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TERRESTRIAL RADIODETERMINATION PERFORMANCE AND COST

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INTERIM REPORT

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16. Abstract

This second interim report summarizes information gathered during a study of the application of electronic techniques to geographical position dertermination on land and on inland waterways. Systems incorporating such techniques have been called terrestrial radiodetermination (TRD) systems. Their most common application to date has been to locate and track a large number of vehicles in real time. Other uses are envisioned for the future.

This report describes the performance of several leading systems that employ TRD. These systems are or have been operational to some degree. Cost data are also given. The report complements and extends the information given in the previous interim report. (See Cantor, Farr, and Kodis, Report No. DOT-TSC-OST-76-7, July 1976).

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PREFACE

The value of radio techniques in providing navigation and position information to ships and aircraft has long been recognized. In recent years, there has been a growing awareness that similar techniques can also be helpful in the operation of transportation and transportation-related systems on land. It is the responsibility of the Department of Transportation to provide for the orderly and efficient development, implementation, and operation of aids to navigation that meet both current and future needs of civil air, marine, and land interests of the United States, as summarized in the National Plan for Navigation.

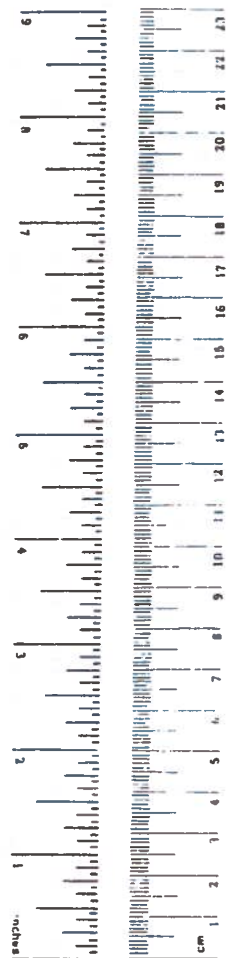
This report documents one portion of an effort to define the Federal role in the area of land navigation and position determination. Leaving aside the support of localized demonstration projects, it seems clear that any Federal involvement in providing a position determination service on land should encompass many users, which involve many different types of uses. It therefore becomes necessary to understand how different systems perform, and what benefits are produced. It also is important to determine cost data for implementing these systems in order to make better decisions concerning the use of Federal resources. This second interim report discusses these matters.

The contributions of Stephen R. Cantor and Harold Stein are gratefully acknowledged.

METRIC CONVERSION FACTORS

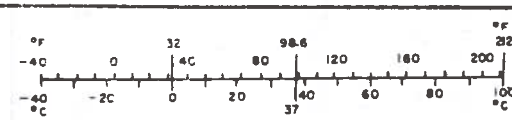
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

This is the second Interim Report dealing with Terrestrial Radiodetermination (TRD). The report concerns "Performance and Cost," whereas the first Interim Report (Reference 1) concentrated on "Potential Users and Their Requirements." One objective of this study is to emphasize the point of view held on radiolocation methods by current and potential users of such systems - e.g., police, public transit, taxi operators. This point of view has not been stressed enough in the past. Our belief is that persons who operate businesses and services that will use radio-location methods are the most knowledgable about their needs. To illustrate this point one may ask: "How much, and in what manner, should a bus driver participate in an Automatic Vehicle Monitoring (AVM) system?" This has a bearing on which type of system is adopted, and operational personnel - e.g., drivers, dispatchers, supervisors - can best answer the question.

Another fundamental point of importance to recognize is the need for a step-by-step approach to the implementation of TRD systems. Nearly all TRD systems are costly, and it is difficult to justify this cost when the whole system has to be paid for at one time. If the system could be constructed in a building block fashion, where the blocks could be added one at a time and each block cound be cost-justified by itself, we believe the use of TRD techniques would be enhanced. In addition, with the building block approach, the users of the system would be able to incorporate each block into their operation in an orderly, evolutionary manner. For example, in the case of vehicle fleet operation, to suddenly install a full AVM system with no previous experience with electronic equipment would present many difficult problems for the operating personnel. This building block or modular approach is mentioned again in Section 2.2.

This Interim Report complements the information presented in the first Interim Report (Reference 1). Section 2 adds to the potential users discussed in the previous report. Section 3 gives more complete descriptions of several systems (Sections 3.1, 3.3, 3.4). The rest of the systems discussed in Section 3 were not included in the previous report.

The performance of systems using TRD must be evaluated with great care. This task is especially difficult because there are differing opinions on how well these systems perform. Persons who have the responsibility of developing a given system tend to report the benefits in more flowing terms than other people who interact with the system. Larson (Reference 5) discusses some of the problems in evaluating AVM systems. For example, he states that for police work, the commonly accepted benefit of reducing response time may not be as good as previously believed because AVM will only affect one portion of the "total" response time. Similar doubts about the effectiveness of bus AVM systems have been expressed by bus operating personnel. The main point is that evaluations of the effectiveness of TRD must consist of an objective weighing of both advantages and disadvantages. At the present early stages of development of TRD, there are usually responsible people who will advocate either side of the issue. In the long run, though, we believe that TRD will be widely used in AVM, site location (Section 2.6), and other land positioning applications.

2. ADDENDUM TO FIRST INTERIM REPORT

2.1 POLICE CAR FLEETS

Among the potential users of a TRD system that were identified in an earlier report (Reference 1), it appears that police departments are the ones most likely to implement a TRD system in the near future. Whereas, other users need to justify a TRD system on economic ground, this is not the only or even the major consideration for police departments. By far, the greater benefits of integrating a TRD system into police department operations are related to the safety of both citizens and police officers. Since deployment of such systems increases the effectiveness of the police department in responding to incidents and in curbing crime, they help to create a safer and more pleasant environment. Citizens pay the costs of these benefits in taxes, but their dollar value cannot always be determined so that justification by means of economic cost/benefit analyses is often not possible.

Many of the benefits of a complete AVM system for police department operations may be realized with digital communications and some form of computer-aided dispatching, but without the necessity of a vehicle location system.

Let us consider a police department with a good two-way voice radio system, but without digital communications, computer-aided dispatching, or automatic vehicle location. What factors might influence the department with regard to the procurement of new electronics systems? The addition of digital communications to the existing voice radio system would provide the mobile unit with the ability to transmit to headquarters a large range of "canned" messages. The police officer, in his vehicle, would be able to initiate by a key-stroke the transmission of a change of status message to the dispatcher, whereas by voice radio he might have to wait a considerable time for a clear channel. The dispatcher's CRT status display would automatically update changes in vehicle status. Thus, the dispatcher would have an efficient means of knowing at a glance the status of all the vehicles under his control. Also, each police vehicle could be provided with a teleprinter to make a hard copy of all digital communications which occur between the dispatcher and the vehicle. It is also possible to outfit each vehicle with a terminal which would allow the police officer to access the central computer directly from his vehicle. He could thus quickly obtain information on such things as potential suspects, specific addresses, and suspicious automobile license plates.

It is clear that digital communications with perhaps some level of computer-aided dispatching would increase the effectiveness of police operations by increasing the safety of police officers and citizens alike.

As a further step, an automatic vehicle location system would provide the dispatcher with real-time information about the status and the location of each vehicle under his control. This could result in a significant reduction in the time it takes for the police to respond to an incident because:

a. The dispatcher would be able to dispatch the closest available vehicle(s) to the scene of an incident.

b. Automatic vehicle location could influence a police department to effect a change in strategy by instituting inter-district dispatching, whereby a police vehicle from one district would respond to an incident in another district if it happened to be the closest available vehicle at the time.

Automatic vehicle location would provide a dispatcher with better control over his available resources. This would be especially important in the event of a major incident, such as a bombing or a bank robbery, when the precise deployment and movement of vehicles is required for such actions as intercepting a high spaced chase or sealing off a particular area.

Officer safety would be further enhanced if a silent alarm were made part of the automatic vehicle location system. In an emergency the officer would be able to key a signal to the dispatcher, either from his vehicle or from a portable unit, and the dispatcher could determine from his display where to send help.

2.2 BUS SYSTEMS

The benefit/cost ratio of AVM for buses, although high enough to justify a good deal of attention by the industry, is still low enough at this date (July 1976) to require careful thought about the proper way to develop these systems. For example, to install AVM without previous experience with radios, computers, or automatic command and control of buses is to impose too much automation on a transit property at one time. Therefore, it seems highly desirable to develop AVM in a step-by-step manner justifying each step on its own merits, and reserving automatic vehicle location as the final step in the process. If this modular approach is used, it is important in predicting the future course of AVM to identify the present status of bus command and control procedures so that progress toward AVM can be made in an efficient and orderly manner.

At present, many large bus companies are installing two-way voice radio systems with both discrete address and digital communication features. These systems provide private-line communication between the bus driver and dispatcher so that the overall efficiency and effectiveness of the service is increased. Two important features of these systems are the automatic transmission of bus ID when the driver calls the dispatcher, and the ability the dispatcher has to call any particular bus selectively. Another important feature is the silent alarm, available to the driver to summon police when help is needed. In addition, some bus properties have included automatic mechanical alarms which signal the dispatcher when malfunctions occur, such as overheating, low air (braking) pressure, and low oil pressure. Approximately 10,000 buses in 18 cities are now equipped or are being equipped with these radio systems.

Two aspects of these systems are significant in terms of AVM development. One is that the bus companies are getting into the "electronic business." That is, bus personnel are learning how to handle electronic equipment, how to maintain and service it, how to operate it, and how to use it in the most effective way to improve bus service. The other significant aspect is that these systems have a digital capability, and hence, have the potential to support an automatic location function. This addition, along with the proper computer equipment at the control center, provides all the key elements that go into the AVM system. Thus, a significant component of the AVM system (i.e., excluding the location capability) could be installed and cost-justified as a two-way, discrete address radio system with digital capability.

There are a number of reasons why AVM may be in common use for bus fleets sometime in the future. AVM is an effective way for management personnel to participate, with the driver, in the control and operation of a very expensive piece of equipment - large buses cost between $60,000 and $80,000. At some future date, electronic equipment costs may become low enough to make AVM attractive to the companies. Therefore, accepting the fact that AVM will become a reality for buses at some future date, the only question remaining concerns the proper manner for developing it. We believe the best way for doing this is the modular step-by-step approach described above. The present rather advanced communication systems being installed could be the natural stepping stome to AVM.

2.3 TAXI FLEETS

It has been the experience of taxicab companies, such as the Yellow Cab Co. of Los Angeles and the Diamond Cab Co. of Montreal, that the revenue-producing capacity of their radio dispatched cabs can be increased by the use of a computer-aided system. In addition, such systems help taxicab companies to enforce proper procedures among drivers, to prevent pirating, and to eliminate dispatcher favoritism. These benefits accrue to the taxicab companie without a vehicle location subsystem. For a taxicab company which operates a large fleet of radio dispatched cabs, such as those in

Los Angeles and Montreal, the economic benefits realized from a computer-aided dispatch system more than offset the costs of implementing and maintaining such a system.

The question arises, however, whether further benefit-cost advantages would accrue if automatic vehicle location were to be added to the computer-aided dispatch system. On the cost side, there are no avenues available for Federal cost-sharing such as those enjoyed by police departments and city transit properties. On the benefit side, the revenue producing mileage of a large fleet might be increased from the present 55 to 65 percent of the total. Another benefit, whose dollar value is hard to define, is the increased driver security that would be offered by a covert alarm and automatic location.

Since the economic benefits afforded by an AVM system over simple computer-aided dispatching are marginal, only the very large taxicab companies could make the required initial capital investment. For smaller companies, AVM would be feasible only if they could participate on a multi-used basis with systems deployed by the municipal policy and/or transit departments. This approach could be expanded to include other potential users of AVM such as fire departments and emergency service vehicles. Such a multi-user system approach could put AVM within the economic reach of many potential users who individually might not be able to justify the costs associated with a dedicated system.

2.4 U.S. POSTAL SERVICE

The U.S. Postal Service, which operates tens of thousands of vehicles, has a dispatch system which is somewhat antiquated by modern standards. The vehicles are monitored by manually plugging pins into a pegboard, where each pin represents a vehicle and the color of the pin or a tag attached to the pin represents the status of that vehicle. Table 1 (Reference 2), presents information describing the number and type of vehicles owned by the Post Office Department for the years 1966 through 1970. Precise figures for 1971-1975 are not available. However, a representative of the

TABLE 1. NUMBER OF VEHICLES OWNED BY THE POST OFFICE DEPT. (1966-1970)

Vehicles Owned by Post Office Dept.*	1966	1967	1968	1969	1970
Trucks and Tractors	36,446	38,104	41,337	45,109	45,151
Trailers	1,064	1,128	1,105	1,170	1,739
Very Light Vehicles and Mailsters**	17,759	18,144	21,688	21,497	33,510
Special Purpose and Other	1,338	1,290	1,446	1,815	1,844
Total	56,607	58,666	65,576	69,591	83,244

*Motor Vehicle Inventory.

**Mailsters are 1/4 ton, 3 wheel, gasoline engine vehicles with 500 pound maximum payload.

Postal Service indicated that they are presently operating a total of about 130,000 vehicles, approximately 108,000 of which are owned by the Postal Service, the rest being leased.

As of the middle of May 1976, the Postal Service was in contract negotiation stage with industry for the award of a Study and Design contract to determine the benefits which might accrue to the Postal Service by the implementation of a computer-aided vehicle dispatch and control system (which could include an automatic vehicle location system). The provisions of that contract require the contractor to perform a detailed requirements analysis of the Chicago Post Office, the Cleveland Post Office, and the Philadelphia Post Office. As part of this study, the contractor is to become familiar with all pertinent facets of vehicle control and dispatch at those three post offices and to perform a detailed analysis of the operation, service provided, manpower required, and deficiencies of those post offices. As a result of this requirement analysis, the contractor will then design a computer aided vehicle dispatch and control system for the Chicago Post Office. The design of the system will be such that it can be adapted to both the Cleveland and Philadelphia Post Offices. The determination as to whether the system design will include an automatic vehicle location system will be made as part of the requirements analysis portion of the study. The system will be designed to control the vehicles assigned to the post office in which the system would be installed, and those vehicles that load and unload from the docking areas. Mail box collection and private home delivery vehicles would not be controlled by the system.

To understand some of the current thinking of the Postal Service, it is interesting to note that in their RFP (Reference 3) it is stated: "It (the system) shall be modular in design to provide for installation and operation of limited system functions with the capability of expanding to full system capability." This modularity of design is a point stressed throughout this report.

The following are some examples which demonstrate the possible utility of computer aided dispatch and automatic vehicle location to Postal Service operations:

a. The Postal Service operates a significant number of large trucks and trailers. When these vehicles arrive at the docking areas to unload their mail, it often happens that they cannot be accommodated at that particular time since the docking areas are fully loaded. These trucks and trailers are then sent to holding areas. With the present manual system, the location and status of these vehicles are often improperly recorded. An automatic system for recoding this information could help to alleviate the present problem.

b. In some instances, when a large truck or trailer comes into a fully loaded docking area, provisions might be made to unload only the priority mail. Then, the partially unloaded vehicle is sent to a holding area with the intent to unload the rest of the mail at a later time. The same problem as mentioned above, of improperly recording the location and status of that vehicle is a common occurrence.

c. The Postal Service operates a number of vehicles on non-scheduled runs. Such an unscheduled run might be made when a customer calls the Post Office and reports that it has a partial truckload of mail ready to go out. The Post Office then dispatches a truck to that company to pick up the mail. It is felt that in order for the Postal Service to be able to utilize such vehicles that operate on nonscheduled runs in a most efficient manner, a computer aided dispatch system, coupled with a vehicle location capability, could help achieve that goal.

2.5 MINING OPERATIONS

A proven use of TRD is in AVM systems for large-scale mining operations. The basic purpose of these AVM systems is to minimize the idle time of expensive mining equipment in large open-pit mines, that may extend over several square miles. Trucks, shovels, and crushers are typical of the equipment used, and these can cost in the neighborhood of $300,000 to $500,000 each. It is easy to see that with investments of this magnitude, anything that reduces the idle time even a small amount would have a significant impact.

In the usual mining operation trucks form queues at, for example, shovels or crushers. The object is to try to keep all the shovels busy and to avoid a situation where many trucks are lined up at one shovel while another shovel waits idle. A central dispatcher can monitor and control the movement of these trucks if provided with their accurate locations, thereby keeping all equipment operating optimally.

This use of TRD is still quite new. There are only two examples that we know about to date, and these are discussed in Sections 3.8 and 3.9. Both were developed by provate companies, without government money. Due to the competitive nature of the mining industry, these companies consider the specifications of their AVM systems as proprietary, so that it is rather difficult to obtain detailed information about them at this time.

2.6 SITE LOCATION

The variety of vehicle location, vehicle monitoring, and vehicle identification systems, that are being developed and demonstrated throughout the United States, testifies to the growing awareness that precise radio location techniques have a useful place in AVM systems. A somewhat different application that has recently been receiving increased attention is called Site Location (or Site Registration). It involves the determination of fixed positions on land, particularly on roadways in both urban and rural areas, for the purposes of accident location, highway inventories, and the fixing of landmarks. Site registration in some form is required of state and local Governments by Federal Safety Standards as administered by the FHWA and NHTSA.

Current highway inventory files generally use a route number and accumulated mileage (mile points) from a reference for identification of segments of highway, which are defined as having uniform characteristics throughout, such as the same width, surface type, number of lanes, etc. When any of these characteristics change, the specification of the segment changes. Also, whenever construction shortens or lengthens a route, the mile points must be physically moved to the right places. With the proper kind of TRD technique, however (i.e., Loran-C or trilateration), at end points of segments could be independently identified. Construction changes would only affect segments directly connected with the construction.

3. PERFORMANCE AND COST

It is most important at the present stage of TRD and AVM development, to try to arrive at meaningful cost estimates of these systems. This importance is matched only by the difficulty in determining these figures. It is extremely difficult if not impossible to prepare simple tables of TRD costs for all potential users, as we would like. The variety of ways to using these techniques is too great, and the costs vary to the same extent. Therefore, we have chosen to give the estimated costs of typical systems, all of which are operational to some degree, and permit the reader to interpolate and extrapolate costs for any purpose he has in mind.

3.1 ST. LOUIS POLICE

In the first half of calendar year 1975, the St. Louis, Missouri Police Department, assisted by a grant from the Law Enforcement Assistance Administration (LEAA), completed Phase I of a test program for a police car location and dispatching system, developed and installed by the Boeing Co., called FLAIR™ (Reference 6). This is a dead reckoning system whose major components are shown in Figure 3-1.

The program involved the installation of dead reckoning sensors on all 25 patrol cars in one police district of the city (there are 9 districts in St. Louis) and the design and construction of a data processing and control center at police headquarters. The successful completion of the Phase I tests and demonstration has led to the implementation of Phase II of the program which will include all 200 cars of the St. Louis Police Department. The estimated completion date for the full system is September 1976.

The question could be raised as to whether FLAIR™ is a TRD system, because location is determined from data obtained in the vehicle; no radio transmissions are involved except for communication. Still, in order to use the vehicle-derived information for monitoring and dispatching purposes, a large volume of data must

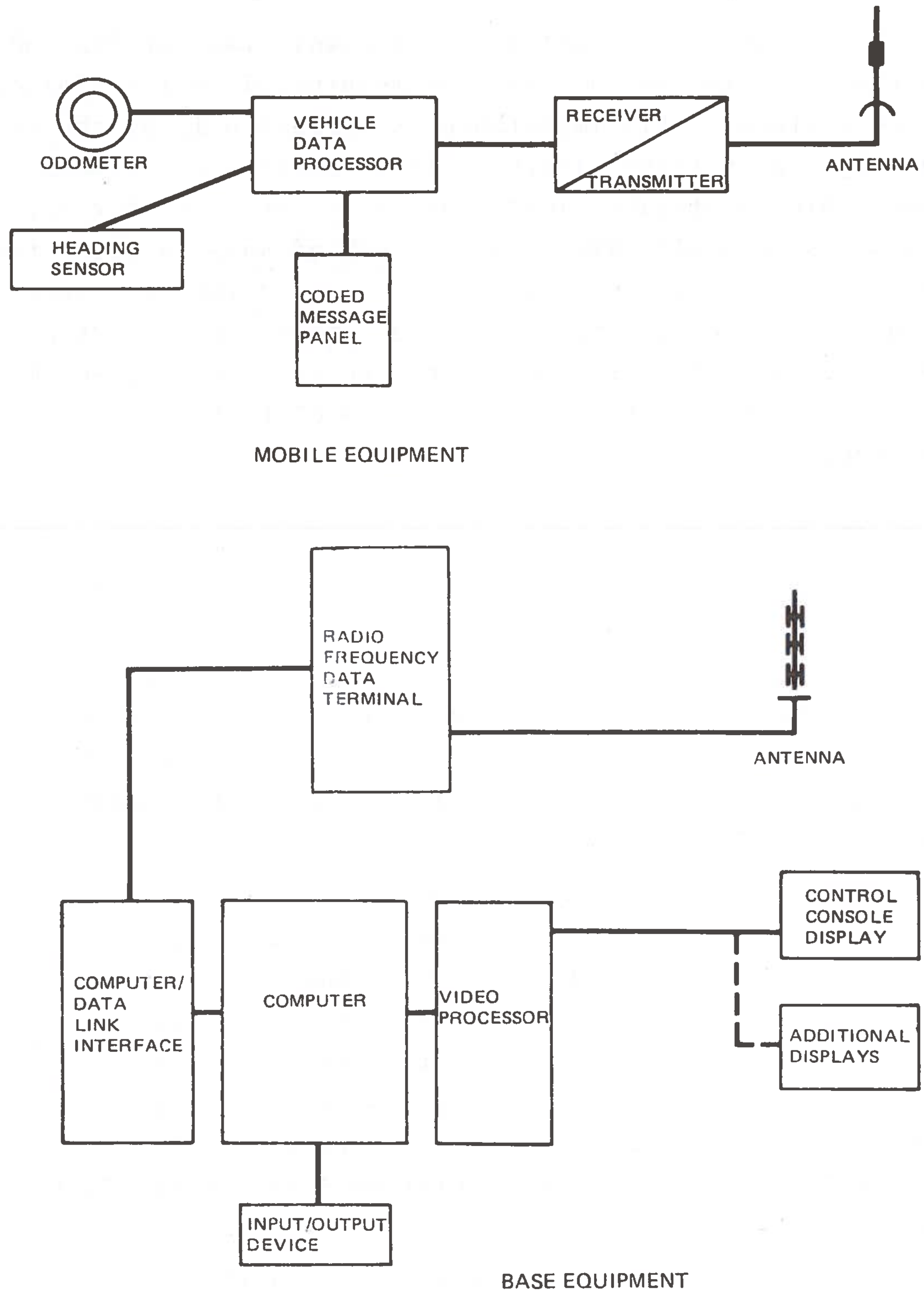

FIGURE 3-1. FLAIR™ SYSTEM BLOCK DIAGRAM

be transmitted to the command center, and there, a modern computer performs the critical functions of the overall system. Because of this use of modern electronic methods, we have chosen to include FLAIR™ as a TRD system.

The sensors in the patrol cars consist of a magnetic compass and a front-wheel odometer. The sensor outputs are processed on the vehicle, and the location data are synchronously transmitted from each vehicle to the base stations, where the data are decoded and processed for presentation on a map-matching display. The vehicles are polled every 1.22 seconds for their heading and odometer readings.

The FLAIR™ system employs a dedicated radio link between the base equipment and the mobile equipment. General Electric MASTR Progress Line 70-watt transmitter-receivers (with modifications) are used as the base equipment RF data terminals. RCA Series 700 FM transceivers (with modifications) are used as the mobile data radios. The radio equipment operates in the UHF band, in the 450 MHz to 470 MHz region. The police cars have separate GE radios for voice transmission.

In the vehicle is a coded message panel which enables the vehicle officer to transmit up to 99 two-digit codes and also indicate when emergency assistance is required. These messages, when received at the control center, are shown on the display map alongside the car identification. There is no digital communication from the base to vehicle.

The computer for the St. Louis FLAIR™ system is a dedicated Varian 73 general-purpose minicomputer. A block diagram of the computer equipment is shown in Figure 3-2. This computer system includes memory and processing units for tracking the police vehicle fleet and for operating the displays. St. Louis will have a second Varian 73 computer for backup purposes in the full system.

Dead-reckoning systems accumulate errors and need occasional resetting in order to maintain their accuracy. The St. Louis system may be set or reset in one of two ways: (1) independently by the driver of the vehicle, or (2) cooperatively, by the driver

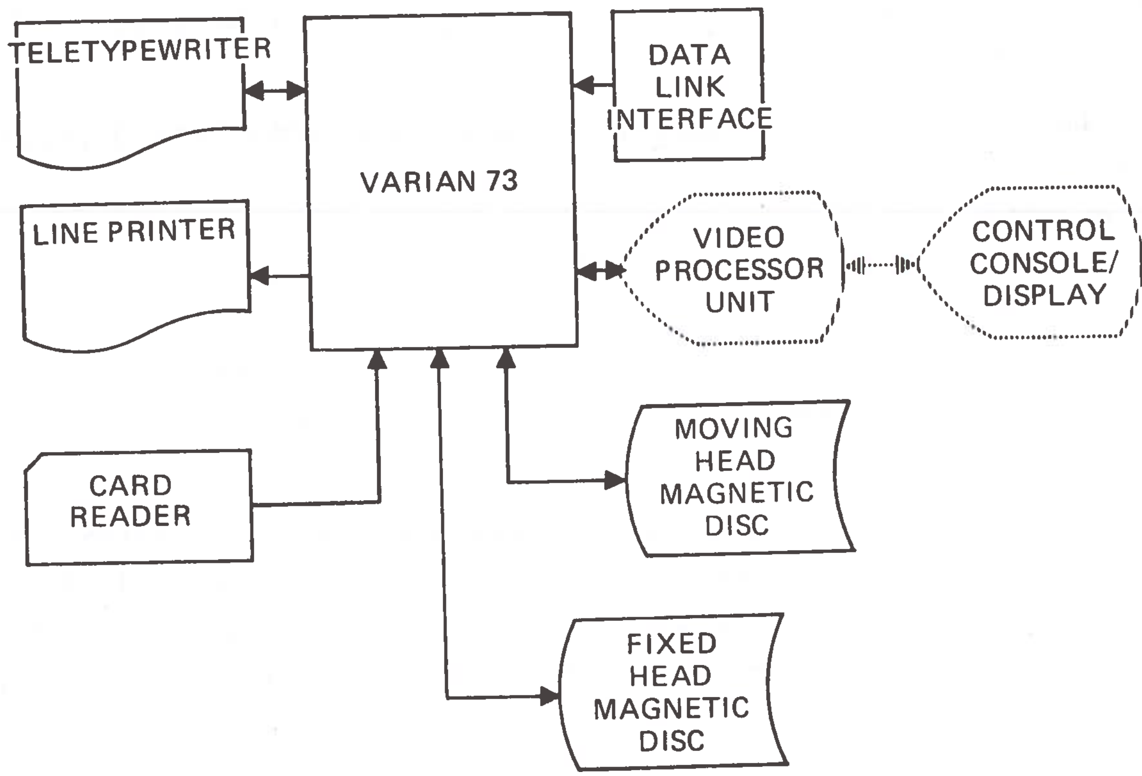

FIGURE 3-2. FLAIR™ COMPUTER SYSTEM

and the dispatcher. To set his initial position independently, the driver (at the start of a patrol, for example) proceeds to one of a number of fixed locations, and by means of the digital coded message panel transmit the location ID to the computer. During a patrol, however, the dispatcher may observe that reinitialization is necessary when the nearest reset point is inconveniently far away. In such a case, the driver can be instructed to proceed to a nearby street intersection. Upon arrival, the driver stops the car. The dispatcher then moves a visible cursor on the display to the correct location, and by pressing a button, brings the target image to the cursor. The same operation automatically enters the correct car coordinates into the computer memory. In most circumstances (excluding U-turns and a few known magnetic anomalies), an instrumented vehicle that is initialized every 6-8 hours will be within 175 feet of its indicated location 95 percent of the time. Overall, St. Louis initializes their vehicles often enough so that their average position error is estimated to be 50 feet.

When an incident is reported, the dispatcher designates the location of the incident on the display map with the cursor control. The call numbers of the four available officers in their order of proximity (the closest one listed first) are displayed in the message column. From this list the dispatcher can assign a vehicle to respond to the call.

The principal benefit of the FLAIR™ system, as reported by the St. Louis police, is reduced response time and the associated more efficient utilization of man-machine resources that result from selection of the nearest vehicle. Although the effect and value of the full city-wide system will not be known until it has been in operation for a while, it is expected that other benefits will accrue. For example, the system should improve many facets of police response to an incident because the dispatcher has full knowledge of the location and status of all the field forces, thus improving command and control of these forces. Situations such as road blocks, civil disturbances, community disaster, and burglary or robbery alarms require that a number of officers be dispatched in a timely manner to precise locations if the operation is to be most effective. Accurate, up-to-date information about the location of responding officers gives the dispatcher the strategic capability to place patrol units around the scene of the crime. Thus, he can be sure that all areas are patrolled and the placement of the patrol can be adjusted as new incident information is received.

Cost

The capital cost for the St. Louis FLAIR™ system is estimated to be approximately $4,200/vehicle, and $900,000 for the Command Center for the entire city. For a fleet of 200 vehicles, this total cost comes to $1,740,000.

St. Louis believes this system will increase their efficiency by 10 to 15 percent, which means that the system has the effectiveness of 20 to 30 more cars (with officers). If the cost of one car is conservatively estimated at $50,000/year, including personnel cost, we see that a one-time cost of $1,740,000 buys the effectiveness of $1,000,000 to $1,500,000 per year worth of police protection. If the FLAIR™ equipment is amortized over 7 years, the cost becomes about $200,000 per year, producing a cost benefit of over $800,000 per year compared to conventional police resources.

In addition to these easily identified equipment costs, there is the rather large labor effort contributed by the St. Louis police themselves. No estimates are available for these personnel costs, and it seems impossible to practically determine these costs.

3.2 MONTCLAIR POLICE

Montclair, California is a small city with a population of approximately 27,000 people, and a geographic area of approximately 5.2 square miles. The entire vehicle fleet of the Montclair Police Department, consisting of twelve patrol cars and four other vehicles, has been equippped to participate in their AVM system. The development of this system has been funded by the LEAA through the California Council on Criminal Justice.

The Montclair AVM system utilizes the proximity sensing technique with active signpost transmitters, which broadcast a digitally coded location ID to the vehicles as they come within range. The vehicle transmitter, in turn, sends this location together with its own ID to the Command Center. The three major operational functions performed by this system are: (1) vehicle location, consisting of the automatic detection and location display of police mobile units at their last detected location as these vehicles move about a geographic area, (2) status reporting, consisting of the transmission and display of coded messages between the mobile units and the Command Center, and (3) emergency signalling, consisting of transmission and display of signals generated by an officer on-foot away from his vehicle, using this vehicle to relay the emergency signal to the Command Center.

A functional block diagram for each element of the Montclair AVM system is illustrated in Figure 3-3 (Reference 4). As shown in this diagram, Wayside Emitters placed at strategic locations throughout the city, emit a signal which is detected by police mobile units. Contained in each Wayside Signpost Emitter is a repetitive code generator, modulator, and radio frequency transmitter. Each emitter transmits, via a low power radio frequency, a digitally coded location message to the passing mobile unit. The Wayside Emitters are mounted on convenient poles and light standards at fifty locations within the city, including all major street intersections. This produces a location accuracy between 600 ft and 1200 ft. Power for these emitters at present is supplied from the street lighting system. Montclair city personnel however believe that future signpost systems should be battery operated (Reference 7).

The Emergency Signalling Unit is a battery operated device approximately the size of a package of cigarettes that is worn on the officer's belt. This unit transmits an emergency to the vehicle which relays that message to the control center, where lights and buzzers alert the dispatcher. The unit is activated by the officer using a switch located on the underside of the case.

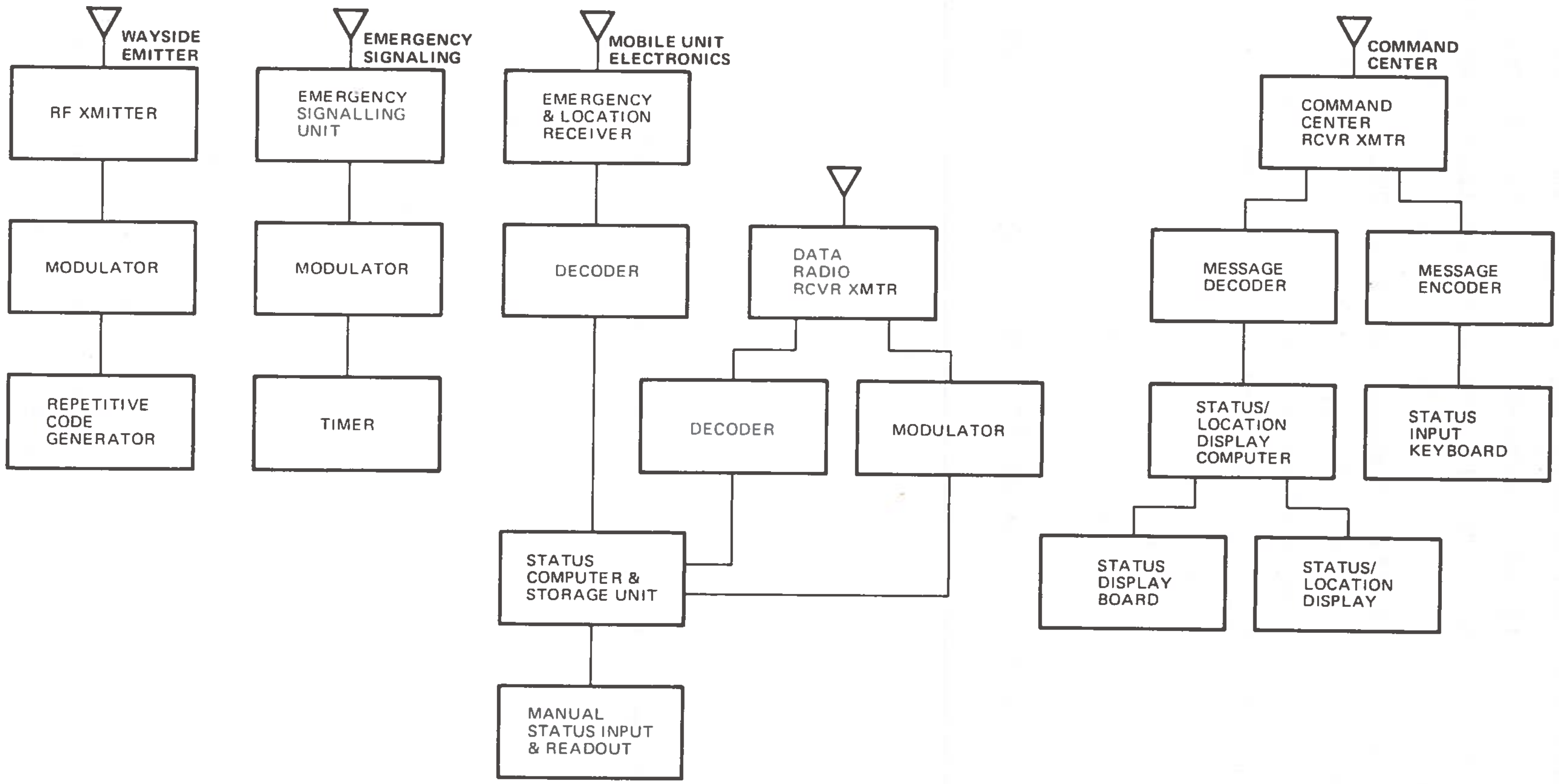

FIGURE 3-3. BLOCK DIAGRAM OF MONTCLAIR AVM SYSTEM

The Mobile Unit Electronics Subsystem consists of the officer's keyboard/display, located in the vehicle, and the electronic, computing and transceiving equipment located in the trunk of the vehicle. The keyboard/display unit consists of eight status message switches, a display showing which message has been received, and a thumbwheel device into which is set the Mobile Unit Identification Number. The truck equipment package contains a complete mobile computer system with full data management capabilities for receiving, storing, and processing location identification messages. In addition, this package provides for receiving and transmitting status messages between the Mobile Units and the Command Center, and it also accepts messages transmitted from the Officers Emergency Signalling Units and retransmits these messages to the Command Center.

The Command Center Subsystem includes a large wall display map of the city of Montclair on which the location of each mobile unit in operation is graphically displayed. On the left side of the map is listed each mobile unit number, status, location and beat assignment for use by the dispatcher and other personnel in the Command Center. When unit location and status information is received, this is displayed using light emitting diodes. With a black background and with data illuminated in red, the display produces minimal eye strain.

Mobile unit numbers, which are presented at various locations on the map, continually change and update as each unit moves about on patrol. When a unit does not move within fifteen minutes, its number flashes to alert the dispatcher.

Located on the desk top of the dispatcher's console is a keyboard/display unit. There are 24 keyboard switches which are used to specify both status message and the mobile unit that is to receive this status message. In the upper portion of this display unit is a panel which shows the latest status message received and the identification of the mobile units from which the message was received. This same status message is displayed on the large wall display mentioned above.

The Montclair AVM system has been operating since 1971, having been the first police AVM system in the country. Montclair reports (Reference 7) that the system is effective in reducing police response time. They also believe that the benefits are enough to outweigh the cost. For example, the number of calls for police assistance that have been answered (i.e., police arrival on scene) in less than four minutes, has increased from 60 to 83 percent. It is estimated that the increased effectiveness of the police force from this AVM system is approximately comparable to one additional police officer. However, it is also reported that considerable checking of locations by voice radio is done by dispatchers, suggesting that perhaps dispatchers do not yet have full confidence in the system.

The initial cost of this AVM system is estimated to be $40,000 (1971 dollars) for command center equipment, $90/signpost transmitter, and $1,000/vehicle. Maintenance costs are about $3,000/year.

3.3 HUNTINGTON BEACH POLICE

With the assistance of grants from the Law Enforcement Assistance Administration (LEAA), the Police Department of Huntington Beach, California, has been engaged in a three-phase modernization program which includes the deployment of TRD system. Huntington Beach is a medium size city occupying a geographical area about 27 square miles in extent. During the years 1960 through 1970, the population increased from 10,600 to more than 116,000 and at present is about 155,000. In addition, the city annually receives over 10,000,000 visitors to its beach. This rapid increase in population along with the large number of beach visitors necessitated a program of modernization within the police department.

The Phase I program, which was completed in December 1972, resulted in the acquisition of an operational computer-aided dispatch system. This involved the design, development, and implementation of a computerized command and control system. As part of this phase, each vehicle was equipped with a teleprinter and a digital status-entry unit.

The command center consists of two complaint writing stations and two dispatching stations. The complaint writing station has a computer terminal and a CRT display. The complaint writer enters an incoming complaint onto the pre-formatted complaint CRT display. The completed complaint is then entered into the computer. The dispatching station has a computer terminal and two CRT displays. One display is for vehicle status, the other for complaint handling. The vehicle status CRT maintains a display of the current status of all vehicles, canned messages from the vehicle, and voice radio use by all police field units. Where the status is complaint oriented, the associated complaint case number is shown in reference to the police unit number.

The Phase II program, was completed in March 1974. It resulted in the acquisition of an on-line master street data base file, which provides detail location references as well as address verification. This data base also includes sub-files relating to warrants, police hazards, gun regulations, selected criminal histories, and other investigative files which are indexed to a specific address.

As a result of interfacing the address data base files (Phase II) with the computerized command and control system (Phase I), all data maintained by the file are immediately available to the police forces. When a call comes into the police department to report an incident at a particular address, the address verification process starts as soon as the complaint writer has entered that particular address into the complaint format. Meanwhile, the complaint writer continues to enter complaint information such as informant's name, address, phone, and nature of incident. Simultaneously, the address file is being searched to determine the validity of that street address. If the address is invalid, an error message is displayed to the complaint writer, which allows immediate correction while the calling party is still on the telephone. If the address is valid, the computer will supply all the location reference data, which is then printed out on a line printer at the dispatcher's station. This information is then sent to the enroute police cars and printed out on the teleprinter in each dispatched police vehicle.

With the completion of Phases I and II its Master Plan, the Huntington Beach Police Department proceeded to Phase III, which involves the development and installation of an automatic vehicle location system. As stated in Reference 8, "This master plan provided for a building block approach. Module by module would be added, until the full system would be built, insuring upward compatibility. This plan allowed for acceleration, dependent upon the technical state of the art, and financial capability."

The Phase III program for the deployment of an automatic vehicle location system is scheduled for completion at the end of August 1976. Each of the two dispatchers will be provided with a color display which will present on a city map the location of all calls for service along with the location of all police vehicles. A zoom capability is being provided so that the dispatcher may view areas from as small as 1/4 mile by 1/4 mile square to the full city. The current status of police units and of cases will be shown color-coded on the display. When a case is called up for viewing by the dispatcher, the display will automotically place the location of the case in the center, and will zoom in to the smallest geographical area that contains what the dispatcher has determined to be the minimum number of available patrol units that should be dispatched to the scene of the incident.

The TRD subsystem is the direct proximity type. Low-power, lithium battery operated transmitter signposts, operating at 27 MHz, are mounted on utility poles. Each signpost is uniquely coded with location data. A unit within the police vehicle will receive the signpost location code. This receiving unit has three levels of sensitivity and will detect whether the vehicle is in the immediate vicinity of a signpost, within a specified outer range, or in an overlap area between two signposts. Also, a processing register, which makes use of changes in signpost signal levels, will compute the direction of vehicle motion. This location and direction information will then be stored in the unit until required by the command and control center.

The modes by which the vehicles may be polled are as follows:

a. Region Poll: When a case appears before the dispatcher, a location code, which gives the address of the incident, will automatically be sent to all police vehicles. Each vehicle's receiving unit will compare that incident location code with its last stored location, and will respond if the vehicle is located within a 2.5 mile by 2.5 mile square centered about the incident. The vehicles so located respond back in a queue, the ordering within the queue being governed by a random number scheme. If the required minimum number of available police vehicles are not in that 2.5 mile by 2.5 mile area, then the system automatically switches to a larger region of the city and repeats the process. This procedure continues until the required number of available vehicles are located.

b. Maintenance Poll: Approximately every 20 minutes, all the police vehicles will be polled for maintenance purposes to determine whether each vehicle's receiving unit is operating properly.

c. All Vehicle Poll: Anytime the dispatcher wishes, he can poll the entire fleet, and the location of all the vehicles will appear on the full city map of the display.

d. Individual Vehicle Poll: The dispatcher can determine the location of a particular vehicle. The display will automatically focus on the 1/4 mile by 1/4 mile square area centered about that vehicle.

e. Automatic Tracking Mode: This mode is used to track a vehicle in a situation such as a high-speed chase. The mode can be initiated either by the police officer's pushing the emergency button in his vehicle, or by the dispatcher. A blinking red light will appear on the dispatcher's display to identify that vehicle. Each time the vehicle's receiving unit gets a new signpost update, that location information will automatically be sent to the command and control center and appear on the dispatcher's display.

The system will comprise 520 signposts. The Huntington Beach Police Department will be equipping their 38 patrol vehicles

(vehicles used by uniformed policemen) for automatic vehicle location. Other vehicles such as staff vehicles, detectives vehicles, and utility vehicles will not be so equipped. The location accuracy is anticipated to be such that 50 percent of all position determinations will be within 300 feet of the correct location, 95 percent within 600 feet. In addition, it is required as part of the system specifications that a vehicle not be able to driven more than 1/4 of a mile in the forward direction without receiving a signpost update.

The total "turn-key" project cost for Phase III is $238,900 of which LEAA, through the California Council on Criminal Justice (CCCJ) is funding $226,955. The vehicle location electronics will be interfacing with the vehicle's existing UHF two-way radio. As part of the contractional arrangement which Huntington Beach has with the vendor, additional vehicle location units can be purchased in 1974 dollars for $900 per unit, and additional signposts can be purchased in 1974 dollars for $250 per signpost.

3.4 CHICAGO TRANSIT

The Chicago Transit Authority (CTA) installed an AVM system on part of its bus fleet in 1971, being the first transit property in the country to do so (Reference 10). The system was built by Motorola for demonstration purposes and not as a full-scale operational system. Seven hundred buses were equipped for this system which used 120 signposts supplemented by dead reckoning.

The major subsystems of the Chicago system are: the signposts, the bus location equipment, the control center, the bus interrogation mode equipment, the bus alarm equipment, and the voice communication equipment.

The signposts consist of low-power radio transmitters operating in the 150.8 to 162 MHz frequency range. These signposts are located at various points along the bus routes. The principal elements of the signpost location transmitter are shown in Figure 3-4.

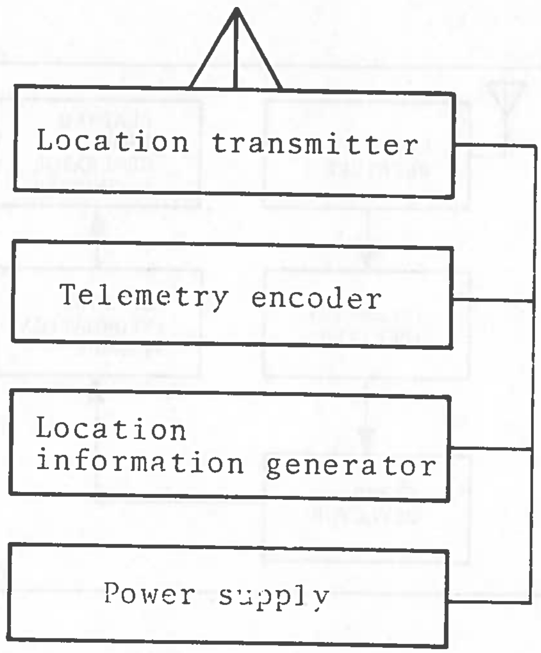

FIGURE 3-4. SIGNPOST LOCATION TRANSMITTER

Each signpost has an associated location information generator which continuously generates, in digital form, the number which has been assigned to the location transmitter site. The number that is generated consists of ten digital pulses (10 bits), which are converted into tones by a telemetry encoder. The tones are then used to modulate the location transmitter in a manner identical to voice modulation. The signal is radiated at low-power with range of approximately 200 feet, thereby preventing accidental receptions from remote transmitters.

The number of the location site is received repeatedly by the bus, while it is within the transmitter range. A block diagram of the bus location equipment is shown in Figure 3-5.

After the location site data has been received by the bus and checked for correctness by the error detector, it is fed into the location storage device, where it is retained until another correctly received number replaces it.

An elapsed time generator is used in conjunction with the location storage circuitry. This device consists of an accurate 12 second timer and a digital counter. After each new location

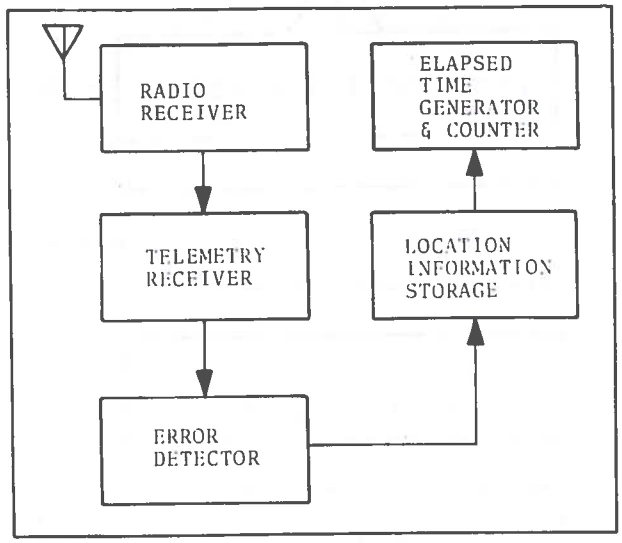

FIGURE 3-5. BUS LOCATION EQUIPMENT

site number is entered into the storage circuitry, the elapsed time generator is reset and begins counting the number of 12 second intervals that have occurred since the last entry. The current number of 12 second intervals is transmitted with the location site number whenever the bus is interrogated by the control center. In this way, the control center knows, within 12 seconds, how long ago the bus passed that reported location site.

When the system is in the location mode, the control center interrogates each bus in turn for its location information, consisting of location site number and elapsed time count. The system was designed to interrogate all 700 buses every two minutes.

The heart of the control center is a digital computer, which contains the schedule of the bus system in memory. Using this schedule, the computer provides, at the proper time, the run number of each bus to be interrogated, and compares the data returning from the bus with the schedule. If a bus is not on schedule, this fact is shown on the visual display available to the dispatcher, who then can take corrective action. A functional diagram of the control center is shown in Figure 3-6.

The location data retrieval process begins when the computer provides the vehicle address generator with the identification number of the bus to be interrogated. This identification consists

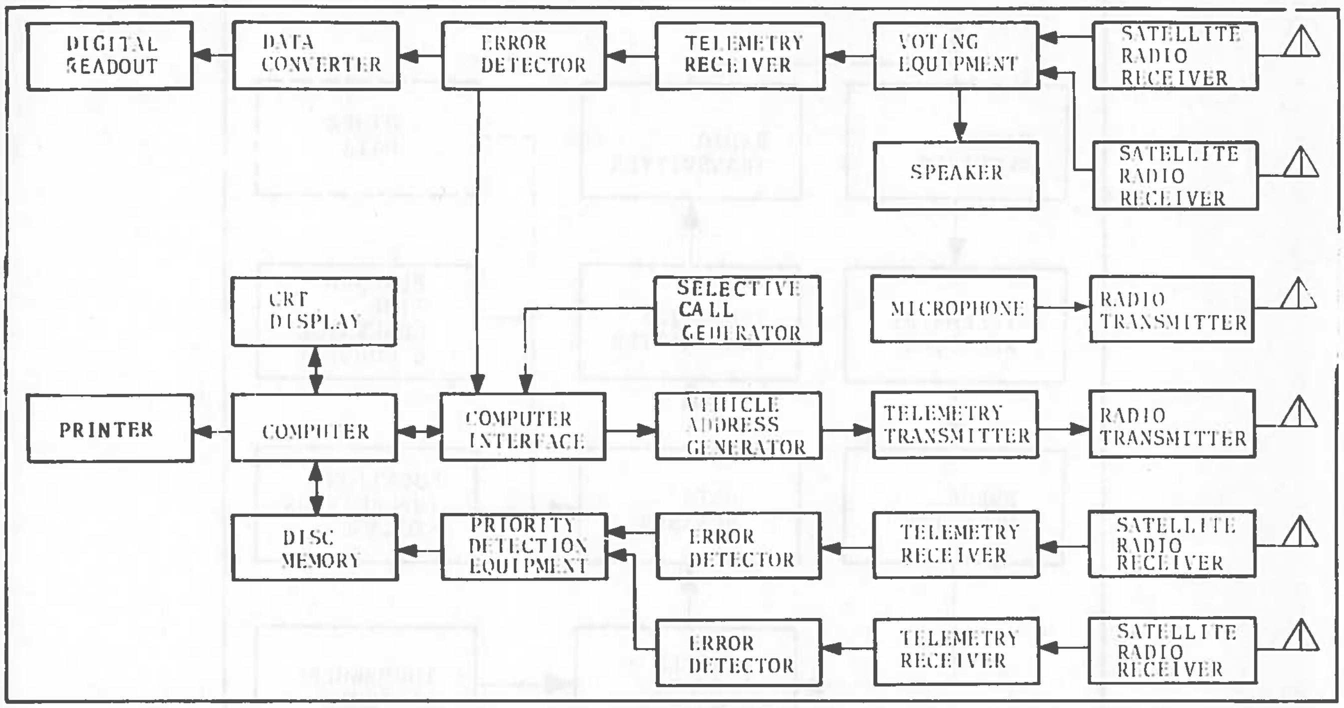

FIGURE 3-6. BLOCK DIAGRAM OF CONTROL CENTER

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of five digits, three for run number, and two for the garage from which the bus originates. The output of the vehicle address generator is a series of digital pulses, which are converted into tones by the telemetry transmitter, and are in turn used to modulate the data transmitter.

A block diagram of the interrogation mode equipment in the bus is shown in Figure 3-7. The received signal is converted into tones, which are converted into digital pulses. The error detector verifies that the message has been received correctly. If it has, then this received identification number is compared with the setting of the thumbwheel switches (run number) and the prewired garage number in the bus. Each time the driver begins a new run with his bus, he sets the run number into three thumbwheel switches accessible to him.

When these two numbers are the same, the comparator activates the data transmission process in the vehicle. The information stored in the location storage circuitry and the elapsed time generator are transmitted to the control center. While the data is being scanned, no new location information can enter the location

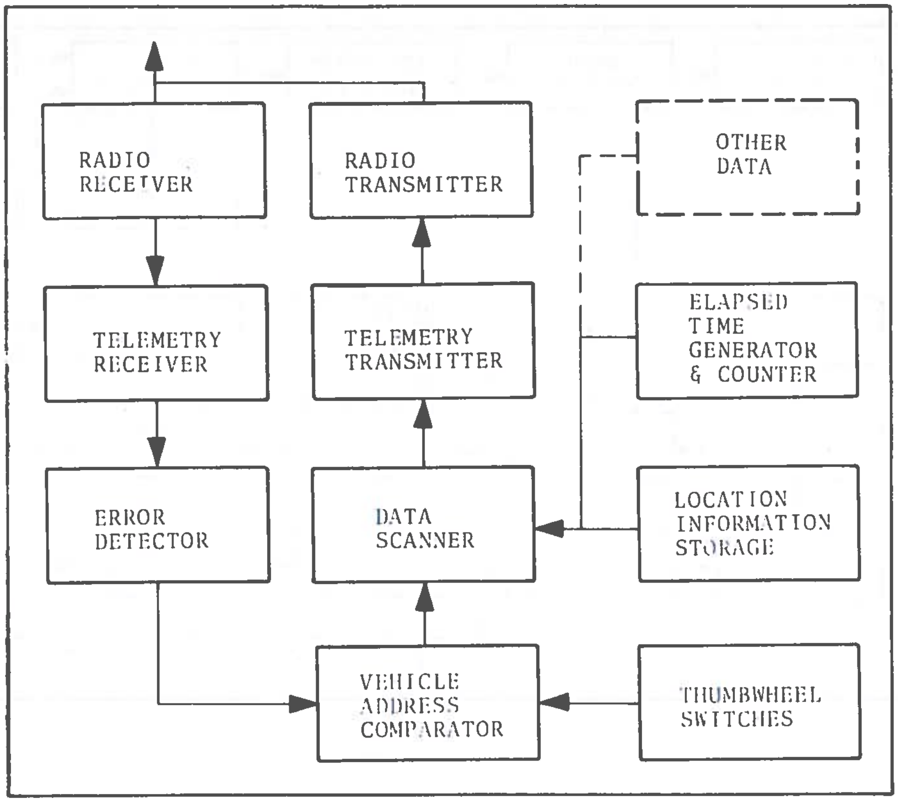

FIGURE 3-7. BUS INTERROGATION MODE EQUIPMENT

data storage circuitry, thereby preventing the transmission of a location number which has been only partially received by the bus.

The mobile transmitters have less range than the control center transmitters due to their smaller output power and lower antenna height. To overcome this problem, several satellite receivers are located throughout the city and are connected to the control center by leased telephone lines.

The alarm feature is used whenever the bus driver encounters an emergency situation and cannot safely communicate by voice. This alarm is covertly activated by the driver by means of a foot switch. A block diagram of the vehicle equipment for the alarm system is shown in Figure 3-8.

When the alarm switch is depressed, the voice channel is activated and the data scanner is started. The vehicle identification number and location information are sent by the voice transmitter to the control center in the manner described for the interrogation mode equipment. The alarm message from the bus is repeated continuously for a period of two minutes to insure that it is properly received. When an alarm is received at the control center, an audible alarm is activated to alert the dispatcher.

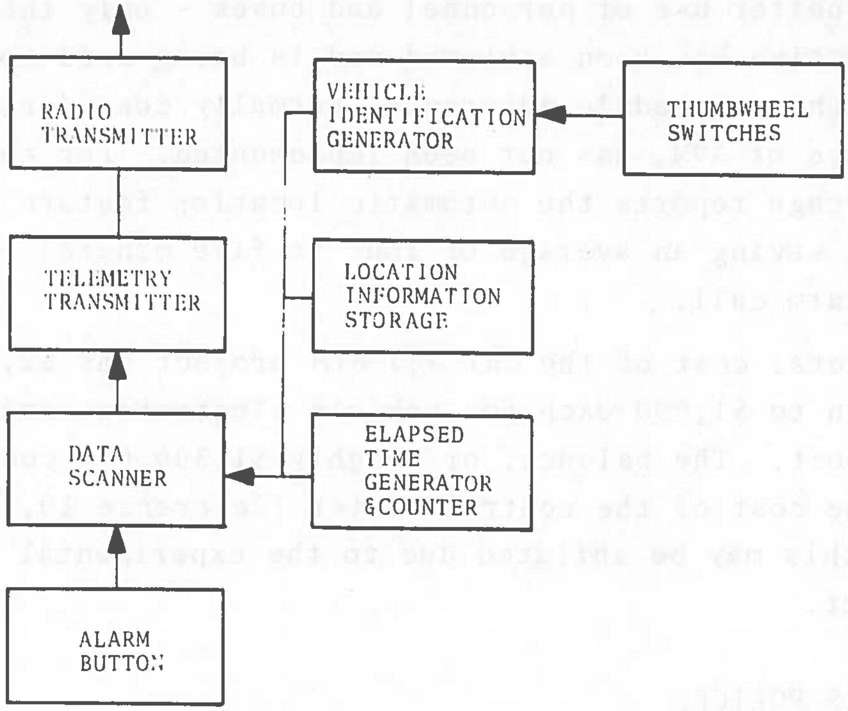

FIGURE 3-8. BUS ALARM SYSTEM

The dispatcher then calls the police and directs a supervisory car to proceed to the bus.

The Chicago system includes the capability for normal voice communications. This can be initiated either by the dispatcher or the bus driver. The dispatcher can contact a specific bus by selecting its identification number on the selective call generator located on the console (See Figure 3-6). This call signal is injected into the interrogation data stream. Voice communication is originated in the bus when the driver removes his handset from its hang-up box and depresses the push-to-talk button. If voice communications are occurring while a bus is being interrogated, the bus will not receive the data interrogation and therefore will not reply for that interrogation cycle.

That part of the Chicago system not pertaining to automatic location is now designated by Motorola as METROCOM™.

The above description is of the original system design, which is now only partially operational. Considering the six objectives of the original project (Reference 10, page 2) - (1) schedule adherence, (2) display by exception, (3) emergency alarm, (4) record data for future analysis, (5) better utilization of radio frequencies, (6) better use of personnel and buses - only the emergency alarm objective has been achieved and is being used today, and then only at night. Schedule adherence, normally considered to be the main purpose of AVM, has not been implemented. For the emergency alarm, Chicago reports the automatic location feature to be very effective, saving an average of four to five minutes response time on each alarm call.

The total cost of the Chicago-AVM project was $2,310,860. This breaks down to $1,890 each for vehicle electronics and $317 for each signpost. The balance, or roughly $1,300,000 could be considered the cost of the control center (Reference 10, page 108), although this may be inflated due to the experimental nature of the project.

3.5 DALLAS POLICE

The Dallas, Texas Police Department, with the assistance of a grant from the Law Enforcement Assistance Administration (LEAA), has contracted for a pulse trilateration TRD system which employs a radar beacon transponder. Since December 1975, Phase I of the system procurement has been underway, with approximately $761,000 being expended. This is to be a wideband system operating in the 904-912 MHz band allocated by the FCC for this type of operation. The initial implementation will be in one district (the Southwest Patrol District) which encompasses 78 square miles and will include the equipping of 43 patrol vehicles. The entire city of Dallas will require 700 vehicles, and it has been estimated that, in production, the equipment will cost $1,500 per vehicle. This automatic vehicle location system will also include communications (digital capability will be added to relieve VHF channel crowding) and out-of-car devices, which will be discussed below. The system is to be integrated with the City's existing Computer Assisted Dispatch System (CADS). The TRD system is being designed with a capacity which will enable expansion, at a future date, to full city coverage of 300 square miles for a fleet of 700 vehicles. (The system will actually have the capability of servicing 5000 vehicles.) The system was designed originally to provide a location accuracy of 75 feet, at a 95 percent confidence level for stationary vehicles. The time interval between location updates will be 2 seconds. Phase II of the procurement, to begin approximately January 1, 1977, will require an accuracy of 300 feet both fixed and moving vehicles. Phase II will last about one year.

In addition to vehicle monitoring, police officers will wear on their equipment belt an emergency signalling device which, when activated by the officer, will remotely activate equipment in the officer's vehicle to automatically relay an emergence code to the base station. This belt-worn unit will be battery powered with a range from the car of at least 1/4 mile under normal circumstances.

The principle of system operation is as follows: A central transmitting station will initiate a roll call synchronization signal which will trigger pre-programmed electronic clocks in each vehicle's transponder. During its unique time slot, each transponder will emit a response consisting of radar location pulses along with a series of data pulses. This data will contain information such as emergency alarm, operations status, and equipment condition. During the front part of its time slot, a vehicle can receive data messages from the base station.

The vehicle's transponder response is collected by three or more receiving stations, where each receiving station measures the time of arrival of the vehicle's radar location pulses and relays the data to the base station via telephone lines. At the base station, a computer algorithm chooses the optimum three receiving stations to use for computation by minimizing the geometric dilution of precision (GDOP) effect. The computer then calculates the difference in time of arrival of the radar location pulses between 2 pairs of receiving stations, and locates the vehicle at the intersection of the hyperbolic lines of position. There are to be a total of seven receiving stations within the initially implemented police district.

In summary, the system includes communication coverage and out-of-car devices in addition to location. Under Phase I, equipment for a control center will also be procured. This consists of a minicomputer, modems, transmitter, and display. Estimated cost of the control center is $75,000-$100,000, which does not include software.

3.6 TWO-WAY RADIOS WITH DIGITAL CAPABILITY

Two-way voice radios with discrete address and digital communication features have proven to be very effective for large bus fleets. In recent years, 10,000 buses in 18 cities have been equipped with these systems. The most widely used is the METROCOM™ system, manufactured by Motorola. Since the METROCOM™ system has the potential to support a TRD function (see Section 2.2), it is important to understand clearly how METROCOM™ works.

METROCOM™ systems are tailored somewhat to the requirements of each bus fleet, and hence, they may be slightly different from fleet to fleet. However, they are all basically the same, and since Baltimore's system with 1021 buses is typical for large fleets, it provides the example described below.

The METROCOM™ communications system provides for both voice and data communications between buses and the dispatcher. Some key features of the Baltimore METROCOM™ system are: two-way voice communications, selective calling, and emergency silent alarm. A bus sensor alarm to monitor mechanical malfunctions, such as low oil pressure, hot engine, and low air pressure, is present on some bus fleets, but Baltimore does not have this feature.

Figure 3-9 shows a bus driver using the METROCOM™ system telephone in the use.* He has three modes in which to communicate with the dispatcher: the regular mode, the priority mode, and the silent alarm mode. The regular mode is used for normal conversation with the dispatcher and is done by simply speaking into the handset as shown in the picture.

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*The photographs in this section were provided by the Mass Transit Administration, Baltimore, MD.

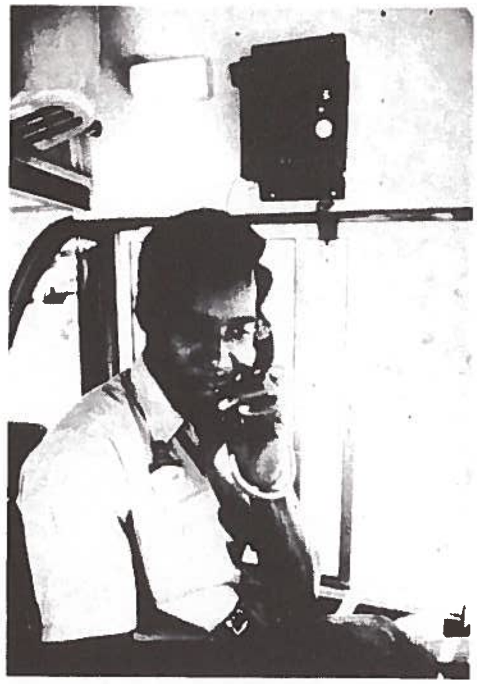

FIGURE 3-9. BUS DRIVER USING THE METROCOM™ HANDSET

The priority mode is used by the driver whenever he has a priority message to convey to the dispatcher, such as an illness on the bus. This is activated by pressing the "Priority Call" button on the handset control unit shown in Figure 3-10. In this mode, the dispatcher will interrupt his regular mode calls and will talk specifically to this driver.

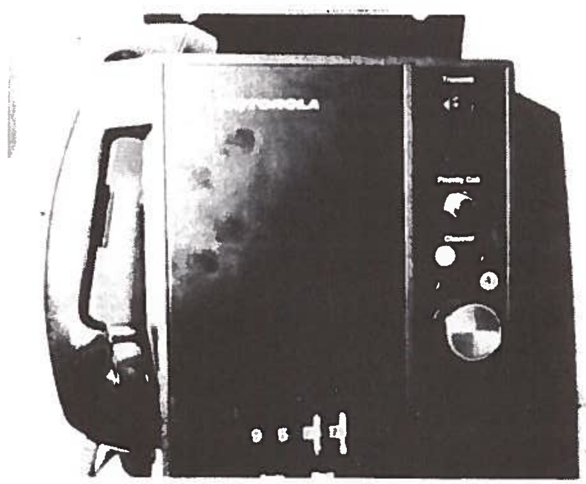

FIGURE 3-10. HANDSET CONTROL UNIT

The emergency silent alarm is activated when the driver depressed a foot-switch. No conversation takes place. An audible signal is triggered at the dispatcher's console, and a record is made of the event on the printer, shown in Figure 3-11. The dispatcher then estimates the position of the bus, by referring to

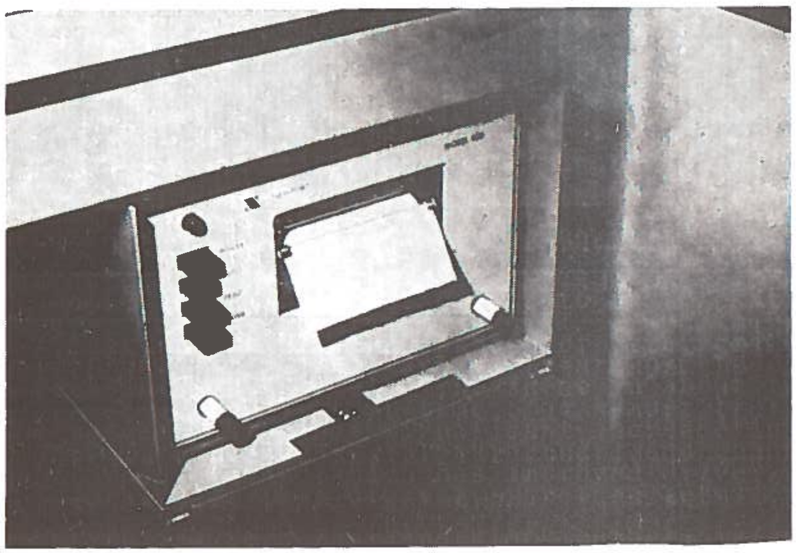

FIGURE 3-11. PRINTER AT THE DISPATCHER'S CONSOLE

the schedule book, and summons the police to that location. By this quick, silent reporting of a robbery or other crime on a bus, police have been able to arrive at the scene in about two to five minutes. The result has been a significant increase in the number of arrests and prosecutions, which has improved driver and passenger security.

The dispatcher works at the console shown in Figure 3-12, which includes the tape printer shown in Figure 3-11. A permanent printed record is made of all incoming calls. Routine calls are printed in black and emergency alarm calls are printed in red. This permanent record consists of time, bus number (for emergency alarm calls only), route number, block number, and channel number. One of the advantages of this digital system in terms of efficiency is that the bus ID (route number and block number) is automatically (and instantaneously) transmitted on every call made to the dispatcher. The driver sets the bus ID into the handset control unit by thumbwheels.

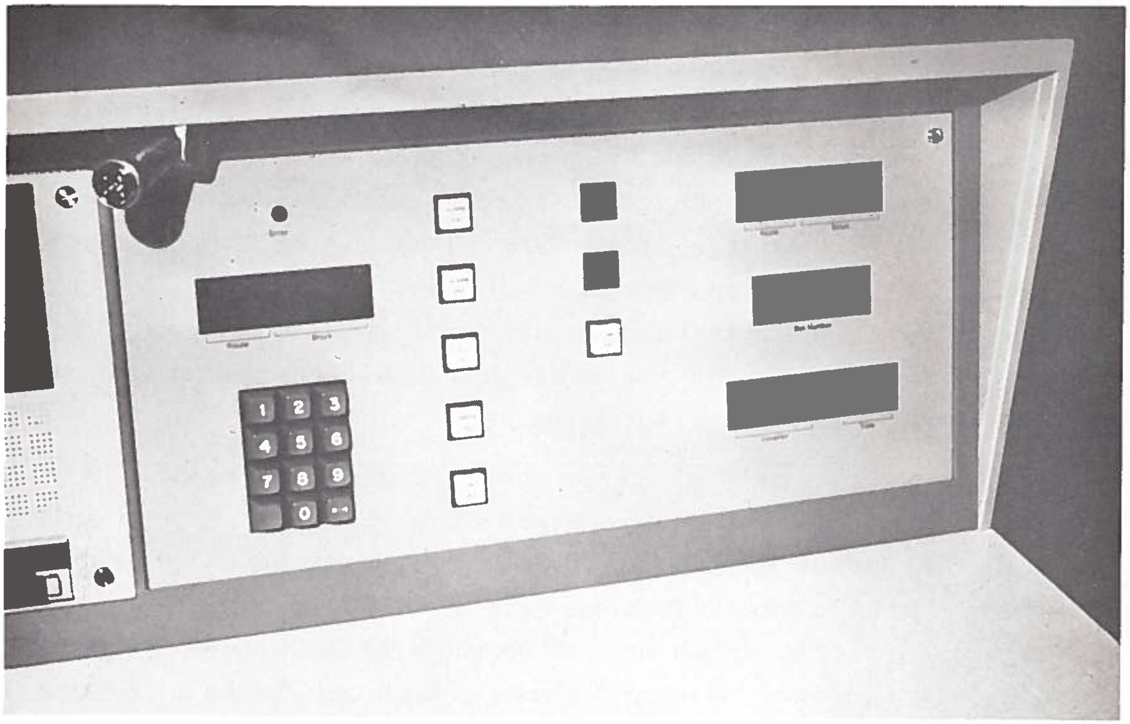

FIGURE 3-12. DISPATCHER'S CONSOLE

An important feature of the METROCOM™ system is the ability for selective calling. The dispatcher can call individual buses, in the manner of a private telephone line. He can also call a group of buses, or all the buses in the fleet at one time.

In determining the location of the bus when the emergency alarm is sounded, a computer could be used to interrogate the schedule, as in Washington, D.C., instead of the manual method used in Baltimore. This could increase the speed of responding to such calls. Given the time, route number, and block number, an estimate can be made of where the bus should be by referring to the schedule. This has proven to be accurate enough to be effective. However, with TRD the exact location can be known (within a few hundred feet) at all times, and the police can be directed more accurately to the affected bus.

The cost of the METROCOM™ system is approximately $2000 per bus.

3.7 ST. MARYS RIVER NAVIGATION SYSTEM

Navigation through confined regions of the Great Lakes waterways system can be accomplished only during seasons when the waterway is not blocked by ice, and then only in weather that permits visual pilotage. For this reason, shipping activities are usually syspended on the Great Lakes from mid-December to early April and in all seasons at times of poor visibility. For a number of years, various attempts have been made to find ways of extending the navigation season by ice-breaking, but the basic all-weather navigational problem remains unsolved.

One heavily traveled route where precise navigation is required is along the St. Marys River from Whitefish Bay in Lake Superior to Detour Passage in Lake Huron, a distance of about 50 miles. This waterway, shown in Figure 3-13, is used by the Great Lakes ore carriers, which may be as much as 1000 feet long and 100 feet wide. In river channels whose widths vary from a maximum of 2000 feet to a minimum of 250 feet, the required positional accuracy with respect to the channel centerline may be as great at 25 to 50 feet.

In order to determine whether navigational accuracy of this order can be achieved by a carefully designed LORAN-C system, the U.S. Coast Guard has installed a "mini-chain" of LORAN-C transmitters to provide coverage along the river passage (Reference 9). The transmitter chain consists of four low-power stations in a diamond-shaped configuration. The navigational equipment uses an AN/SPN-45 Receiver and an HP-9100B Programmable Calculator. These drive remote displays which provide position and velocity information to the ship's navigator and conning officer.

Navigational guidance is provided to ships in terms of a series of 25 way-points connected by straight track line segments (refer to Figure 3-13). The route is pre-stored in the memory of the calculator as a set of time differences from the mini-chain transmitters. This information is compared with the receiver output and the results are displayed as cross-track error, cross-track speed, along-track speed, and distance to the next waypoint.

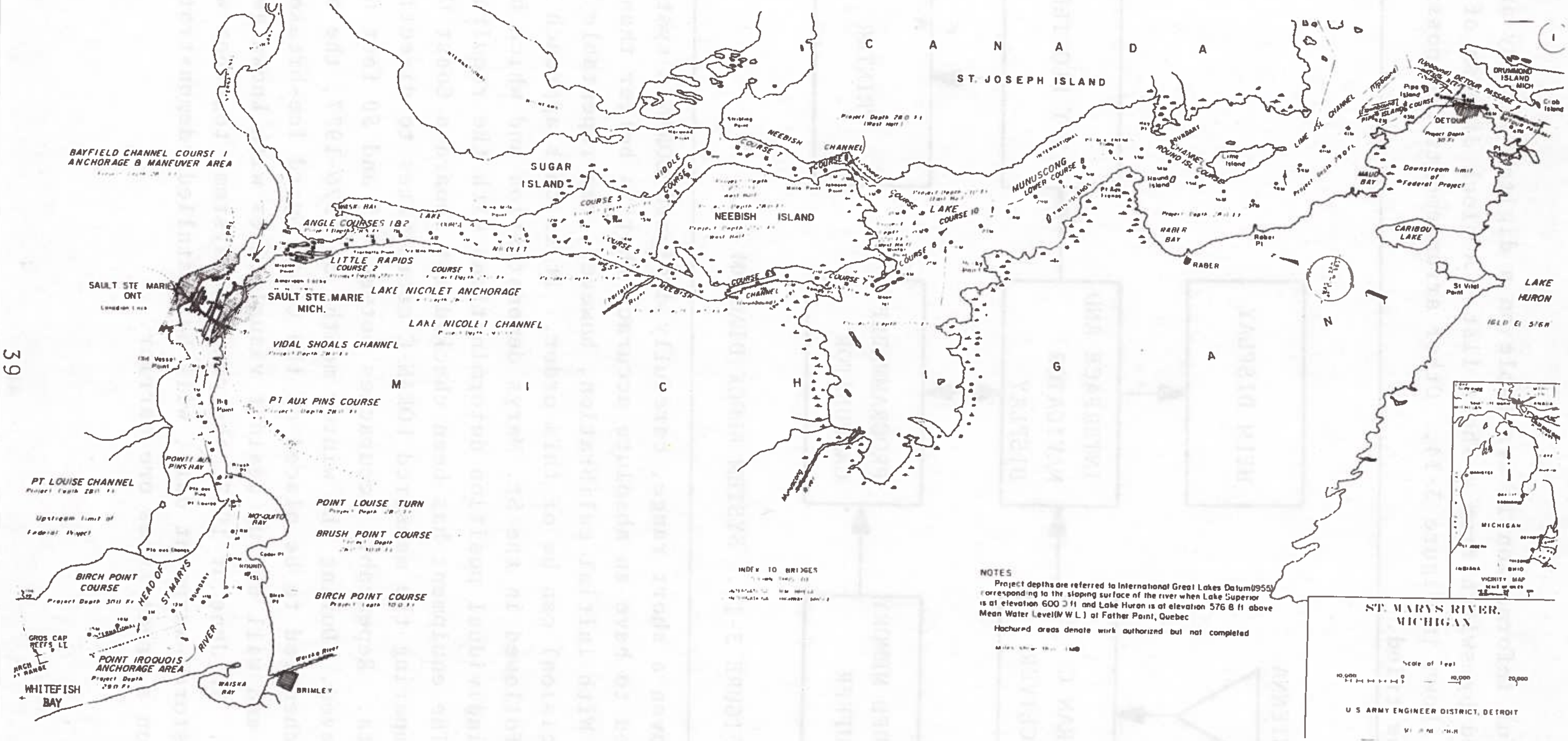

FIGURE 3-13. ST. MARYS RIVER, MICHIGAN

Other useful information is available on a digital display and may be selected by switch from a short list. A block diagram of the system is shown in Figure 3-14. Other arrangements are possible and will be tried.

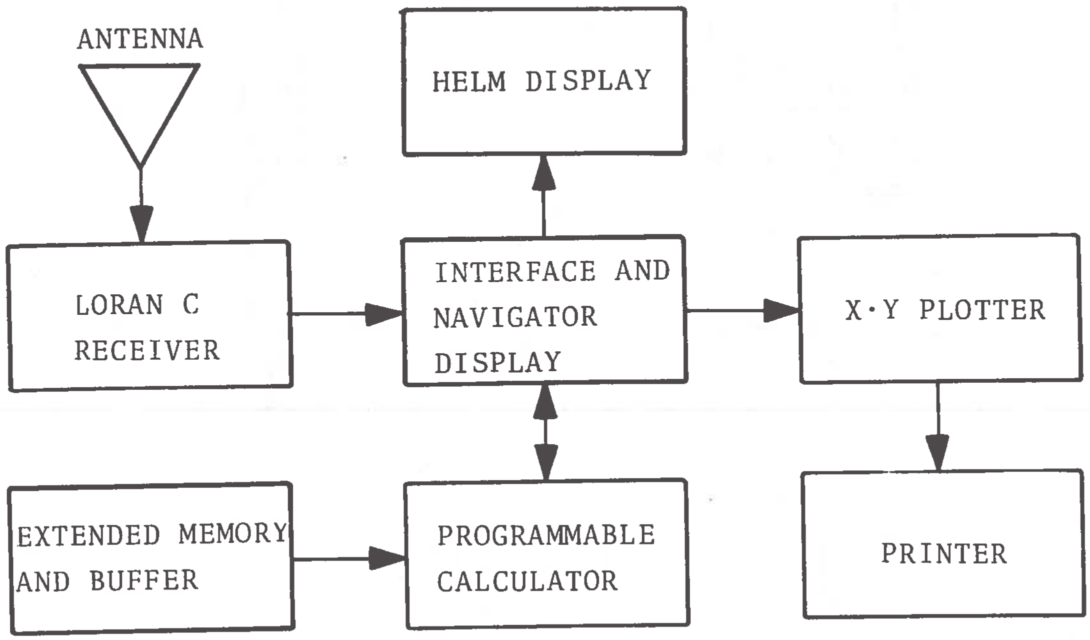

FIGURE 3-14. SYSTEM BLOCK DIAGRAM

Not even a short range, carefully designed LORAN-C system can be expected to have an absolute accuracy that is better than about 50 feet. With initial calibration, however, the repeatable accuracy (precision) can be of this order. It is this approach which is being followed in the St. Marys demonstration and which has produced individual position determinations with the required precision. The equipment has been checked out aboard a Coast Guard tug by comparing the measured LORAN-C coordinates to direction finder data. Repeatable accuracies between 25 and 50 feet have been achieved. During the winter months of 1976-1977, the equipment is scheduled to be placed on the Coast Guard Ice-breaker "Makinaw" and will be run against visual fixes with known geodetic locations. In June of 1977, the complete system, together with computer-stored waypoint data, will be installed, demonstrated, and verified on a Great Lakes ore carrier.

Total cost of the user equipment for this system, including hardware procurement (receiver, computer, and disc memory) and software development was about $100,000. It is worth noting, however, that the receiver itself, in quantity production, will probably cost less than $3,000 per unit.

Since the LORAN-C signals from the mini-chain are also available on the landside of the St. Marys River, the Coast Guard is presently preparing a coverage diagram for potential users on land

3.8 ANACONDA COPPER MINE

The Anaconda Copper Co. installed an AVM system in 1974 at a large open-pit copper mine in Butte, Montana. The mine measures approximately one mile across and one-half mile deep.

The basic purpose of this AVM system is to control the ore trucks so as to minimize equipment idle time. There are 16 shovels and 150 trucks involved in the operation. These are large, very expensive pieces of equipment. The trucks form queues at the shovels and the object is to avoid having no trucks ready for one shovel while idle trucks are lined up at another. There is a dispatcher who coordinates the movement of the equipment, but since the area involved is so large, he can not do this visually. Hence the need for AVM along with voice radio.

The contractor for the Anaconda system was DYNIMAN Inc., a subsidiary of Information Systems, Inc., the same contractor that built the Montclair police AVM system. It uses 35 signposts, called emitters which are portable and solar powered. The computer at the control center is a Jumbo Alpha 16 minicomputer, made by Computer Automation Co.

The estimated cost of the electronic equipment for each truck is $3500 to $5000, including the radio. The emitters are $200 each. The hardware cost for the control center is $75,000, including computer, and the software is approximately $40,000. No further information is available about this Anaconda AVM system at this time.

3.9 QUEBEC CARTIER MINING CO.

An AVM system is being developed for the Quebec Cartier Mining Co. (U.S. Steel) in Labrador. The contractor is Systems Control Inc. of Palo Alto, California. The open pit ore mine employs 20 shovels, 38 trucks, and 2 crushers. As in the Anaconda Mine system, the goal of this AVM system is to minimize idle time of equipment.

The system comprises 37 signposts, 17 at wayside locations and one at each shovel. The computer is involved in all aspects of the mining operation including scheduling lunches, scheduling refueling, clearing pits for blasting, reassigning vehicles after blasting, and other tasks. The signpost transmitters are made by the Hoffman Co. The vehicles are polled every 4 seconds, and transmit at the rate of 1200 bits/sec. The signpost identification code consists of 16 bits.

Phase I of this experimental project has been completed. This consisted of equipping 2 vehicles only. The next phase is to develop a fully operational system with completion scheduled for May 31, 1977.

The estimated cost of this AVM system in $400/transmitter, $2000 each for vehicle electronics including a GE radio, and $810,000 for computer, displays, software, and all the command center. No further details are available about this system at this time.

4. COST SUMMARY

The cost estimates for the systems described in Section 3 are listed below in Table 2. It should be stressed that these are systems that are or will be operational to some degree. By considering cost data on systems that have actually been built, one can get a more accurate picture of the cost of TDS systems. Although these costs are the best that could be obtained at the present time, they should be considered only as very rough estimates. The data are in dollars at the time the system was built - no attempt was made to correct for inflation. One should be aware that although inflation increases prices, there is the counter force of advancing electronic technology which will reduce prices (note the recent reduction in price in hand calculators).

TABLE 2. COST ESTIMATES

	Cost Per Vehicle for In-Vehicle Electronics	Number of Vehicles	Cost Per Signpost	Number of Signposts	Cost of Control Center
St. Louis Police	$4,200	200	NA	NA	$900,000
Montclair Police	$1,000	15	$ 90	50	$ 40,000
Huntington Beach Police (1)	$ 900 (2)	37	$250	480	$ 84,700
Chicago Transit (3)	$1,890	500	$317	120	Uncertain
Dallas Police	$1,500 (5)	43	NA	NA	User Dependent (6)
Two-Way Radios with Digital Capability	$2,000	Any Number	NA	NA	Minimal
Anaconda Copper Mine	$4,250 (4)	150	$200	35	$115,000
Quebec Cartier Mine	$2,000	46	$400	37	$810,000

(1) Total project cost is $238,000.
(2) Assumes Motorola-Micord ratio already installed.
(3) Total project cost is $2,310,860.
(4) Actually represents a range of $3,500 to $5,000.
(5) Projected cost for production.
(6) A probable range is $100,000 - $500,000

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