropriate bus. This signal is sent a number of times to increase the probability of its being received and recognized by the vehicle. Included in the signal are instructions to the logic circuitry to switch the radio to an open voice channel chosen by the dispatcher. When the bus radio logic transmits an acknowledgement back to the central equipment, a voice channel buzzer sounds in the vehicle. This will indicate to the driver that he can lift his handset and begin conversation with the dispatcher.

At the end of the voice conversation, the driver replaces the handset and the dispatcher causes a digital message to be transmitted on the voice channel,causing the radio to revert back to the idle position. This message is also transmitted a number of times to again assure proper reception by the vehicle equipment. When the vehicle radio logic receives the message and returns to the idle position it forwards an acknowledgment on the data channel,thereby ending the "request-to-talk" procedure.

While this system may seem a little complicated, it is really intended to reduce the confusion caused by multiple voice communications on a single channel.

When the dispatcher wishes to initiate voice communications with a particular vehicle a similar process is used. The dispatcher enters the vehicle identification into the central equipment, which causes a digital message to be transmitted to the vehicle. Included in this message are instructions to the vehicle radio logic unit to switch to a particular voice channel. When the vehicle equipment has complied with these instructions, it sends an acknowledgment back to central control and sounds an audible buzzer in the vehicle. This will indicate to the driver that he is to pick up the handset and communicate with the dispatcher. Once the conversation is complete, the dispatcher will cause the radio to return to the idle state in the same manner as previously described.

If the dispatcher transmits any voice audio with a coded squelch on any channel selected in the vehicle, and the handset is in the cradle, the audio can be routed to an auxilary speaker output. This feature can be useful if the vehicle radio fails to switch to a voice channel or if the dispatcher wishes to speak to all of the vehicles. The "all call" feature causes all of the vehicle radios to switch to their corresponding voice channel. The digital "all call" transmission can be transmitted in the digital channels under control of the central equipment. It is not necessary for the vehicle radio to acknowledge the receipt of the digital transmission for an "all call" situation and it need not be necessary for the audible buzzer to sound. After the announcement is completed, which will have been heard through the auxiliary speakers, the dispatcher will transmit digital messages on the voice channel that will return all radios to the idle state.

The dispatcher also has the option of performing a "selective all call" whereby he can contact the vehicles on a particular route or in a specific area. This can be accomplished by installing equipment that will allow the dispatcher to transmit a string of individual bus identification numbers. This would allow the dispatcher's announcement to once again be routed to the auxiliary speaker.

The bus radio logic package must also be designed to handle the functions of alarms and passenger counting. In the design of this equipment it will be necessary to include the appropriate delay mechanism to prevent the transducers from forwarding a fault message when the vehicle is started. Allowances must also be made to keep the security alarm energized during periods of storage.

The bus radio logic package must be capable of responding to the polling signal from the central equipment. Upon receipt of the polling transmission, the bus radio should respond with the entire contents of its buffer. If the transmission from the vehicle is not received it will be necessary for the central equipment to poll the vehicle again. It is often desirable to make polling checks of those vehicles that are stored to check the security alarm sequence and the radio equipment.

The type of digital messages that might be expected to be transmitted between the vehicle and central control are listed below.

<u>Central Equipment</u>

- Individual bus voice channel enable
- Individual bus voice channel disable
- "All Call" voice channel enable (no buzzer)
- "All Call" voice channel disable
- "Selective All Call" voice channel enable (no buzzer)
- "Selective All Call" voice channel disable
- "Group Call" voice channel enable (no buzzer-multiple individual calls)
- "Group Call" voice channel disable
- Polling Signal - empties buffers
- Acknowledgment

Bus Radio Equipment

- Bus Identification
- Request-to-talk
- Mechanical Alarms
- Covert Emergency Alarm
- Instrusion Alarm
- Polling Response
- Acknowledgment

The radios and systems installed should be capable of expansions to include future possible requirements. Among these requirements might be odometer information and farebox receipts.

The driver console or control head used for onboard readout facility varies according to the complexity of the system. Those consoles currently being employed in Toronto consist of a 16-button keyboard for entering data and precoded messages, an alphanumeric display for receiving instructions from central control, and four display lights for displaying status of equipment being monitored by the transponder. The 16-button pad is configured similar to the standard touch tone telephone numeric key pad, so that the driver is able to use the key pad for entering numeric data such as his identification number and special service conditions. The alphanumeric display is used by the control center to prompt the driver with questions ensuring that correct information is entered into the console. The design and positioning of the control console was based on a survey of driver preferences and by the experience of both the German and Swiss transit authority[1].

The driver console in the Toronto system was designed for hands-off operation coupled with a full duplex radio so as to enhance vehicle safety by leaving the driver free to concentrate on the road while talking in the radio system. An internally pre-amplified magnetic handset microphone system can also be used for private conversations with the control center.

The radio transceiver,which is in the transponder package, operates in full duplex on the UHF frequencies. This configuration results in less noise and fewer problems of jammed channels.

The basic purpose of the driver console is to display and transmit relevant information with a minimum of driver effort. Function keys are utilized whenever possible to attain this goal. Mobile digital terminals for other users such as police patrols require drastically different equipment. Those police departments that are currently testing mobile terminals are using status/full text terminals which are comprised of 40-to-50 key keyboards[2].

---

1. Berney, L.G., et. al, "Transit Communications and Information Systems," Telimove Automated Vehicle Monitoring Conference Proceedings, September 1976.

2. Fujaros, R.G., "State-of-the-Art of Mobile Radio Data Systems for Police Users," Telimove Automated Vehicle Monitoring Conference Proceedings, September 1976.

The basic mobile vehicle equipment is available from a number of manufacturers and can often be purchased requiring no modifications to the production model. This is dependent upon the number of functions that it will be required to handle by the particular transit authority. The following paragraphs detail some of the specifications that should be required of the individual components.

● Controlhead

The transit vehicle controlhead should contain a specified number of indicator lamps according to the operational concepts of the Transit Authority. The following list is construed as the minimum number of indicator lamps:

- Power on
- transmit
- request to talk function
- channel indicator

While the indicators can be expanded upon, they should not become so numerous that they create a confusing array to the driver. An audible alert should also be provided for an indication of the "voice enable completion." The volume control should be located on an external face of the controlhead,while the squelch control can be located internally. The volume control should adjust both the handset and the auxilary speaker with no additional adjustment necessary when interchanging from one to another. When the volume control is set to its minimum, sufficient audio should be heard through the speakers.

The unit should be of rugged construction, be weatherproofed to provide protection against water damage, and be easily removed for maintenance. A telephone type handset with a push to talk button and armored cable has been found to be adequate in other installations. The handset holder should provide positive hangup to prevent dislodging.

The controlhead should be mounted to provide for convenient operation and visibility of indicators.

● Power

The radio system shall operate from a nominal 12 volt D.C. source having either a negative or a positive ground. Filters and noise suppression devices are required to prevent interface to the radio system from the vehicle's electrical equipment.

The "power on" switch should be electrically bypassed. Power should be supplied to the equipment through the vehicle's ignition switch. The radio and logic units should operate when the vehicle's master switch is in either the run or stand-by position.

● Equipment Housing and Installation

The bus radio and logic units should be housed in a rugged, metal, waterproof enclosure. This enclosure should have no louvers or ventilation openings which may increase the problems of dust and moisture. Special attention should be expended to ensure that the units and connecting hardware are vandal proof.

● Display Legibility

If an electronic display is used it should be easily readable by the vehicle operator from his normal driving position. The displayed characters should be at least 0.2 inches in height (preferably larger) and meet all readability and legibility requirements for vehicle operators of all ages, some of whom may have the need to use bi-focal lenses. A system installed in Rochester, New York, had characters of approximately 0.11 inches, resulting in numerous complaints form vehicle operators that the characters were not large enough.

● Display Visibility

The vehicle terminal display, if used, should have sufficient brightness and contrast so as to be readable under normal daylight conditions with appropriate shields if necessary to reduce extraneous outside glare.

● Signaling Reliability

The goal for signaling reliability should be a 99% probability of error free reception of a digital messages by the vehicle components.

The hardware components necessary for an onboard readout facility is commercially available. The use of such equipment in law enforcement areas has demonstrated that the equipment operates as intended with minimal component failure. The published report papers in this area do not, however, provide quantitative data regarding maintenance and reliability problems. However the manufacturers of the various components provide maintenance guidelines, that can generally be followed by existing transit personnel.

The cost of such a feature (onboard readout facility) is an incremental cost for an automatic vehicle monitoring system. The state of the art has not established the distinguishable cost-benefit criteria for such a system in public transit applications.

The potential for such a system in public transit application seems good. It is quite possible to have a system which handles not only public transit but also emergency vehicles. The aid to transit passengers and efficiency of the vehicle operation has not been measured quantitatively, but the state of the art indicates the value of this system in public transit by using qualitative evaluations.

● <u>CONCLUSIONS</u>

The following conclusions can be made from a review of the state of the art:

1. The use of onboard capability in public transit systems is feasible.
2. The hardware components are available in the market.
3. The system in most cases needs to be put together, especially since the compatibility and specifications of each system may vary. There are various system houses as well as equipment manufacturing companies available to perform this task.
4. The benefits that can be derived out of a system include assistance to vehicle operations, passengers, increased confidence among the passengers, and systematic surveillance from the control center.
5. The incremental costs are not significant if an automatic vehicle monitoring system is used in a community.

XI. REAL TIME DATA DISPLAY

Real time data display in transit applications of AVM systems is useful to the vehicle operators, transit dispatchers, and the transit passengers. Information is provided to the appropriate user by the dispatcher by using a variety of display techniques. The displays are varied in their physical configuration and usually take the form of wall maps or displays, cathode ray tubes, passenger signs, and performance audits.

The acquisition of the data necessary for the displays is obtained from the vehicle sensors, passenger counters, alarms, and vehicle location. Outputs from the system are available in real time or as close to real time as the polling schedule will allow. Information immediately beneficial to particular transit segments can be channeled directly and displayed immediately. Off-line outputs can be used to portray information that has no immediate use, such as transit productivity, on a systematic schedule to scheduling, operations management, planning, and analysis personnel of the transit authority.

● Central Displays

The availability of space and design flexibility that is possible in the planning phase of dispatcher base stations makes feasible large-screen projection, cathode ray tubes, and large wall maps. Considerations of overall utility, cost, flexibility, and maintainability lead to the choice of a CRT system, because it is capable of delivering the desired functional capability most effectively. CRT display system can be responsive to current needs: they are extremely flexible and easily adaptable to changing operational procedures and future requirements.

A system offered by Teledyne Systems consists of graphic CRT terminals that can be used to display alphanumeric characters and or maps of an area or route.[1] The terminals have alphanumeric keyboards that enable the operator to manually place any desired message on the display, such as occurrence time of events or special messages.

During operation each controller has a graphic terminal, consisting of a CRT display, a light pen, and a data entry keyboard. One possible manner in which this equipment could be utilized is for the computer to generate a map of an area or route. The controller can choose to have the map scaled to view only a portion of the area or route under consideration. On this map will be displayed the vehicle identification number at the map location of the field unit. The position of these vehicles can be automatically updated on the map by the vehicle locating and monitoring system. The controller may also manually move any field unit location with his light pen wand. To accomplish this he merely points the wand at the symbol or vehicle identification number he wishes to alter, presses the button on the wand, moves the symbol to the new spot, and releases the button.

If desired, the size of the map can be reduced and the resulting margin used as a menu list. For example, when the dispatcher is informed of an incident, such as an accident, he would hold the light pen over the A symbol, press a button on the wand, and move it to the proper location on the map. When the button is released an A will be displayed on the map at this spot. If the incident is not yet resolved, it may be so indicated by a blinking light.

1. "Bogota Automatic Vehicle Location System," Teledyne Systems Company, July, 1976.

This would be accomplished by moving the wand to the blink symbol, pressing the button and moving it to the A, and releasing the button. A description of the incident and identifying data is entered into the data block, using the keyboard, and the wand is used to position the data block near the map location. When the incident has been resolved the symbol A and the data block can be removed with the wand. This use of the wand allows the dispatcher to use various techniques to indicate priorities (blink and brightness controls) and to apply them as the situation warrants. The variety of alphanumeric characters that can be used by the wand is only restricted by the limits of the computer.

In an AVM-system initiated by General Motors in Cincinnati, CRT displays were used to convert AVM derived data into a wide variety of information formats. A few of these displays are discussed in a General Motors publication and are presented below.[1]

a. Emergency and mechanical alarm information is available to show the current alarm status of the fleet. These alarm status displays are correlated by coach number, operator number, geographic position, and other factors relevant to the dispatching of emergency aid.

b. Coach availability audits are continuously available to aid in the coach deployment or redeployment process. These audits may involve interactive inputs from coach staging areas which input data to the system from remote locations. A multiterminal network linking coach staging areas to Central Control provides the dispatcher with timely and accurate information for handling coach breakdowns.

c. Schedule adherence summaries are available for display either in a "by the coach summary" form or on a routewide basis correlated by

---

1. "Urban Transportation Laboratory, A Progress Report," GM Transportation Systems, May, 1978.

route number. Displays are also available which show a tabulation of coaches that are in violation of their service schedules.

d. CRT displays can also be provided which replace headway reference manuals. Schedule or headway sheet data organized along routes or by block number are available for instantaneous reference.

e. The system is designed to handle conversational inquiries into data bases which protray present or past status summaries of fleet operations. The system can be programmed to support custom designed dispatcher operation aids accessibile by keyboard entries of the CRT terminal.

These and other real-time CRT displays which either use the real-time AVM acquired data or off-line data files can be tailored to the application. The dispatcher, with instant two-way radio contact available to him, can execute a broad range of strategies of coach control based on the real-time status information the AVM System is supplying to him. In addition to providing both global and micro views of transit status for fleet control, the AVM System is also designed to control and monitor all of the voice protocol necessary for voice communications. Communication discipline is more easily managed when the AVM System is used as a protocol device in support of transit voice communications events.

For supervisory and higher control purposes it is possible to install repeater CRT displays identical to those at the controller stations but without the input devices. This will allow the supervisory personnel to select a display being viewed by any of the controllers. An arrangement such as this can reduce decision time for unusual incidents and serve as a safeguard against incorrect actions on the part of the controllers.

Experience in Toronto has demonstrated that color CRT are very cost effective. The use of color serves to reduce the visual and mental fatigue of the controllers. In addition to this advantage, the expeditious use of color can highlight and emphasize particular routes or incidents. For example, silent alarms can appear as flashing red, which would aid in preventing the signal from being inadvertently disregarded.

Display terminals are also of advantage to the vehicle driver, although not to any great extent for fixed route transit systems. The largest advantage of mobile CRT's are in random-route transit applications, police and emergency services. When used in random-route applications alphanumeric messages pertaining to passenger pickup points and route directions can be transmitted. This can facilitate service and reduce passenger wait time.

● <u>Wall Maps</u>

Automated wall maps are an effective means of giving a global view of the transit system. In addition to providing a graphic representation of the transit routes,it acts as an impressive public relations instrument. Visitors are frequently impressed when viewing a large, illuminated, multi-colored display.

The automated map is usually mounted on the front wall of the dispatch station and automatically reports the fleet status by the use of colored indicators and variable message signs. The variable message sign can be programed to display excessive delays or unusual incidents on the routes being controlled. Special symbols can be used to indicate the direction of travel, location,and identification number of those transit vehicles that are behind schedule. While this information is not as comprehensive as that available on the individual CRT's, the wall map display serves to show other transit management observers and visitors the general system status.

Another option that can be used to create a dynamic wall sign is the

General Dynamics Large Screen Projector Display Model 303A. These units, in use for air traffic control and tactical control displays, are an excellent means of providing group viewing. The approximate cost of $50,000 is, however, a major drawback to their use. This cost does not include the cost of a display generator, but the same display generator that is used for the controller's displays can be used to drive the projection display. The major advantage to this system is that the wall display can be more comprehensive than the method previously discussed and can display essentially the same information as the controllers display.

Two additional concepts are available using a slide projector. One of these concepts is static and the other dynamic. The static image is created by changing slides when a different route or sector needs to be displayed. The static image can be created by using the slide projector to display the map on the wall or screen. The dynamic data would be generated by the computer in the display system and would be projected on top of the map image. Any information stored in the computer could be displayed.

- Passenger Message Signs

The real beneficiary to a comprehensive system is the transit passenger. Five status transmissions from the transit vehicle can be transmitted to a electronic processor, which can manipulate a variable message sign informing waiting passengers of pertinant information. Information concerning seating availability, expected arrival time, time to the next vehicle, and any other messages that the transit operator may wish to relay, can be forwarded to passenger shelters or other terminal locations on the route. Messages concerning transfer points with other lines along the route can be displayed to aid the passengers in planning their trip. It is possible for the variable message signs to have a commercial value as well as an aid to the passenger. Time could be leased to advertisers and the message integrated with the operational software for the real-time displays. In this manner, commercial messages, weather reports, actual time,etc.,can be transmitted when the sign is not being utilized for transit needs.

General Motors expanded the variable message sign concept to render a service which was termed "bus finder," This involved including a small route map display shown in conjunction with a variable message sign. These signs were located in passenger shelters or other high transit activity areas. The passengers obtained information via a text message on how long it would be before his bus arrived at his location by pushing a button adjacent to his route number on the display. The map display was also equipped with some LED's to depict the zone that his bus was presently in.

Variable message signs are also useful for onboard applications. The on-board message systems can allow the controller to make special announcements, notify passengers of route changes, explain delays, discuss transfer connections etc., without having to first contact the driver. This system can serve to reduce the work load of the driver by preventing passenger questions and thereby allowing the driver to spend more time on his primary task of piloting the vehicle.

Transmissions of coded data are generally handled by a electronic processor over voice grade telephone lines. The display media itself can be fabricated from lamp bulbs, rotating drums, electrostatic flags, and electromagnetic flags. Consideration must be paid to how elaborate the device need be. Options such as color schemes, size, and animated displays, for example, can affect both the purchase and operating costs.

Electromagnetic display signs have definite advantages in terms of:

1. operational cost
2. maintenance
3. energy conservation
4. overall weight
5. weatherproofing
6. vandal proofing

The electromagnetic sign consists of round elements that are colored on one side and black on the other. Each element is rotated, under control of the microprocessor, until the correct combination of colored and black elements displayes the desired message. Once set in the oriented position, the mechanism needs no additional power to retain its message. Thus, additional power is not needed until the message needs to be changed. This set/reset characteristic reduces the power consumption of the device. In addition, solar energy transducers are available that allow the device to use solar energy in lieu of electrical energy during hours of sufficient daylight.

● CONCLUSIONS

Passenger message signs at terminal areas are a highly effective and low-cost means of substantially improving the perceived level of service offered by bus transit authorities. Experience gained from a bus information system initiated by the Mississauga Transit Authority in Canada demonstrates that considerable operating economics can be made by keeping the passenger better informed.[1] This is accomplished by changing the traditional

1. "Progress Report No. 2 on Demonstration of Automated Bus Passenger Information System (ABPI)," Urban Transportation Research Branch, Canadian Surface Transportation Administration, February, 1977.

image of transit by making the user and potential user an active participant in the service rather than a passive victim of it. By keeping the passenger informed he can use the bus in much the same manner as he is accustomed to using taxi-cabs. Increases in ridership were experienced in Mississauga especially during inclement weather, when the passengers are often exposed to the environment and do not know when the next transit vehicle will arrive. Table 9 presents a sample of the displays that are available in a fourth-generation vehicle monitoring system.

The data displays available to the central control location provide the means to meet the dynamic conditions that confront a transit authority daily. The continual need to change priorities in order to meet the variety of specific transportation problems on any individual route are of an unpredictable nature. This necessitates that the controllers and supervisors possess the ability to make rapid decisions based on accurate and timely data. The availability of this pertient information is expedited by the expeditious choice of data display hardware.

In addition of the utility of the data displays, they can serve as an impressive public relations tool. This is especially true for large multi-colored map and status displays.

Commands. The commands display, located on the central display screen, indicates requests to talk, vehicle communications queues, emergencies, commands to vehicles, information requests from vehicles, telephone communication and inspector commands to the computer system. The Commands display would be the main operational display for the interactive control system.

Headway displays are of the Paris type which enables the inspector to visually inspect graphic lines for evenness of headways of vehicles on a route. This display is most useful on low headway routes, during rush hours, and in the downtown area where maintenance of headways is more important than maintenance of schedules.

Schedule - Zurich. Schedule display is of the type used in Zurich in which the graphical representation indicates adherence to a predescribed schedule.

This display is most useful controlling routes in suburban areas where maintenance of a fixed timetable is of prime importance.

Schedule - Dublin. A schedule display can also be based on the Dublin version of route time display although this does not give as graphical a representation of schedule adherence. This Schedule - Dublin display is most effective for schedule maintenance on routes where there are a large number of vehicles, whereas the Zurich schedule display appears to be more effective for the larger headway routes with lower numbers of vehicles.

Load Profile. The load profile display is a bar chart indicating vehicle loading at that instant in time for an entire route. This information would be most useful to a controller manually trying to readjust vehicle allocation from areas of low loading to areas of high loading.

Table 9. Example of Displays Available

Berney, L. G., et al., "Transit Communications and Information Systems," Telimove Automated Vehicle Monitoring Conference Proceedings, September, 1976.

Table 9 - Example of Displays Available (continued)

Where. The Where display gives the exact location of each bus on the route in terms of a number of feet past a particular spot. This is most useful to an inspector who is trying to identify the exact position of vehicles in a queue.

Information - Drivers. The Information - Drivers display contains pertinent information on vehicle drivers on a route. For example: the system displays driver badge, driver name, years of service, hours worked during the week, availability for overtime.

Information - Vehicles. Information - Vehicles display contains general information and the particulars of vehicles running on a route including vehicle technical identification number, driver badge number, route number, run number, radio channel, exact location, adherence to schedule.

Information - Route. Information Route contains a display of information pertinent to operation of routes, including route number route name, number of vehicles, number of runs scheduled, number of runs operating, schedule adherence, passenger loads, etc.

Information - General. The Information - General display is an overall systems summary of all the vehicles in the CIS system. It contains all information available in the Information Drivers, Vehicles, and Routes displays. This display could be utilized by senior management to obtain the status of the complete system at that time.

M2. The Map display, similar to one developed in Bristol, is a detailed geographic position of vehicles on a route. While such a display is not of prime use for route supervision, in cases of emergency it may be useful in directing emergency vehicles to the scene.

XII. DIGITAL DATA HARDWARE

Available digital data hardware has increased significantly in the past decade. When the Tornoto Transit Commission was implementing its AVM system in 1973, there were no existing devices readily available on the market that would cost effectively provide the more comprehensive communications capability required. Therefore, the Toronto Transit Commission was required to develop its own Electronic Processor as an onboard unit for each vehicle to monitor and control communications, location, passenger counting, and other information devices. During 1974-1975, they developed and built prototype equipment, acquired hardware components from various suppliers, and assembled actual test equipment. Today numerous manufacturers have constructed and tested their equipment in various applications. They will modify their production models to handle the particular engineering requirements of the purchaser. Many manufacturers will help the purchaser plan and select the equipment that is correct for the particular application.

Standard devices for mobile installation range from simple automatic vehicle identifiers to data terminals which include printers and graphic display cathode ray display tubes. Control center equipment ranges from basic recording and display equipment to complex terminals that switch and control information from multiple radio channels and data sources. The discussion of digital data hardware can best be accomplished by covering mobile and control center digital hardware separately.

- Mobile Digital Hardware

The mobile equipment basically consists of four elements; vehicle location identifier, communication transceiver, digital interface, and data head.

- Location identifier. The specific particulars of vehicle location identifiers are dependent upon the specific locational technique employed (i.e.,signpost, radio frequency, dead reckoning, etc.). The unit usually has no operator controls and is factory adjusted to operate properly over the tactical area. Its output is in digital form and is usually supplied to a digital interface. In some systems the digital interface is an integral part of the locational identifier unit.
- Communication transceiver. The communications system is the means of transmitting the data gathered on the vehicle to the control center. Many vehicle fleets are already equipped with radios for voice communication. If this is the case, it can represent a significant savings when the costs of implementing an AVM system are considered. This is because it is usually a simple matter to impress the digital information on the vehicle radio with barely noticeable effect on normal voice communications. A typical digital transmission requires less than one-one thousandth of a second, which is of no consequence to normal conversation. If the vehicle fleet is not equipped with two way radios, it is usually possible to select a unit which is optimum for voice as well as digital transmission.
- Digital interface. This module is the logic box-the brains of the mobile system. It contains the major portion of the electronics in the mobile data package. The module provides automatic control of the communication transceiver, encodes and decodes data messages, contains logic facilities for selective signaling and automatic station identification, and performs various timing functions which are

required during operation of the system. This information is coded and put in the proper format for transmission to the control center via the vehicle radio. This unit has no operating controls and is adjusted at the factory.

- Data Head. This is the unit that allows the operator to input into the system. The radio handset and radio operating controls may be integrated into the unit, making it possible to locate the two way radio remotely. The purpose and operating characteristics of this unit have been previously discussed in Section X.

  Appendix I contains the technical specifications for a mobile digital terminal supplied by the Garland Division of E-Systems. While this terminal is designed to be utilized by police patrols, the brochure demonstrates the many functions that can be performed by mobile terminals with equipment that is already on the market.

- <u>Control Center Hardware</u>

The control center is the focal point of all AVM activity. Inputs to the control center are data reports in digital form from the vehicle fleet, voice communications as necessary from the vehicle operators, and command instructions from the control center operators. This data is handled by the use of computers and magnetic tape units. The primary purpose of the magnetic tape unit is to provide an accurate record of day-to-day activity to be used in operational evaluation and statistical studies.

- Control console. The control console provides the interface between the dispatcher and the AVM system electronics. It consists of a communications panel, an AVM control panel, and a display panel.

The communications panel can be designed for each particular application. It contains the radio controls that enable the dispatcher to receive and identify incoming calls as well as to call specific units in the field. The size and complexity of these panels vary with the number of units operating,but all tend to fall into standard component arrangements. Microphones, headset or speakers,and other standard items of regular voice communications are a part of this equipment. Those operations that are utilizing two-way communications with the vehicle fleet probably already have communications panels in operation.

The most noticable impact on this equipment resulting from integration with AVM system is the reduction in voice messages due to the digital data transmission capability. A small keyboard is used to select a "canned message" and to cause a standard message to be transmitted in digital code. Confirmation is also digital and available to the dispatcher automatically as soon as the receipt of the message is acknowledged by the vehicle operator via a pushbutton depression. This reduces the need for actual voice communication and increases the amount of traffic that a single dispatcher can handle. The small keyboard used to communicate with the vehicles may be a part of the communications panel or of the display panel. A discussion of the display panels for central control is presented in Section XI.

- Electronic Processors. The computer is programmed by operational software to periodically accept data from the transit fleet and to present this data as directed to display panels,off line printouts, magnetic tape,or internal storage. A variety of software packages can be integrated with the operational software to use the available data in many other areas of transit operations. In addition to providing real-time communications and vehicle tracking, the computer can be used to automatically log and time-tag all data associated with measuring vehicle productivity. Management summaries designed to portray daily operations (from this point of view of showing correlations and aggregations of transit performance across months and even years) are possible using data stored and analyzed by the computer. In addition, many of the mundane functions, routine decisions, and remedial commands can be handled by the computer, thereby increasing the traffic that can be handled by the dispatchers.

- Digital Interface. The digital interface unit employed at the command center demodulates the digital information transmitted from the vehicles. All ingoing and outgoing messages from the command center flow through this unit,which automatically performs message conversions, priority analysis, error checks,and status reporting. The unit checks incoming messages for duplicates and transmission errors and presents the error-free messages to the computer.
- Digital Line Printer. These devices print messages on paper tape and can distinguish the type of message by selective printing or including a special character. Emergency transmission, such as silent alarms, can be printed in red. They are available with an internal timing mechanism to enable them to keep an immediate log of all communications, whether emergency or routine. Real-time and message data can be printed for base and mobile transmissions.

The "daily tape" aid the dispatcher and management by supplying an ongoing record for managing the system and conducting analysis. During emergencies the printer lists messages that may be missed if the dispatcher is busy or away from the terminal and eliminates the dispatcher's record-keeping duties.

A typical AVM block diagram is shown in Figure 10. While this will vary in detail for particular applications and location techniques, it represents the major components of the system.

- CONCLUSIONS

Significant advances have been made in the electronic technology necessary for AVM systems during the past decade. Transit authorities that are contemplating installing an AVM system today are not placed in the predicament of constructing their own equipment, as Toronto was in 1973. Today there is a variety of equipment available from a number of manufacturers that can either be purchased from the shelf or custom made.

Technical assistance is available from these manufacturers in designing the overall system and tailoring the individual electronic components to perform prescribed tasks. They also have training programs to aid the transit personnel in making the transition from manual techniques to real time data control.

Before making any commitment to any particular AVM configuration it would be advantageous for key personnel to visit a location that has recently implemented an AVM system. First hand observation of the system layout and personal contact with individuals with implementation experience could give an insight into the problems that might be encountered. This knowledge would be beneficial in choosing the equipment best suited to satisfy the needs of the transit authority.

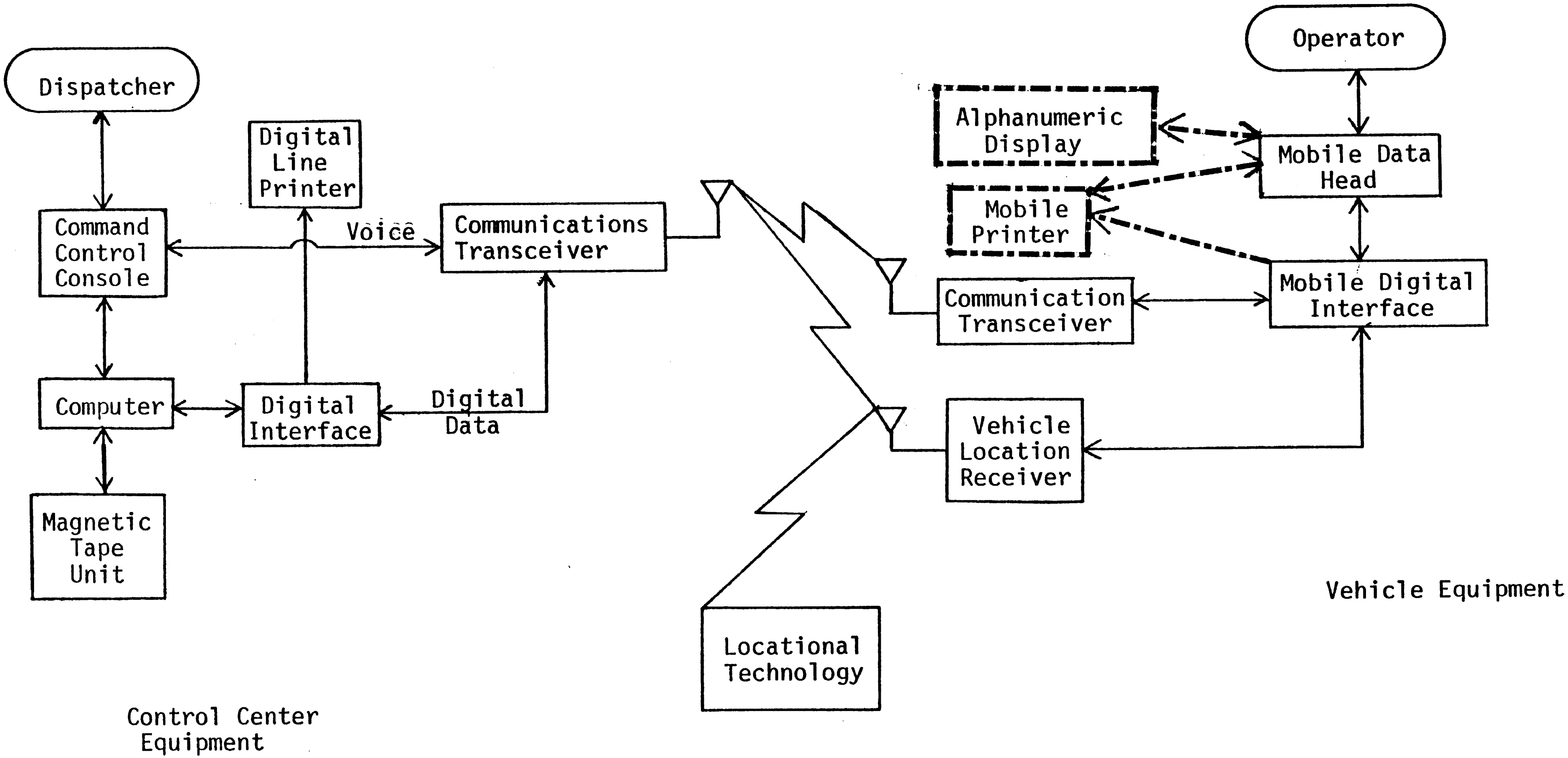


Figure 10 - Typical AVM System Block Diagram

BIBLIOGRAPHY

1. Alepin, Pierre, "Automated Bus Passenger Information Systems,"(A Statement of Progress), Telimove Automated Vehicle Conf. Proceedings, September, 1976.

2. "Ann Arbor Transportation Authority Teletron Communication and Dispatching System - Operations Manual," Metroscan, June, 1975.

3. Bauer, Christian S., Risher, Thomas A., "A Simulation Analysis of a Computer-Controlled Freeway Margins System," Florida Technological University, March, 1977.

4. Bauman, Dwight M., Au, Tsung; Copper, Jack, "Automation of Paratransit Fare Compilation and Dispatching," Carnegie-Mellon University.

5. Berney, L.G., et. al, "Transit Communications and Information Systems," Telimove Automated Vehicle Monitoring Conf. Proceedings, Sept., 1976.

6. Blood, Bernard E., Klien, Bernd, W.A., "Experiments on Four Different Techniques for Automatically Locating LAND Vehicles: A Summary of Results," USDOT Report #UMTA-MA-06-0041-77-2, TSC, November, 1977.

7. Blood, B. E., "Multi-user Automatic Vehicle Monitoring," Telimove Automated Vehicle Monitoring Conf. Proceedings, Sept., 1976.

8. "BOGOTA Automatic Vehicle Location System," Teledyne Systems Company, July, 1976.

9. Catton, F.D., "Bus Transit Automatic Vehicle Monitoring Systems," Telimove Automated Vehicle Monitoring Conf. Proceedings, Sept., 1976.

10. "Conference Record of the Twenty-Seventh Annual Conference IEEE Vehicular Technology Group," papers presented at the 27th Annual Conference, March 16-18, 1977.

11. Dano, Jerome M., "Automatic Vehicle Monitoring For Fleet Operations: Dallas, Taxas and Philadelphia, Pennsylvania Field Test Programs," Hazeltine Corp, 1977.

12. "Design Requirements and Procurement Specifications for Two-Way Transit Communication System," Southeastern Pennsylvania Transportation Authority (SEPTA), UMTA Project PA-03-0032.

13. "Digicom Information Packet," E-Systems, Garland Division, 1978.

14. "Digital Communications System Interface," E-Systems, Garland Division.

15. Drolet, Lucien, "Medical Emergency Dispatch and Coordination Centre," Telimove Automated Vehicle Monitoring Conf. Proceedings, Sept., 1976.

16. "Electronic Systems Development for Bus Transit as Displayed in the Urban Transportation Laboratory," GM Transportation Systems.

17. Ellis, Harry H., Jr., Dombert, W.E., Spatz, S., "Automatic Container Identification Through a Microwave System," Fairchild Inc., September, 1974.

18. Fitzgerald, B. J.,"Automated Monitoring and Control of Public City Bus Services," Telimove Automated Vehicle Monitoring Conference Proceedings, Sept., 1976.

19. Foote, Robert S., "Developments in Automated Vehicle Identification During 1974 and 1975," Port Authority of New York and New Jersey.

20. Fujaros, R.G., "State-of-the-Art of Mobile Radio Data Systems for Police Users,"Telimove Automated Vehicle Monitoring Conference Proceedings, Sept., 1976.

21. Fyffe, G.M., "Computer Dispatch, A Central Dispatch and Control System for Taxi Operations,"Telimove Automated Vehicle Monitoring Conference Proceedings, Sept., 1976.

22. Goldsmith, Arthur, "Department of Transportation National Plan For Navigation," Report #DOT-TST-78-4, November, 1977.

23. Gruver, G.W., "Philadelphia Field Tests Of An Overlapping Signpost AVM System During the UMTA Multi-user AVM Program," March, 1978.

24. Gruver, George W., Reichardt, Otto A., "The Huntington Beach Automatic Vehicle Monitoring System Utilizing Overlapping RF Signposts," March, 1978.

25. Instruction Manual for MDH-10 Mobile Data Head," Rydax, Inc., August, 1976.

26. Irwin, Neal A., "Concepts for Improved Communications and Information Systems in Urban Transportation,"Telimove Automated Vehicle Monitoring Conference Proceedings, Sept. , 1976.

27. Irwin, William C., "Planning and Construction of a Computerized Traffic Control System," March, 1977.

28. Kearns, James H., "New Concepts in Transit," Telimove Automated Vehicle Monitoring Conference Proceedings, Sept., 1976.

29. Kedar, M., "Manual Centralized Fixed-Route Fleet Monitoring and Control (Sudbury Transit Control Systems)," Telimove Automated Vehicle Monitoring Conf. Proceedings, Sept., 1976.

30. Kleim, Bernd, W.A., "Investigation of European AVM Experience," USDOT, Report #UM711-PM-76-13, December, 1976.

31. "LAVM: System Test - Salt Lake City, Utah," Teledyne Systems Company, 1976.

32. Leech, E.R., Outlaw, W.T., "A Communication System Custom-Designed for the Montreal Metro Rapid Transit Subway," WABCO, March, 1977.

33. "LORAN AVM," Teledyne Systems Company, April, 1974.

34. Ludwick, John S., Jr., "Analysis of Test Data From An Automatic Vehicle Monitoring (AVM) Test," Mitre Corporation, March, 1978.

35. McAdoo, G. H., "Computer-Controlled Versus Computer Aided Dispatching," Regina Transit System, 1977.

36. "Mobile Digital Terminal," E-Systems, Garland Division.

37. Morrison, D., "Random Vehicle Monitoring System Design and Testing," Telimove Automated Vehicle Monitoring Conference Proc., Sept., 1976.

38. Pokorny, A. J., Briefel, H., "Report on Phase One Tests of Fairchild Automatic Vehicle Monitoring (AVM) System," Fairchild Space and Electronics Company, Report UMTA-MA-06-0041-77-3, August, 1977.

39. Potter, Barbary, "Ann Arbor's Dispatching System," Metroscan Inc.

40. "Progress Report No. 1 on Demonstration of Automated Bus Passenger Information System (ABPI)," Urban Transportation Research Branch, Canadian Surface Transportation Administration, August, 1976.

41. "Progress Report No. 2 on Demonstration of Automated Bus Passenger Information System (ABPI)," Urban Transportation Research Branch, Canadian Surface Transportation Administration, February, 1977.

42. "Progress Report No. 3 Demonstration of Automated Bus Passenger Information System (ABPI)," Urban Transportation Research Branch, Canadian Surface Transportation Administration, October, 1977.

43. Raithel, Wilhelm, "UMTA's Paratransit Vehicle Project," UMTA, USDOT.

44. Reberio, R. B., McKim, T. R. G., "The Transportation Management Centre Concept," Telimove Automated Vehicle Monitoring Conf. Proc., Sept., 1976.

45. Reed, David H., Roos, Mary; Wolfe, Michael; DiGregorio, Ron, "A Study of the Costs and Benefits Associated with AVM," Report #UMTA-MA-06-0041-77-1, February, 1977.

46. Reichardt, O.A., "AVM Applications: The State-of-the-Art: Fire," Telimove Automated Vehicle Monitoring Conference Proc., Sept., 1976.

47. Riccio, Alexander H., "Automated Vehicle Location - Dallas Test Results," Hazeltine Corporation, March, 1977.

48. Rukholm T., "Sudbury Transit Control System," Telimove Automated Vehicle Monitoring Conf. Proceedings, September, 1976.

49. "Schedule Control and Management Information System Study," IBM Federal Systems Division, November, 1974.

50. Skomal, Edward N., "Comparative Analysis of Six Commercially Available AVL Systems," Aerospace Corporation, March, 1978.

51. "Specifications for Bus Radio/Management Information System," Massachusetts Bay Transportation Authority, October, 1976.

52. Stapelton R., Chambers, F., "Loran Automatic Vehicle Monitoring System, Phase I Volume I: Test Results," Teledyne Systems Company, Report #UMTA-MA-06-0041-77-10, August, 1977.

53. Symes, Danis J., "Multiuser Area - Coverage Automatic Vehicle Monitoring Program," IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 2, May, 1977.

54. "Transportation and Vehicle Monitoring," Gould Corporation, September, 1976.

55. "Twenty-Eight IEEE Vehicular Technology Conference," Conference Record of papers presented at the Twenty-Eigth Annual Conference, March, 22, 24, 1978.

56. "Urban Transportation Laboratory, A Progress Report," GM Transportation Systems, May, 1978.

57. Volk, Helmut M., "Communications Options for Computerized Traffic Control System," Honeywell, Inc., March, 1977.

58. Walker, F. W., Jr., "Durability of Vehicles: What is That?," Transportation Systems Division, General Motors Division.

59. Ward, John E., "Radio and Digital Mobile Terminal Equipment for An Expanded PERT (Dian-A-Ride) Service in Rochester, N.Y." Report #ESL-R-635, MIT, July, 1973.

60. Ward, John E., Rausch, Robert G., "Vehicle Communications For A Dial-A-Ride System," Report #USL TR-70-15, MIT, Urban Systems Laboratory, March, 1971.

61. Weinstein, Seymour M., "Development of An Automatic Vehicle Monitoring System for the City of Dallas," Hazeltine Corp., 1977.

62. Wilson, Geoffrey D., "Automatic Vehicle Location System Selection," Aerospace Corporation, March, 1978.

63. Wilson, Nigel, H.M., "Automated Vehicle Dispatching, Routing and Control" Telimove Automated Vehicle Monitoring Conference Proc., September, 1976.

64. Wolff, R.N., "TELIMOVE Automated Vehicle Monitoring Conference Proceedings," papers from a conference held September 20-22, 1976 sponsored by UTRB of Transport Canada.

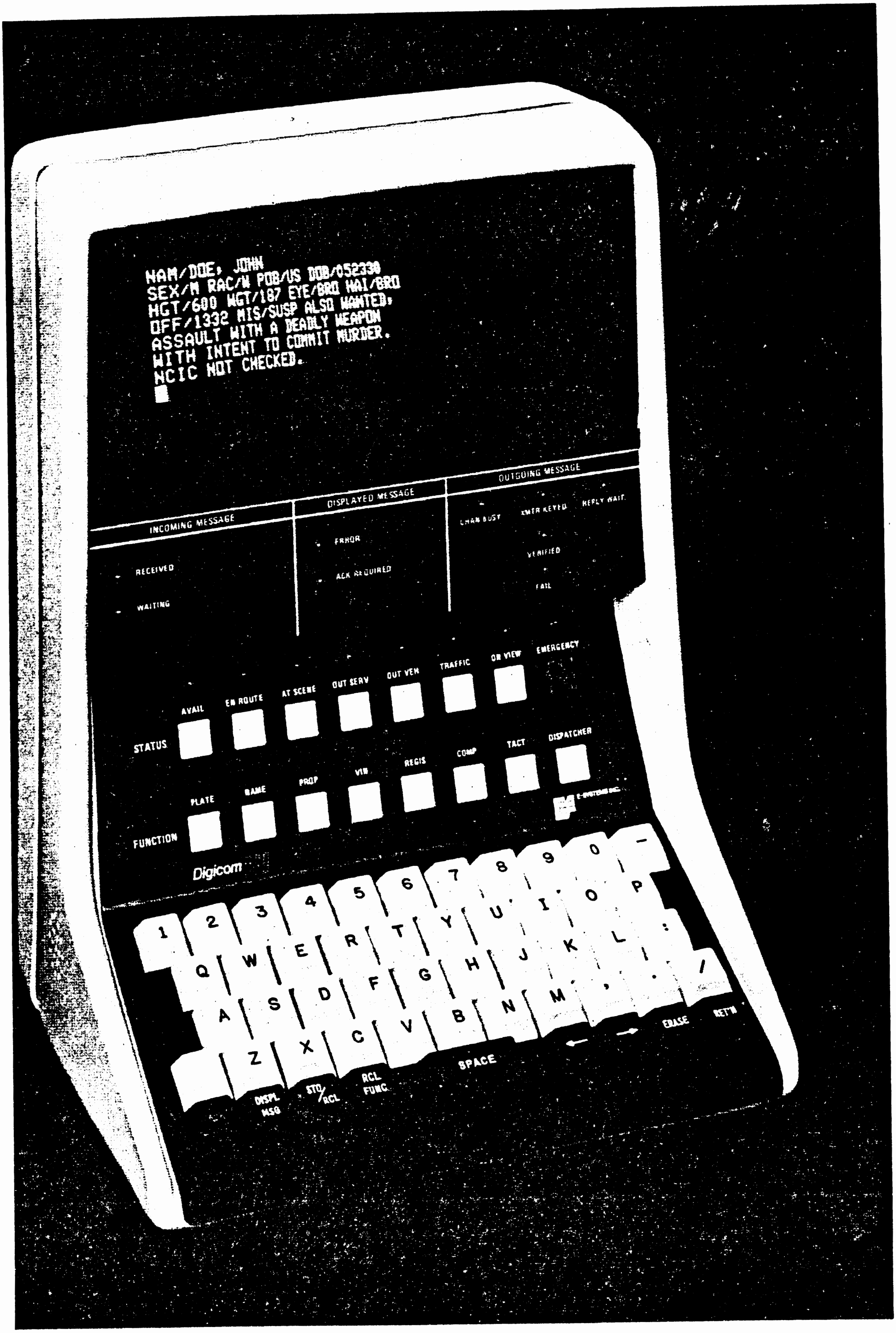
APPENDIX I

E-SYSTEMS
Garland Division

Technical Specification

Mobile Digital Terminal

MDT-800



E-SYSTEMS
Garland Division

I. E-SYSTEMS MDT-800 DESCRIPTION

The MDT-800 provides reliable and secure digital communications, via existing voice grade radio equipment, for fast and accurate status update of mobile fleets, direct access to selected remote data base files, dispatch, and informative messages to field forces, and external interface capabilities with such devices as mobile printers and Automatic Vehicle Location systems. Key features of the MDT-800 include:

- Visibility in Direct Sunlight
- Heads up Display for:
  - Ease of Operation and Viewing
  - Greater survivability in crash over the hump mount configurations.
  - Ease of Right Door Egress for Driver
- Made for Policemen; not computer operators
- Ease of Removal, Replacement & Maintenance
- Heat and Humidity Tolerance
- Speed of Operation

II. SPECIFIC DESIGN SPECIFICATIONS

A. Physical

The MDT-800 has a modular design to ease maintenance and minimize the equipment congestion in the front seat. As a result of this design philosophy, the keyboard/display module is separated from the control processor. By placing the bulk of the electronics in a separate package, the keyboard/display is a smaller, more effectively maintained package.

The display/keyboard module consists of the display, alphanumeric keyboard, status/function keys and indicators. The module is contained in an ABS plastic case, which is vacuum molded to form a small, durable and water/rust resistant skin suitable for heavy duty use in public safety vehicles. Its dimensions are 13 1/8" x 10" W x 10" D, and it weighs about 10 pounds. The physical design of the MDT-800 allows easy

mounting in the vehicle's front seat area without restricting the officer's normal operation of other on-board equipment, or exit from either door.

The MDT-800 display/keyboard module is mounted between the driver and passenger on a swivel mount. This mount places the viewing portion of the terminal at the level of the dash thus allowing minimal eye movement when reading data. The swivel allows optimum viewing angles from either the driver or passenger seat.

Due to the unique indirect display technique utilized in the MDT-800, it is possible to view the display in bright direct sunlight. A front screen with a special coating decreases glare.

Controls for the display, indicators, keyboard lighting, and audible alarms allow the officer to adjust the brightness of the display for night or day use, and the audio alarm level.

The MDT-800 processor module contains the logic required to operate the display/keyboard module plus the modem and radio interface. This module is house in a rugged metal container 16" x 10" x 3½" in size and is designed to be mounted in the vehicle's trunk to allow ease of installation and removal. The control and display/keyboard modules are connected by cables of rugged design to prevent damage due to vibration.

The radio interface unit connects the mobile unit's processor to the mobile radio in the vehicle. Since the radios in the vehicles may not be of the same type, the interface to the radio must be set up to compensate for the difference in input and output parameters of the various radios. Since the radio interface is individually packaged, it can stay with the radio which allows the major electronics package, the processor and console units to be changed out for repair, and still maintain the proper radio compensation.

B. Environmental

The MDT-800 has been tested over a range of ambient temperatures from -30° F (-40°C) to 176°F (80°C). The terminal is packaged to prevent dust and liquid such as soda, sugar, coffee, ashes, etc., from impairing operations. The MDT-800 conforms to humidity, vibration, and shock standards as outlined in EIA RS-204A.

C. Electrical

The MDT-800 nominal operating voltage is 13.5 volts, but it will operate between a range as low as 10 volts and as high as 17 volts. Total current drain is less than 1.8 amps.

D. Electrical Construction

Both the display/keyboard and control modules of the MDT-800 are modular in design. This construction allows fast servicing of units, which decreases the mean time to repair (MTTR). With the exception of the CRT display, CMOS solid-state design is used to provide low power drain on the vehicle's electrical system.

E. Keyboard

The MDT-800 utilizes a standard typewriter alphanumeric keyboard with the punctuation keys; period, comma, slash, colon, and dash. Located on the keyboard are the cursor control keys (left arrow, right arrow, space, screen erase, and return). Also located on the keyboard are the buffer control keys...display message, store/recall, recall function, and the manual acknowledge. All key caps are white with black engraved labels to prevent obscuring the key markings after prolonged use. The control keys are black with white engraving, except the manual acknowledge key which is engraved red.

F. Display

A five-inch cathode ray tube is employed to display up to eight (8) lines of characters each for a total capability of 256 characters. A special optical system and vertical tube mounting combine to provide wide-angle viewing, minimum reflective glare and minimum unit depth dimension. Safeguards have been incorporated to prohibit the user from gaining access to the high voltage portion of the display. To allow viewing of the display in bright sunlight and prevent washout, the CRT is mounted facing up into a front surfaced mirror. A brightness control allows adjustment of the display from off to full brightness. A special front coating and mounting angle of the viewing window reduce glare from windows and vehicle headliner.

Character size is adjustable with an average character size of 3/32" W x 3/16" H on a screen size of 4" W x 2" H. Character generation is a 5 x 7 dot matrix on a 9 x 7 dot matrix field. These features provide character size and spacing sufficient to permit reading the display from any location in the vehicle and from distances in excess of 12 feet.

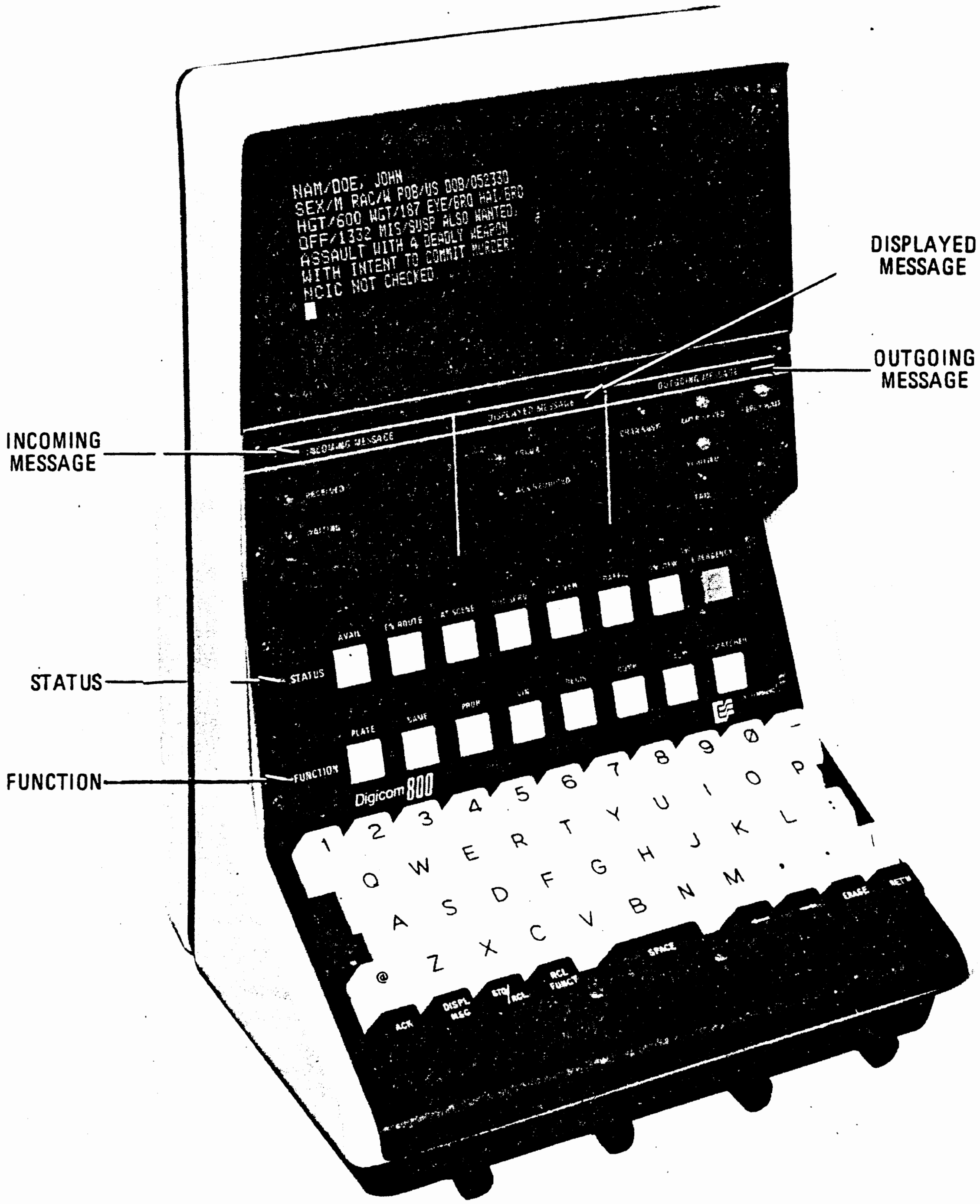


FIGURE I. INDICATOR LOCATION

G. Indicators

The MDT-800 uses light emitting diodes (LED's) of various colors for indicators. LED's are used for high reliability, low cost, and low power drain. All LED's are high intensity with a controlled diffusion angle of light which makes the LED easier to see in sunlight. The brightness of the LED's is fully adjustable to provide for optimum level under all illumination conditions. See Figure I.

- <u>Incoming Message Area</u>

  The incoming message indicator group consists of two (2) red LED's labeled RECEIVED and WAITING.

  RECEIVED...Indicates a routine message has been received by the terminal.

  RECEIVED (blinking)...Indicates a priority (emergency) message has been received by the terminal.

  WAITING...Indicates a routine message is being held at the base station.

  WAITING (Blinking)...Indicates a priority (emergency) message is being held at the base station.

  NOTE: The "WAITING" light will not be lit unless the receive buffer is holding a message and the "RECEIVE" LED is on.

If the "WAITING" LED is on, pressing the DISPLAY MSG key causes three events. First, the message in receive buffer is displayed. Second, an automatic transmission of an acknowledgment, indicating that the buffer is empty, is transmitted to the base station. Third, the RECEIVE and WAITING LED's are turned off. Lighting either of the incoming message indicators is accomplished with an audible alarm.

- <u>Outgoing Message Area</u>

  The outgoing message indicator group consists of two (2) red LED's labeled CHANNEL BUSY and FAIL, two (2) yellow LED's labeled REPLY WAIT and VERIFIED, and one green LED labeled XMTR KEYED.

CHANNEL BUSY...Indicates two events. First, the MDT-800 is in a transmit sequence and has found the channel busy. This indicator only shows channel busy during a transmit sequence. Second, due to the buffering capability, two different data transmissions could be stacked. To alert the user that he has stacked transmissions, the channel busy light comes on, and an audible alarm is sounded.

XMTR KEYED...Indicates the MDT-800 is keying the radio and data is being transmitted to the base station.

REPLY WAIT...Indicates the terminal has completed transmission of a message and is awaiting an acknowledgment from the base station. The length of this wait is normally set to six (6) seconds, but is adjustable. After the wait period, if no acknowledgment was received from the base station, the transmit sequence may be repeated a total of up to eight times. The cycle is terminated by a base station acknowledgment.

VERIFIED...Indicates acknowledgment from the base station of receipt of an error-free message. The length of time this indicator is lit is normally set for two (2) seconds, but is adjustable.

FAIL...Indicates the terminal has transmitted a message the prescribed number of times (up to seven) without receiving an acknowledge message. This indicator is accompanied by an audible alarm.

- Status

The status indicator group consists of eight (8) red LED's; seven are available for normal status (such as enroute, etc.), and one is for the emergency function. When a transmit sequency begins and the LED over the status key is lit, any other normal status LED which is lit is turned off. If for any reason the status transmission fails to be acknowledged after the prescribed number of

tries, the fail indicator in the outgoing message group is lit and the status LED begins to blink.

Pressing the emergency key does not effect a normal status LED which is lit. Transmission of an emergency status message repeats until verified by the base station.

H. Security

The MDT-800 utilizes a standard on/off power switch in conjunction with the unit's I.D. code to provide a secure means of lockout when the officer leaves the vehicle. This lockout can be accomplished in the following manner:

As the officer leaves the vehicle, he presses the out of vehicle status key. (This status key label may differ for each using agency). Upon returning to the vehicle, the officer enters his badge number and presses the "computer" function key. This now places his terminal back in an operational mode. Any attempt to use the terminal by an unauthorized person would cause the MDS software to log that terminal "off" and alert the dispatcher and watch commander that such an unauthorized attempt to log on is being made.

I. Controls

The MDT-800 provides individual adjustment of the following controls:

- Display intensity - from total off to full brightness.
- Keyboard light - from very dim to full brightness for night use.
- Indicator lights - from very dim to full brightness for night use.
- Audible alarm - from full off to full on.
- On/Off - a standard slide switch is used and the presence of a cursor identifies that the unit is on.

J. Memory

The MDT-800 utilizes four (4) buffers (memories) to provide greater flexibility to the field officer and the system. Each buffer has a capacity of 256 characters in a

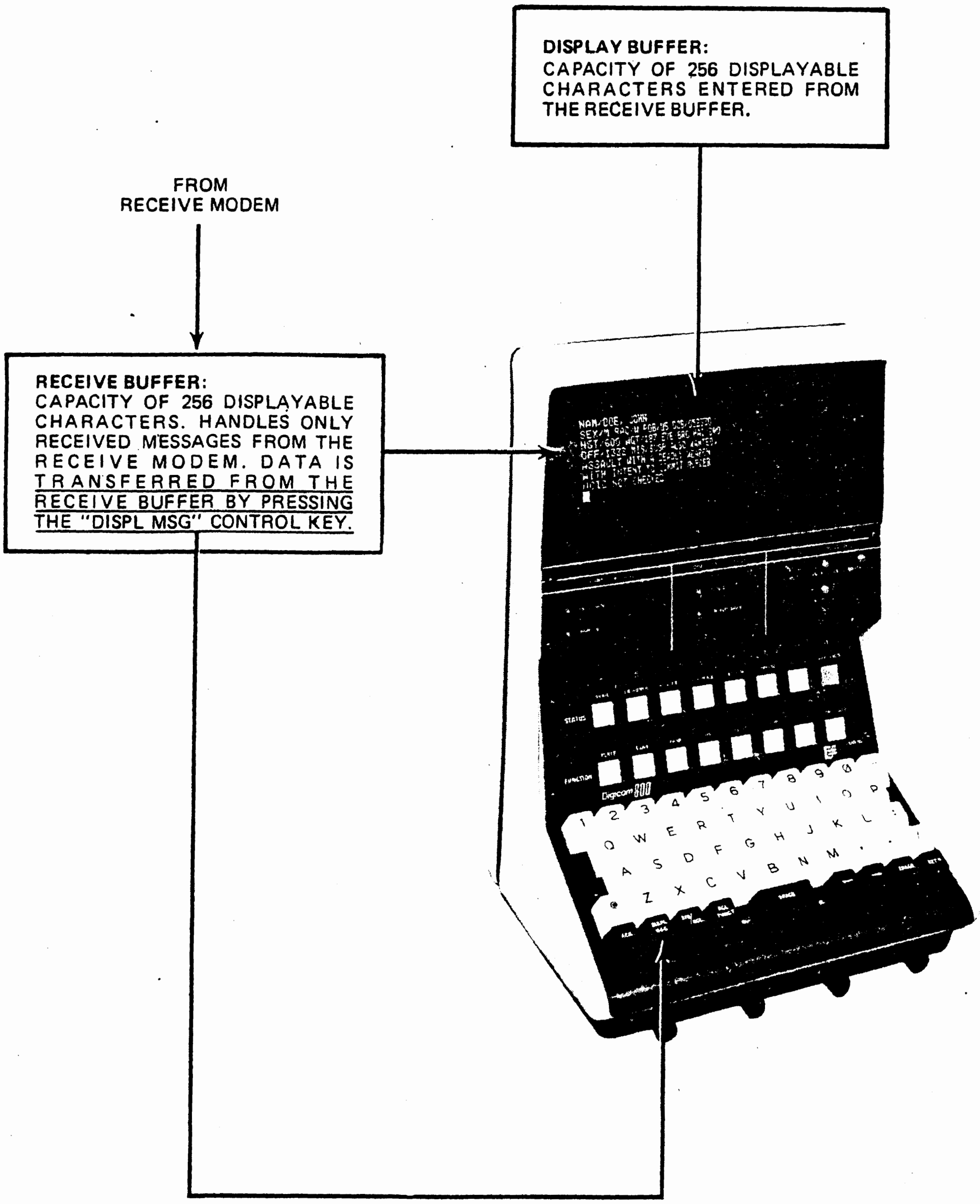


FIGURE II. RECEIVE BUFFER

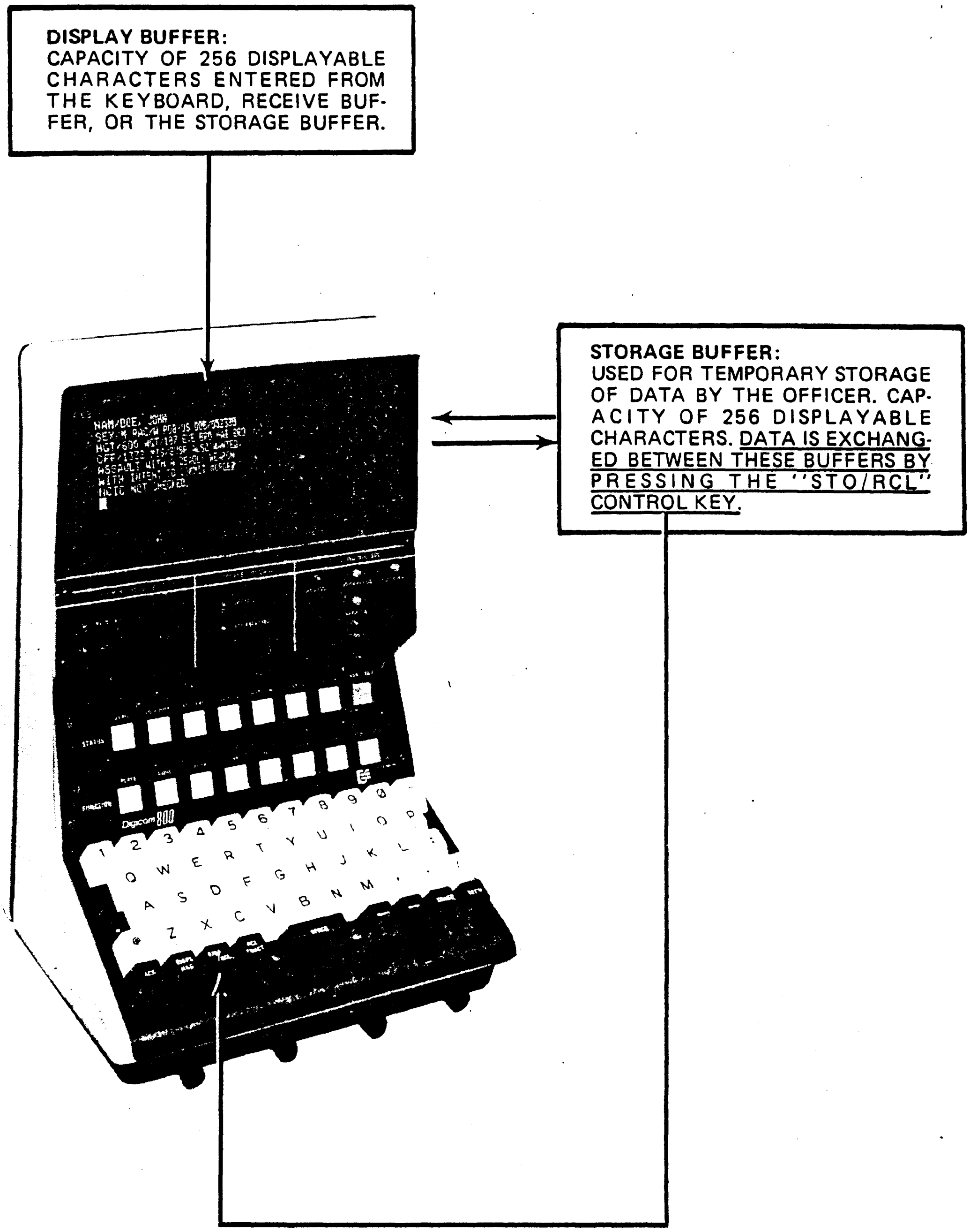


FIGURE III. STORAGE BUFFER

single transmission from the base station. Operation of each buffer is as follows:

RECEIVE BUFFER (Figure II) - The receive buffer is used for receiving messages up to 256 characters in length from the base station only. No data may be transferred into this buffer from another buffer.

DISPLAY BUFFER - The display buffer is used to display keyboard entries for verification of accuracy prior to transmission, to display data from the receive buffer, the storage buffer, and the transmit buffer. Up to 256 characters can be displayed from this buffer.

STORE BUFFER (Figure III) - This buffer is used for temporary storage of up to 256 characters of data. Pressing the STO/RCL key causes the exchange of the contents of the STORE buffer and the DISPLAY buffer.

TRANSMIT BUFFER (Figure IV0 - This buffer is used for transmission. When a function key is pressed, any data in the display buffer ia automatically transferred to the transmit buffer and the transmit buffer may also be used as a storage buffer and its contents are displayed by pressing the RECALL FUNCTION key. Pressing the RECALL FUNCTION key immediately terminates any transmission in progress.

K. Modem

The MDT-800 interfaces directly or in parallel to voice grade radio equipment. The Phase Shift modulation utilized by E-Systems Inc. allows a transmission speed of 2400 bits per second. The modem in both the MDT-800 and the base station radio facility are identical, allowing both modulation and demodulation without special modification to the mobile radios.

L. Effective Data Rate

The MDT-800 can receive, verify, and display a full screen, 256 characters, in .75 seconds. The effective data rate for a 256 character display is 1993 bps.

M. Operational Safety

The MDT-800 mount allows direct emergency exit from either door. The durable high impact plastic case is able to absorb the shock of high speed collision. Laminated

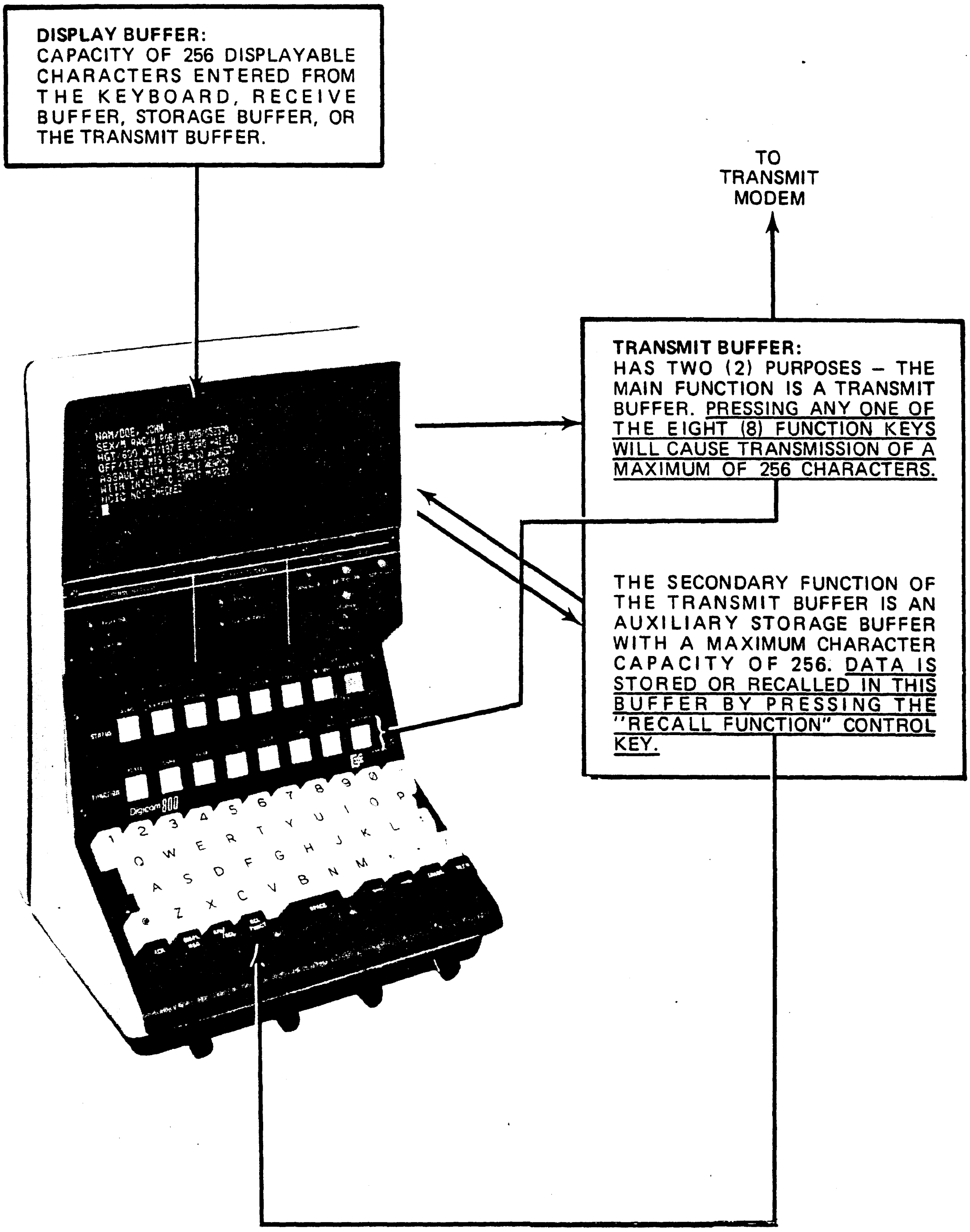


FIGURE IV. TRANSMIT BUFFER

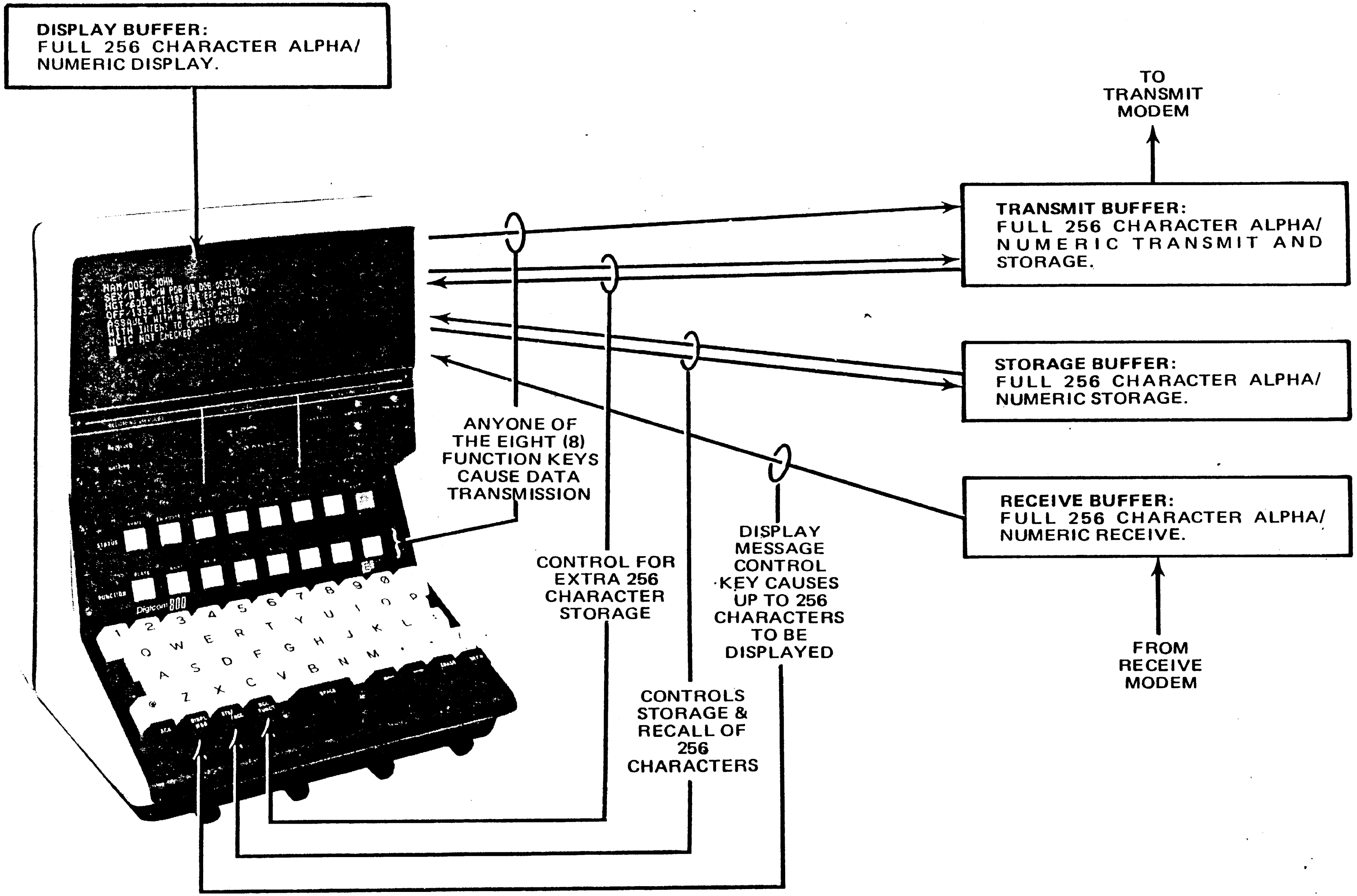


FIGURE V. BUFFER INTERACTIONS

safety glass on the display unit prevents the possibility of flying glass during collisions.

III. SPECIFIC OPERATIONAL SPECIFICATIONS

Each of the following types of messages are uniquely identified by unit I.D., function and status.

A. Normal Status

The MDT-800 provides seven (7) normal status keys. The labeling of the status keys will be specified by the using agency. For example, keys might be labeled AVAILABLE, ENROUTE, AT SCENE, OUT OF SERVICE, OUT OF VEHICLE, TRAFFIC STOP, and ON VIEW. Ten codes can also be utilized.

Transmission of a status change is initiated by pressing the desired status key. As the normal status message is being transmitted, the officer may continue to utilize the terminal for message construction.

B. Function Messages

The MDT-800 provides eight (8) function keys. The labeling of the keys will be specified by the using agency.

A function message transmission is accomplished by typing relative data on the terminal's display and pressing the appropriate function key. Pressing the key causes the displayed data to be transferred to the transmit buffer, and the transmit sequence to begin. This makes the display available to receive another message or for message composition.

C. Emergency Status

The MDT-800 provides an emergency key identified by name, color of key (red), and a protective ring to prohibit accidental pressing. When the emergency key is pressed, repeated transmission of an emergency message occurs until acknowledged by the base station. All transmissions from the terminal contain unit I.D., status, and control bits (emergency, ACK, functions, etc).

The MDT-800 also provides the capability, which may be used in emergency situations, to be polled; the poll will cause automatic transmission of all data in the display and storage buffer without action from the officer.

D. Informative Message Transmission

If an informative message is to be sent to another MDT or to the dispatcher, a function key is pressed. This

initiates transmission of the message along with the terminal's I.D., status, and function code. Upon receipt of the message by the base station, the system would automatically route the message to the proper dispatcher or MDT.

E. Data Base Inquiries

Data base inquiries may be sent from the MDT-800 by the use of function keys. As the inquiry is received at the base, the function desired is decoded and correct routing by the CAD computer is conducted. As the response from the remote data base returns, the data is formatted for display, and transmitted to the originating terminal. If the total number of characters exceeds 256, the message is split and after the first portion of the message has been received by the terminal, the second portion is transmitted. The officer may then store the first portion, display the second, and by using the store/recall key, switch from first page to second.

F. Audible Alert

The MDT-800 has the capability to provide external signals to/from various items of equipment. The normal MDT-800 audible alert signal is available at the unit output connector. This signal may be connected to a matching transformer provided by the using agency through a switch to the vehicle's existing P.A. system. As the officer leaves the vehicle, he switches the "audible" switch on and turns his P.A. on. If any message is received during his absence, a 1000 Hz tone will sound via the P.A. system.

G. Automatic ID (Digital)

All MDT-800 messages contain a twelve (12) bit ID code. This ID is adjustable so that the ID number may be changed by service personnel. This 12 bit ID code allows over 4,000 unique addresses.

H. Automatic ID (Voice)

The MDT-800 has the capability of interfacing to the radio in such a way that any time the mike push-to-talk button is depressed, the terminal's ID is transmitted. This ID also contains a function code to signal the CAD computer that the message was initiated by pressing the mike push-to-talk button.

I. Automatic Acknowledge

Once the terminal has received a message from the base station, which has been verified, bit 16 is checked. If bit 16 is a "1", the automatic acknowledge flag is set.

After receiving the text (if present) and verifying that the text is error free, an acknowledge message is transmitted to the base station. This is an automatic transmission in response to a base station request.

J. Channel Sense

The activity detector circuitry can be used in conjunction with the CTCSS signal from the mobile transceiver to inhibit transmitter keying. Digital data transmission is delayed until the CTCSS tone is no longer present on the receive channel.

K. Manual Acknowledge Required

When the base station wants assurance that the mobile unit operator has received a message, the base station may send a message using the manual acknowledge operation code in the standard message. This will cause the ACK REQUIRED light on the terminal to be lit. The operator will then acknowledge the received message by pressing the ACK key.

L. Group ID

Each MDT-800 can be assigned to one of fifteen groups. The unit will receive all messages sent to its assigned group. Group assignments can be made dynamically under base station software control.

M. Emergency Alarm Sounding

The MDT-800 has the capability of interfacing with a speaker or horn for sounding an Emergency condition. This is done under computer control only. The officer would have to enable this feature prior to exiting from the vehicle.

N. Mobile Digital Equipment Standard

The MDT-800 meets or exceeds the specifications established by the National Institute of Law Enforcement Criminal Standard for Mobile Digital Equipment per document #NILECJ-STD-0215.00.

For additional information, please contact E-Systems Inc., Digicom Products.

E-SYSTEMS
Garland Division
P.O. BOX 226118 • DALLAS, TEXAS 75266 • (214) 272-0515