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TERRESTRIAL RADIODETERMINATION POTENTIAL USERS AND THEIR REQUIREMENTS

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INTERIM REPORT

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16. Abstract

This interim report summarizes information gathered during a preliminary study of the application of electronic techniques to geographical position determination on land and on inland waterways. Systems incorporating such techniques have been called terrestrial radiodetermination (TRD) systems. Their most common application has been to locate and track a large number of vehicles in real time. These and other potential uses and requirements are identified and discussed.

The final portions of this report describe the design and operation of a number of TRD and TRD-related systems that have been or soon will be deployed for demonstration. Most of these systems are associated with the computer-aided dispatching and monitoring of either municipal police car or bus fleets.

The benefits and limitations of these systems, as determined by their users, are presented for consideration

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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.

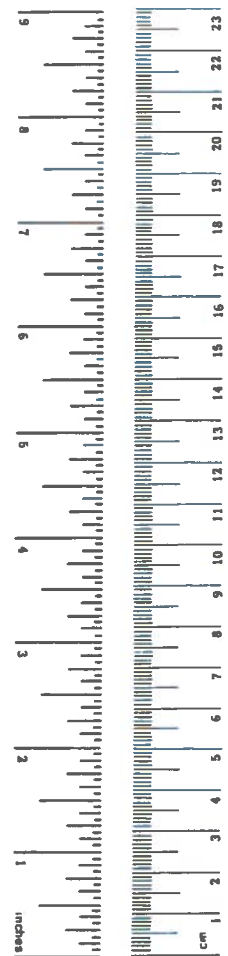
This report documents one portion of an effort to define the federal role in the area of land navigation and position determination. Leaving aside the support of localized demonstration projects, it seems clear that any federal involvement in providing a position determination service on land should encompass large areas and many users. It therefore becomes necessary to identify and categorize the varied uses and requirements for vehicle location systems in order to determine what manner of common service would be most beneficial with least cost to both the user and the government. Such a determination is the ultimate goal of this project; this is the first project interim report.

The material included in this report has been gathered from many sources. In particular, the contributions of Dr. Reuben Eaves and Mr. Thomas Sullivan in the area of transit operations are gratefully acknowledged.

METRIC CONVERSION FACTORS

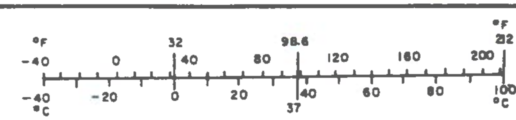
Approximate Conversions to Metric Measures

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

It has been recognized for several years that improved service and efficiency in the operation of transportation and transportation-related systems can be achieved through the ability to locate and monitor (track) a large number of vehicles in real time. These improvements are a consequence of reduced open channel calling and waiting time, increased confidence in the accuracy of reported positions, and a greatly reduced need for surveillance by street supervisors. The performance of the primary location function requires a complex combination of old and new equipment, together with the effective application of modern technology. System requirements are obviously widely different for different categories and modes of transport. In some applications, however, dedicated systems cannot be justified, and elements of commonality must be provided in order to assure a measure of benefit to all users at a cost that each can afford. It is the purpose of this interim report to identify potential users of terrestrial radiodetermination systems and to provide a basis for arriving at suitable performance requirements.

Before proceeding, however, it is appropriate to introduce and define certain terms that are frequently used in the context of land navigation.

The generic term, terrestrial radiodetermination (TRD), refers to the determination, on land or on inland waterways, of the geographical position of any entity by means of one or more techniques that involve electronic instrumentation. A particular technique may be active or passive, long-range or short-range, automatic or manual. If successive position determinations can be made at suitable intervals, then the time past a fixed point and the state of motion of the vehicle may also be included in the TRD subsystem data output.

TRD subsystems are often an integral part of plans to provide some measure of central control over a large number of dispersed vehicles. This extended function requires considerable additional equipment such as: 1) communication links to interface with a data bank; 2) a computer with software designed to analyze TRD data and produce outputs that are appropriate for command and control decisions, and 3) a display operated by the computer for the use of human controllers. When a large part of this total system is designed to operate without human intervention, it is termed an Automatic Vehicle Monitoring (AVM) system.* This report includes only the TRD subsystem and the various considerations directly associated with it.

Potential users of land navigation systems for the location and monitoring of vehicles may be classified according to the geographical range of their operations.

a. Vehicles operating in or near a city over an area whose maximum linear dimension does not exceed 35 miles (municipal police, transit buses, and taxis).

b. Vehicles operating between cities over an area whose maximum linear dimension is 40-500 miles (state police, emergency vehicles, and trucks).

c. Vehicles operating across state lines over an area whose maximum linear dimension is 600-3000 miles (transcontinental trucks, buses, and trains).

The vehicles included in each of these three categories operate in a similar environment but may have different requirements relative to the accuracy and resolution of the location system. Within a metropolitan area it may be necessary to know the position of a police car to within 100 feet; for buses in the same area 500 feet may suffice. In state-wide operations an accuracy of 1000 feet is probably adequate for most applications. Over the longer transcontinental routes, accuracies of 1/4-1 mile would serve to locate a vehicle within the range of more precise radio location

*More limited, but related functions that also make use of TRD subsystems are: Automatic Vehicle Location (AVL); Automatic Vehicle Identification (AVI); and Automatic Car Identification (ACI).

devices. Target densities and up-date intervals also tend to vary between users, but in most cases the shortest polling interval required for any single vehicle will be of the order of a few seconds.

Since each class of user has somewhat different operating requirements, the overall system functions of data acquisition, data processing, and data transmission must be adaptable to changing demands. The system should also have the potential to expand as its benefits are demonstrated and more users come on line. Certain general considerations follow from these basic features:

a. The system must operate reliably over long periods of time with minimum maintenance of vehicular equipment. Capital and operation costs must be acceptable to the users.

b. Since no single set of operating characteristics can satisfy all the technical and economic demands that may be made of a system, it must be flexible enough to accommodate the minimum needs of all potential users at a cost acceptable to each.

c. For maximum advantage the location system should be designed to be accessible to more than one user (fleet).

2. Applications of TRD

The need for terrestrial radiodetermination is not felt with equal urgency by all potential users. While the requirements of a metropolitan police department are real, realistic, and immediate, for taxis they are not so urgent. When applied to forest management operations, TRD would seem to be a desirable aid, but its benefits may not be worth the cost unless a very inexpensive system can be made available. It will therefore be noted that in the descriptions given below the level of detail is not uniform. In the first six sections (2.1-2.6) a number of the more likely users are identified and their particular applications described. For them TRD offers more than marginal benefits and could possibly be implemented in the foreseeable future. Section 2.7 contains a list of some additional applications for which the need may not be as great or for which the costs may heavily outweigh the anticipated benefits.

It should be emphasized that any conclusions drawn from this report are tentative and subject to modification as TRD technology improves and more information becomes available.

2.1 POLICE CAR FLEETS

Effective police operations depend primarily on the ability of patrol cars to respond quickly to emergency calls for service. Perhaps the single most important factor in reducing this response time is for the dispatcher to know which patrol cars are nearest the scene of the action and what they are doing. Such information can be most effectively provided through an automatic vehicle monitoring system that makes use of a suitable vehicle location technique and communicates relevant information to a central dispatcher who is in radio contact with the entire operational fleet. Such a system would be especially advantageous to fleets required to cover large areas or regions with irregular geographic features that tend to increase the travel time between the known location of the vehicle and the point where it is required.

Operations of this kind combined with the ability of police officers to obtain prompt assistance through an integral silent alarm, represent major benefits to a police department and its personnel. By reducing the time required to respond to a reported incident, the operational efficiency of the fleet is increased so that fewer patrol cars and police officers are needed. At the same time, the prompt appearance of a patrol car at the scene of an incident leads to a more positive public attitude toward all police operations involving the public safety. From the individual policeman's point of view, the ability to alert headquarters covertly and get prompt reinforcement at a time of need more than compensates whatever objections he may have toward automatic, centralized surveillance. Finally, the dispatcher's continuous knowledge of the location and status of all cars under his control eliminates most of the traffic incidental to voice location messages. This reduction in communication channel use has led to further improvements in the efficiency and promptitude of police services.

2.2 BUS SYSTEMS

The uses of terrestrial radiodetermination that have potential near-term value for bus operations in an urban area are: (1) improved schedule adherence and (2) increased driver and passenger security by means of a silent alarm. For the longer range future, important uses are the automatic collection of operational data and the dynamic rerouting of buses.

Urban bus operations are usually planned around fixed routes and fixed schedules with pre-determined headways. On actual routes, however, unpredictable environmental and human factors cause buses to depart from their schedules. Due to the inherent dynamic instability of bus headways, the initial, small schedule perturbations tend to be magnified, and transmitted throughout a route, which leads to overcrowding on some buses and an unduly small load factor on others. If the process is unchecked, the pairing and aggregation of buses is an inevitable consequence unless some technique is adopted to help maintain schedules and headways. The use of TRD to improve scheduling and schedule adherence results in better service, more efficient use of equipment, and reduced operating costs. These improvements and efficiencies are a consequence of reduced open channel calling and waiting time, increased confidence in the accuracy of reported positions, and a greatly reduced need for surveillance by street supervisors.

For this application, the actual position of the bus as determined by TRD is compared with the scheduled position--usually over a period of time. Appropriate command signals are issued to the bus either to continue its normal schedule or to make adjustments based on passenger loading conditions, traffic conditions, and the disposition of other buses. If some buses are behind schedule, for example, central dispatching might instruct a lightly loaded bus to pass the one ahead. Alternatively, central dispatching could send a reserve bus, or one deadheading in the opposite direction to fill a gap.

Driver and passenger security can be improved by installing a silent alarm, which is covertly activated by the driver. Knowing the position of the affected bus, the control center could summon emergency help. A demonstration with the Chicago Automatic Vehicle Monitoring System has shown this to be a useful device. (See Section 4.1.1.)

In most bus companies, operational data are now collected manually. By means of TRD, these data could be collected more efficiently and in a form suitable for analysis and processing by computers. For example, travel time between stops could be determined and problem areas pinpointed. More accurate schedules could be prepared. If passenger counting and reporting devices were installed on the buses, more efficient deployment could result.

Dynamic rerouting is a more advanced form of real-time control than schedule adherence in that buses could be diverted from a less-used part of the system to a burdened route as the need arises. Information about loading conditions and on-board passenger counts, along with the location data, would be needed. This process could be viewed as a departure from the conventional fixed-route, fixed-schedule operation because routes and schedules could be varied more easily.

For intercity buses, it does not appear at this time that TRD would be cost-effective. Mobile radios probably provide enough contact between the bus and the dispatcher. However, ways of using TRD effectively may be developed in the future, possibly in terms of improving passenger and cargo security or by improving the efficiency of terminal operations due to more accurate information about bus arrivals.

2.3 TAXI FLEETS

The basic motives for applying terrestrial radio determination to taxis are to improve service and increase their revenue producing mileage. The most direct way of doing this is to increase the efficiency of radio dispatching. TRD could be a useful means toward this end because it would enable taxi dispatchers to monitor a relatively large number of vehicles and assign each call for service to the nearest free vehicle. With the aid of a computer, TRD could further improve the service provided by large fleets by combining all the taxis in a metropolitan area into a single fleet for dispatching purposes. As reported in (1), managers of cab companies have indicated a willingness to merge their operations in order to exploit the full potential of computerized dispatching.*

In a TRD-aided computerized dispatching system, human operators would take the telephone calls and punch origin-destination data into the computer. From the TRD-collected data, the computer would select a vehicle to answer the request according to management policy, which might call for the nearest free vehicle. Transmission of the computer's decision could be by voice from the operator to the cab driver, or in a more sophisticated system, directly from the computer to a display installed in each vehicle. A TRD-aided system could also offer an estimate of the pickup time to the customer.

A computerized dispatching system using TRD could help to

*Reference numbers appear in parenthesis. Refer to Bibliography.

allay suspicions of dispatcher favoritism. Many drivers feel that dispatchers now give choice assignments to favorite drivers and that "kick-backs" are sometimes expected from them. Taxi company managers believe that computerized dispatching would give dispatchers less leeway for such manipulation and a completely automatic dispatching system would eliminate it entirely.

A TRD system could include a covert, silent alarm similar to that discussed in connection with buses. This would provide added protection for cab drivers. The well-publicized existence of such a device could itself be an effective deterrent to crimes that are committed on taxi drivers.

TRD-aided dispatching would facilitate the operation of pooled taxis and taxi-like services. Such services include small city transit, pooled taxis, dial-a-ride transit (DART), and transportation for the physically handicapped. In none of these applications does fixed route service meet the need. On the other hand, single fare door-to-door service is much too inefficient and expensive. The use of TRD-aided taxicab (or mini-bus) pools on flexible routes might permit sizable fare reductions at an acceptable level of service, thereby tapping a substantial new market. A major advantage of a TRD-aided computer dispatching system is that it could have the capacity to manage all three services at the same time: single fare taxis, pooled taxis, and DART.

2.4 TRACKED VEHICLES

2.4.1 Railroads

It has long been recognized that in order to increase the productivity of rail freight operations, the railroads must find more efficient ways of keeping their cars loaded and moving. This requires a degree of control over trains, locomotives, and cars that can be achieved only if accurate position and status information is available when needed. (See Section 4.3.3). Generally, such information is not available to anyone in a position to control train movements. Trains are assigned tasks and given schedules, but whether these assignments and schedules are being carried out effectively is often a matter of conjecture. If railroads are to exercise the necessary control over their engines and trains, they will need to have some form of automatic location system whose resolution and accuracy are adequate for both terminal and road operations.

Terminal operations are characterized by short distances, slow speeds with frequent stops, and complex track geometries. Resolution and accuracy requirements are severe if one must discriminate and control individual engines in all possible configurations. Road operations, on the other hand, are characterized by relatively high speeds and long distances, but involve fewer tracks and simpler geometries. Since the density of trains is low, resolution and accuracy requirements are not so stringent.

The use of automatic car location equipment would enable yardmasters and dispatchers to observe and control engine and train movements with a precision that is not otherwise possible. If the information thus made available is fed to a computer-driven display, significant improvements in the efficiency and safety of railroad operations should be possible.

2.4.2 Urban Tracked Vehicles

Many of the requirements for the location of conventional rapid transit vehicles in an urban environment are similar to those of long-haul railroads. Most transit trains run at moderate speeds, with adequate headways, and their signalling systems use much the same hardware organized in similar ways. Unique requirements may arise, however, whenever conventional systems run underground or when non-conventional (automated) systems operate with headways that are shorter than the minimum safe stopping distance of the train. During tunnel operation, advanced vehicle location techniques that depend on radio propagation (LORAN, trilateration) would become inoperative, and some version of proximity or dead reckoning would have to be used. In current practice, train location is based on track-circuits (proximity by contact) whose accuracy is limited by the length of a fixed/or moveable block of track. The simple information derived in this way is used to set a variety of train control signals.

In a dense system with short headways, track circuits, if at all feasible, would tend to become unreliable. Under such circumstances, non-contacting proximity techniques are more attractive and have generally been based on continuous inductive circuits laid between the tracks. A number of designs that use this technique have been developed in Europe and Japan and offer high reliability and accuracy. The unavoidable complexity is transferred to the wayside communications system. Techniques of this kind provide data from which both the location and the speed of a tracked vehicle can be derived to a high degree of accuracy and used for precise control of an urban rapid transit system.

2.5 TRUCKS

One possible use of TRD in the trucking industry is to track the movement of a truck from its point of origin to its destination. This function would be especially beneficial for armored cars and for trucks carrying valuable or highly dangerous cargo, such as radioactive materials. By monitoring the positions of these trucks in real-time at a control center, security personnel could maintain a clear picture of the whereabouts of each cargo and could intervene quickly in the event of a suspected theft or highjacking. This use of TRD would be beneficial for both intracity and intercity trucking. With TRD, it might even be possible to monitor the individual containers on a truck, so that the control center would be alerted by an attempt to tamper with its locks.

A significant contribution to truck security has been made recently by an electronic surveillance device developed with the sponsorship of the U.S. Department of Transportation (3). In this system, a transponder with a unique address is installed on the roof of a truck before departure. If at some later time it should become necessary to locate that truck, a police helicopter, approaching within a few miles of the truck whose approximate location may be known, sends out a signal which addresses that particular transponder and triggers a reply. The receiver in the helicopter determines that the reply was made and the direction from which the received signal came. Police in the helicopter are thereby able to home-in on the desired truck. This system is intended primarily to counteract truck hijacking. It can be viewed as an all-weather, day-night system which extends the current police helicopter surveillance technique of searching for trucks by visually observing their roof-top markings.

It is often suggested that TRD could be used by parcel delivery services to reduce response times by assigning the nearest truck to incoming service requests. Some companies offering delivery service do not now feel the need to undergo the degree of automation and to support the costs associated with TRD (1). Perhaps mobile radios alone would be sufficient to enable a control center to dispatch vehicles efficiently, if manual procedures prove inadequate.

2.6 DATA COLLECTION

2.6.1 National Weather Service

The Upper Air Stations of the National Weather Service launch between 70,000 and 100,000 radiosonde balloons per year for the purpose of measuring a number of atmospheric parameters as functions of altitude. Each of these balloons is located and tracked up to an altitude of 90-100,000 feet at ground ranges up to 75-90 miles by means of a passive, ground-based radio theodolite and an accurate pressure altitude provided by instruments on the balloon.

The radio theodolite operates on a radio frequency signal at 1680 MHz transmitted from each balloon. This signal is received by a pair of radio antennas that can be pointed accurately in altitude and azimuth to the distant radio source. Pressure altitudes and angles are combined to give successive positions in space, which are used to compute wind speed and direction as a function of height. The wind velocity measurements made in this way have an accuracy of 3-5 knots in speed and ± 5 degrees in direction.

This large-scale program for collecting meteorological data operates on a daily basis throughout the continental United States.

2.6.2 Census Bureau

The Census Bureau has carried out limited demonstrations of the use of LORAN-C on land for locating housing units in rural areas. The bureau's requirement is to determine the geographic coordinates corresponding to each mailing address in areas where either streets or accurate street maps do not exist. These coordinate locations serve primarily to improve the census data base, but will also make it possible to send enumerators to the physical location of a housing unit whenever a re-survey or a new census is to be carried out. In rural areas the repeatability requirement need be no better than 150 to 200 feet and has been easily achieved with current LORAN-C equipment.

A full-scale field test of this approach is scheduled for the winter of 1976-1977.

2.7 OTHER POTENTIAL USERS

In this section, a number of other possible uses of TRD are identified. Most of these applications are judged to be realistic but perhaps less significant and more speculative than those discussed above. Still other possibilities have been rejected as unrealistic. It is to be expected, however, that once a TRD system is installed, new users will appear that have not been identified here and that were not planned for explicitly in designing the system.

Ships moving over inland waterways would benefit from the use of a highly accurate navigation system. This application of TRD, though strictly one of water navigation, is similar to land navigation in that the same techniques can be used. It is therefore included in this study. On navigable rivers and lakes automatic location techniques would permit vessel operations during inclement weather and through some part of a winter season of ice-covered channels. One example is the current Coast Guard project to examine the feasibility of using a local Loran-C chain to navigate ore carriers in the St. Marys River (between Lake Superior and Lake Huron). Another is the Department of Commerce study to develop a precise radar navigation system to be used during the winter season on the Great Lakes.

A forest may be viewed as analogous to a body of water or of airspace in that no permanent, identifiable objects are available for reference points. In such circumstances radiolocation techniques might prove useful for obtaining position determinations of value to the Department of Agriculture in forest fire control, to chart the location of a fire and to guide fire-fighting crews. A further application is in forest survey operations to lay out a road; to provide location information to timber cruisers, geologists, and wildlife managers in resource surveys; and for aerial mapping. A third possibility is for insect and disease control to map insect infestations, to lay out spray blocks, and to locate sample trees for insect spray assessment.

Both the Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) have established a requirement for the centralized detection and location of accidents. One aspect of this requirement is related to the objectives of data collection, highway safety, and highway planning. It depends on the ability to identify the location, on roads and streets, where an accident has occurred. Another aspect is to enable appropriate real-time responses to be made by ambulances or other emergency vehicles. TRD systems would be of use for both of these functions. At present, the NHTSA is establishing requirements and specifications for an accident detection and location system.

The Federal Highway Administration (FHWA) has a need to identify the locations of roads and streets where data observations are made, in order to coordinate and integrate information concerning highway safety, highway planning, and highway maintenance. If a computer is to be used for processing the data, it is important to have a common location system within a state and possibly in all the states. TRD systems with wide area coverage could meet these needs.

3. REQUIREMENTS

Since all aspects of vehicle location and monitoring are closely inter-related, detailed statements of TRD user requirements cannot be made without reference to a particular system design. On the one hand, the parameters of the system must be determined by the operational use to which the system will be put. On the other hand, they are limited by the location technique to be employed. Moreover, all of these factors may vary considerably, not only between categories of users, but even within a single category. For example, different police departments or bus companies may have differing requirements due to coverage geometry, numbers of vehicles, and local environmental factors.

The primary parameter to be considered in specifying the operational requirements of a land location system is the accuracy of its position determinations. For moving vehicles, this accuracy requirement involves not only the precision of static position determinations, which is a characteristic of the location technique, but also the time interval between updates, which is a system parameter. Furthermore, since the update interval depends on additional system parameters such as the number of vehicles to be polled, the maximum vehicle speed, and the service to be performed, a reasonable specification of the required accuracy is possible only after some degree of system definition has been achieved.

An example of the inter-relationship between system parameters and location technique can be found in the contrast between the demonstration AVM systems currently employed by the St. Louis Police Department and proposed for Los Angeles. The St. Louis system combines dead reckoning (heading and distance traveled) with map-matching. It was designed with police security in mind. A prime requirement, therefore, was that the location of every vehicle should always be known with an accuracy no worse than the average length of a city block, i.e., about 200 feet. At a maximum speed of 50 ft./sec (about 34 mph), the minimum update rate for the required accuracy is one position determination every 4 seconds. To provide some redundancy, as well as to allow for cornering, the actual rate was set at one every 2 seconds. With 20 vehicles in the system the interrogation-response cycle on a time-shared basis could not exceed 100 milliseconds per vehicle. In Los Angeles, the system has been planned primarily for buses. With stops, their average speed is no more than 20 ft./sec. (about 14 mph). Thus an accuracy of 600 feet, or about two city blocks, can be achieved with a 30 second update interval. This rate was deemed adequate for the purposes of the Los Angeles demonstration and, with 200 buses, leads to an interrogation-response cycle time of 150 milliseconds, which is not much different from the St. Louis requirement for this parameter.

As with the update rate, other system characteristics, although important, cannot be specified in a general way since they are highly dependent on the system design and the needs of a particular user. Some of these characteristics are: 1) fixed or random routes, 2) total number of vehicles to be monitored, 3) area of coverage, (4) position resolution, and (5) additional communication requirements. Nevertheless, reasonable estimates of required accuracies for a number of potential TRD users can be made and are presented in Table 3-1.

TABLE 3-1 ESTIMATES OF REQUIRED ACCURACIES

User	Estimated Position Location Accuracy
1. Police	
a. Dispatching	
i. Urban and high density areas	200 feet
ii. Suburban and medium density areas	750 feet
iii. State police and low density areas	1000 feet
b. Officer-on-foot	<100 feet
2. Urban buses	300 to 500 feet
3. Taxis	1000 feet
4. Tracked vehicles	
a. Railroads	
i. Terminal and marshalling yards	50 feet
ii. Main line operations	2000 feet
b. Urban transit	
i. Low density	1000 feet
ii. High density	<25 feet
5. Trucks (Security for high value and dangerous cargoes)	<1 mile (coarse determination)
6. Medical services	1000 feet
7. Other	
Shipping on St. Marys River	25 feet

4. DEMONSTRATION SYSTEMS

This section contains brief descriptions of a number of TRD and TRD-related systems which have been selected on the basis that they include an automatic location function in one form or another, and have been or soon will be deployed for test and evaluation. These criteria exclude the multitude of two-way radio links currently being used in police cars, taxis, trucks, buses, and other vehicles. In some cases, indeed, such two-way radios may be able to transmit digital messages containing ID information and/or emergency alarm signals (as with METROCOM), but unless an electronically derived position location is continuously available for transmission, the essential element of a TRD system is considered to be absent. Similarly, some location techniques that have been thoroughly discussed on paper have nevertheless been omitted because no plans are being made for their implementation.

4.1 OPERATING SYSTEMS

4.1.1 Chicago Transit

The Chicago Transit Authority uses a proximity system for automatically monitoring its bus fleet. Low power radio transmitters, called signposts, are located at various points along bus routes and continuously transmit a 10-bit identification signal which is detected by a receiver on the bus when it is in the immediate vicinity of the transmitter. The bus receiver stores this identification number in its memory until the next signpost is encountered and supplies a new number to be stored in place of the old one. When the bus passes out of the range of a signpost (nominally 200 feet), an elapsed time generator, which was reset when the bus entered the range of the signpost, is started. This device delivers a pulse every 12 seconds to a counter, which stores the number of pulses generated since the last signpost was passed. While the bus is within range of the signpost signal, the pulse counter is switched off and reset to zero.

Sequential interrogation of approximately 12 buses per second is performed by transmitting a coded signal from central control. One base-station radio transmitter, which covers the entire metropolitan area, transmits a signal which is received by all buses in the system. The bus receivers decode the signal and compare the transmitted ID to the bus ID. The bus being addressed by the control center then transmits its location information, which consists of the identification of the last signpost and the number of timing pulses generated outside the range of that signpost. The bus identification number consists of a garage number, prewired into the bus, and a run number which the operator enters into the equipment by means of thumb wheel switches. Since the range of the mobile transmitter on a bus is less than that of the base-station transmitter, a number of repeater stations are located throughout the city to receive the bus signals and relay the information over telephone lines to the control center.

In addition to vehicle monitoring, other modes of operation are possible. Ordinary voice communication between bus drivers and the central dispatcher may be used to transfer information about schedule problems, vehicle status, traffic, and other conditions. In the event of an emergency such as an injured passenger, accident, or hold-up, the operator may activate an alarm signal by means of a covert switch.

4.1.2 Hamburg Transit

Since 1969, a bus monitoring and location system has been fully operational in Hamburg on 24 routes served by 1152 buses. Vehicle location is accomplished through low power RF proximity detectors spaced at intervals of 5-10 kilometers. Distance between proximity signposts is interpolated by an odometer which counts in discrete hectometer (100 meter) units. Bus location and passenger counts are requested by and relayed to central via two duplex radio channels in the 150 MHz region, and information obtained through this data link is updated at 2-minute intervals. A radio telephone link with the buses is also provided to request additional information and to give control commands.

The bus locating system described above automatically determines the real-time positions of all buses in service and furnishes that information to a central data processing unit. When schedule delays or headway deviations are found, they are displayed to a dispatcher who takes action to remedy the situation through direct communication with drivers. In practice, the system has cut headway deviations by about 50% as against comparable uncontrolled routes. With this degree of control, the quality of the bus service has improved to the point that even at major interchanges during the rush hours, passengers have to wait no longer than five minutes for a bus. At the same time, outdoor supervision has been reduced to only three motorized inspectors and the reserve bus fleet has been cut by 25 buses, or roughly 4 percent.

4.1.3 London Transit

London Transport efforts in AVM began in 1969 with the installation of an inverse proximity system on seven bus routes. Buses are equipped with coded reflective strips, so that they may be identified as they pass fixed optical sensors located at intervals of about three miles. The passage of buses is communicated to central via land line. In 1972, London Transport installed a more successful dead-reckoning TRD system on one route of 44 buses. Bus location is measured by an odometer reading of the distance travelled from the start of the run. Odometer readings, which are accurate to within 1% through careful recalibration, are transmitted to central at 5 second intervals via two channels at 107 MHz and 140 MHz. The data channel is interrupted for controller-driven voice communication as required.

4.1.4 Paris Transit

In 1973, the Paris Transportation Authority (RATP) introduced an experimental AVM system on a single bus route serviced by 35 buses. The selected route runs from the center of the city to a terminus 10 kilometers to the west. The purpose of the experiment was to determine whether the use of an automatic vehicle location and monitoring system would improve the regularity of the bus service.

Automatic bus location is started by the bus driver at the beginning of his run when he keys his destination code into the vehicle memory storage. This action sets all the distance counters in the bus to zero, and makes available to the central computer a message containing the destination data. The location of the bus relative to subsequent station stops is measured by an electric odometer. Whenever the bus comes to a stop during its progress from one station to the next, the total distance traversed is stored in a second digital message and transmitted on demand to the central computer. If the message also contains a "door opened" bit, the accompanying distance code is compared with pre-stored distances for each station. When one of these numbers agrees with the odometer distance to within the precision of measurement (about 4 meters), the odometer is reset to the correct value for that station and the process is repeated.

Bus location information together with data on the numbers of passengers entering and leaving at each station are coded into digital messages. Following interrogation of the vehicle concerned, the current message is transmitted over a half-duplex radio channel at 450 MHz to a relay station, thence by telephone lines to the control center. The interrogation cycle for all 35 buses is 8-10 seconds, each bus being individually addressed in turn during the cycle. The dispatcher regulates individual buses by means of digital and voice channels to each bus.

If the system succeeds in improving the regularity of bus service, it will be extended to 8 other RATP bus routes.

4.1.5 Zurich Transit

The city of Zurich has installed a modern computer-controlled radio communications system for its public transportation vehicles. TRD is included as part of this system. It uses the proximity (signpost) technique augmented by odometer readings. No additional information about this system was available to the authors at the time of writing.

4.1.6 St. Marys River Navigation System

A Loran-C "mini-chain" has been installed by the U.S. Coast Guard in an area of the St. Marys River between Lake Superior and Lake Huron in Michigan (a distance of approximately 50 miles). The chain consists of four low-power transmitters (a master station and three secondaries in a diamond shaped configuration) and a service area monitor station. This system will be used to guide ore carriers through the St. Marys River and demonstrate the use of Loran-C in restricted waterways.

A typical vessel, for which the system is being designed, is a Great Lakes ore carrier of 1000 foot length and 100 foot beam, operating at a speed between 4 and 17 miles per hour. During periods of reduced visibility, these vessels must be safely guided through the St. Marys channel whose width varies from 275 feet to over 2000 feet along a trackline that is characterized by numerous abrupt changes of direction. To meet this objective the Coast Guard has fixed the system accuracy requirement as a 95% probability that the maximum crosstrack error at the receiving antenna will not exceed 25 feet. Position fixes are to be updated at least once every 5 seconds.

To help meet the stated accuracy requirement the system is to be calibrated within the coverage area at a series of approximately ten surveyed points along the river. Intermediate calibrations will be achieved by interpolation. The system will be provided with a computer-driven display which will show the desired trackline, the vessel's position and attitude, its velocity and velocity components relative to the trackline, and other necessary data. A two month demonstration of the precision guidance system on typical user vessels is scheduled for 1 April to 30 May, 1976.

4.1.7 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. The program involved the installation of dead reckoning sensors on all 25 patrol cars in one police precinct of the city and the design and construction of a data processing and control center at police headquarters. 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 station, where the data are decoded and processed for presentation on a map-matching display.

Dead-reckoning systems accumulate errors and need occasional resetting in order to maintain their accuracy. The St. Louis system is no exception and may be set or reset in one of two ways: 1) independently by the driver of the vehicle, or 2) cooperatively, by the driver 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 a digital code box transmits the location ID to the computer. During a patrol, however, the dispatcher may observe that re-initialization 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% of the time.

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 in a uniform, computer-aided monitoring and dispatching system.

4.1.8 Montclair Police

Montclair, California, is a small city with a population of about 27,000 people, occupying a geographical area about five square miles in extent. Within the limits of the city, the Montclair Police Department operates twelve patrol cars and four other police vehicles. With funding support from LEAA, all sixteen of these vehicles have been equipped to participate in an automatic vehicle location system that provides data to a computer-aided dispatching service.

Vehicle location is accomplished by a proximity sensing technique that makes use of active signposts, each of which broadcasts a digitally coded location ID which may be picked up by the receiver in any vehicle that comes within its range. The vehicle transmitter, in turn, sends this location data together with its own ID to the control center where the information is automatically decoded and displayed to the police dispatcher. In Montclair, wayside emitters (signposts) are mounted on convenient poles and standards at 50 locations within the city, including all major street intersections. The average distance between signposts is about one every 1/3 mile, which provides a location accuracy of approximately 1/4 mile. With an average update rate of about 25 seconds, sufficient information is available to the dispatcher to affect a significant improvement in the over-all efficiency of the Montclair police car operations.

Additional features of the Montclair system have helped to increase its acceptability to police personnel. They are:

1) the ability to transmit digital status messages between dispatcher and vehicle by means of keyboard push-buttons.
2) the provision of an emergency signalling unit, about the size of a cigarette pack, attached to the Officer's belt. When activated by a concealed push-button, the unit transmits an emergency message

to the vehicle which relays that message to the control center, where lights and buzzers alert the dispatcher.

The automatic vehicle location system installed and demonstrated at Montclair, California, has increased from 60% to 83% the proportion of events responded to in times less than 4 minutes.

4.2 PROPOSED SYSTEMS

4.2.1 Los Angeles Transit and Police

The Urban Mass Transportation Administration is currently sponsoring a program under the management of the Transportation Systems Center to demonstrate a multi-user Automatic Vehicle Monitoring System in the Los Angeles area. The purpose of the system is to supply vehicle information to a central dispatch station and to return control and advisory messages based on this information to the vehicles. The program differs from other efforts in that it is a multi-user demonstration designed to provide quantitative measurement of the benefits of such a system.

The principal participant in the demonstration is the bus company serving the Greater Los Angeles area, the Southern California Rapid Transit District (SCRTD). The routes selected for AVM coverage include approximately 200 of the 2,300 buses in the SCRTD system. In addition to this fixed-route coverage, a six square mile area in the Los Angeles central business district has been selected to demonstrate the random-route coverage necessary in a multi-user AVM system. Up to 25 auxiliary transit vehicles (service vehicles, supervisor vehicles) and 25 Los Angeles police cars will be equipped for AVM coverage within the random-route region.

The system design is based on performance and functional specifications alone, so that all technological approaches may be considered. In particular, the performance requirement for location accuracy is that 95% of all position determinations must be within 300 feet of the correct location and 99.5% must be within 450 feet. Furthermore, the location information for each vehicle must be updated at least once every 40 seconds, with a design goal of one update per vehicle every 25 seconds. Clearly, some technologies may have difficulty meeting these requirements, but none is precluded from consideration.

4.2.2 Los Angeles Cargo Security

With the assistance of a grant from LEAA a pilot program to evaluate the use of TRD in a Truck Cargo Security System will be conducted in the vicinity of Los Angeles, California. Transcon, Inc., a carrier operating 100 pickup and delivery vehicles in the Los Angeles area will supply 5 trucks to participate in the tests, which are scheduled to begin about February 1, 1976. Each truck will be instrumented, and the tests will be conducted along 5 different truck routes within a 480 square mile area. For these tests the stated cargo security requirement is a position location accuracy of 600 feet. However, the system contractor has set for himself a TRD design goal of 300 feet. Since one of the test objectives is to determine the required update rate, this parameter will be a variable of the system. In addition to the location data, digital messages sent to the central station will include such status information as: 1) whether the cargo door is closed; 2) whether anyone is moving about in the cargo hold; and 3) whether any locks are being tampered with.

Two TRD techniques have been selected for evaluation:

1) A proximity technique,
2) An AM phase lock technique.

The proximity technique uses HF band radio frequency signposts which continuously radiate coded signals containing their location coordinates. When detected by a vehicle receiver and correctly decoded, the identification code (ID) of the most recently passed signpost is stored in one of three registers, depending on signal level. A processing register makes use of changes in the signpost signal levels to compute the direction of vehicle motion. These data are accumulated in an output register for transmission to the central data processor. The decoded vehicle transmissions are translated by the central processor from signpost ID and ID change into map coordinates for the vehicle. The vehicle trajectory is plotted on a computer generated CRT street map of the fleet deployment area.

Signpost spacing is determined by the geographical separation of street intersections and the desired location accuracy. For representative installations a net RMS error between 100 and 200 feet has been calculated. Using a dedicated FM duplex channel, 200 vehicles can be polled in 8.7 seconds.

The AM Phase Lock System is a trilateration system which makes use of signals from three commercial AM broadcast stations. The system requires that the three AM broadcast transmitters be situated in suitable geographic locations and be phase locked to a stable frequency source. Three AM stations in the Los Angeles area are participating in the pilot test program. One has been equipped with a rubidium standard, and is designated as the master station. The other two stations have been equipped with electronics which slave them to the master station. The vehicle receives the AM broadcast signals from the three stations. Vehicle position is determined by measuring the phase difference between two station pairs. The vehicle is then located at the intersection of the two resulting hyperbolic lines of position. The phase comparison between the three stations is done by circuitry on board the vehicle and the position of the vehicle is determined at the central station. Because of AM signal propagation problems in certain areas of a city such as tunnels and highway underpasses, it is necessary to augment this AM Phase Lock System with signposts for position updating in those areas.

4.2.3 Dallas Police

With the assistance of a grant from LEAA, the Dallas, Texas Police Department has contracted for the fabrication and installation of an AVM system that makes use of a pulse-ranging beacon-trilateration technique for the TRD sub-system. The initial installation will include 43 vehicles patrolling the 78 square mile area that constitutes the Department's Southwest Patrol District. However, the system will be designed with the potential for expansion to include the entire Dallas police fleet of 700 vehicles covering all 300 square miles of the city. Within this defined area of coverage, the TRD performance requirement is a location accuracy for stationary vehicles of 75 feet at a confidence level of 95%. The maximum time interval between location updates for each vehicle is specified to be 10 seconds, subject to the condition that there shall be at least one update for every 300 feet travelled by any one vehicle.

The Dallas AVM system will be integrated with the city's existing Computer Assisted Dispatch System (CADS). It will have two modes of operation. In one mode it will drive a CRT display which will monitor in real-time the patrol coverage in the District for the use of the dispatcher. In the second mode it will provide each officer with the ability to request assistance by using an emergency signalling device either in the car or on his person. The activation of either device will cause an appropriate digital emergency signal to be sent to the base station where both audio and visual means will be employed to alert the dispatcher.

The TRD equipment that is being fabricated for this application consists of a central transmitting station, 7 receiving stations distributed over the District and 43 transponders, one in each vehicle. The transmitter initiates the synchronous interrogation of each transponder, which replies with a coded digital data pulse sequence. The leading edge of the first pulse is used to determine a time-of-arrival at each receiving station from which time-differences and intersecting lines of position may be computed. In order to achieve the required accuracy the pulse rise-times must be short and the system bandwidth relatively wide. To this end the FCC has allocated the frequency bands 904-912 MHz and 918-926 MHz to AVM operations that use pulse-ranging for high-accuracy terrestrial radio determinations.

4.3 RELATED SYSTEMS

4.3.1 San Diego Transit

The San Diego Transit Corporation has been using a relatively advanced communication system on their buses since 1972. This system, called "METROCOM", does not include TRD, but is basically a mobile two-way radio system which gives management direct and constant contact with all buses in the fleet, and greatly improves responses to any interruption in service. All 300 vehicles in the fleet are equipped with METROCOM.

The METROCOM system provides voice communications with all vehicles. It has a data communications capability which furnishes the dispatcher with automatic bus identification and allows for digital communication with buses on an individual basis to maintain schedule adherence. Two alarm systems are included: One is an emergency silent alarm which allows a driver to call for aid without being observed. This is particularly helpful in case of robbery, vandalism or other detrimental action. The other is a malfunction warning system consisting of a bus sensor alarm, which automatically reports to the dispatcher the number of any bus which has developed low oil pressure, overheating, low air pressure, or tampering with emergency doors.

One of the principal advantages of San Diego's METROCOM system is its efficiency of operation. Voice communication with drivers can be obtained by using the selective calling feature, whereby a specific bus can be contacted by the dispatcher without disturbing the other buses. It also has the capability for communication from driver to driver and from dispatcher to all buses. In addition, on driver-initiated calls, bus identification is transmitted automatically (digitally) thereby saving air time.

Similar digital radio systems with sensor alarms have been installed or are being planned for as many as 20 public bus companies throughout the United States. Fleet sizes vary from 32 buses in Gardena, Calif., to 2800 buses in Washington, D.C. A few transit properties are also planning to include automatic bus location and/or polling features in their radio systems.

The METROCOM system has also been installed in the 160 bus fleet of Syracuse, New York. It is reported that this bus company has plans to add the automatic bus location capability in the future.

Other commercially manufactured systems are currently available which are similar to METROCOM.

4.3.2 New York/New Jersey Bus Identification

An important demonstration project has been conducted recently by the Port Authority of New York and New Jersey dealing specifically with buses (4). The project has been funded mainly by the U.S. Department of Transportation. One of its principal objectives was to evaluate a number of automatic vehicle identification (AVI) systems and determine whether they could be used to record toll charges for moving buses. The demonstration was carried out at the Lincoln Tunnel.

AVI technology permits the fully automatic and unique identification of vehicles. Since this is done by a sensor at a known location, the process becomes very similar to TRD. Conversely, some of the techniques used in TRD could be used for AVI. Thus the two fields of TRD and AVI are related and sometimes overlap.

Four systems, provided by different manufacturers, were tested. All of them are inverse proximity systems that use a low-power, radio frequency transponder mounted on the bus, and a roadside interrogator which detects signals from the transponder. Coded information is transmitted from the transponder to the roadside interrogator through a roadway loop. The power for transmitting this information for three of the systems comes from a magnetic field generated in the loop which in turn induces a voltage in the transponder as the bus passes over the loop. The fourth system has a transponder powered by a self-contained battery. The information gathered by roadside interrogators is transmitted over leased telephone lines to a central computer. Tests were run on forty buses which had all four transponders mounted on them.

The conclusion drawn from this demonstration was that AVI systems do perform in an acceptable manner. As a result of these tests, the Port Authority is proceeding to implement a pilot AVI toll system and has ordered 100 transponders and two interrogators from one of the four manufacturers.

4.3.3 Railroad Car Identification

Keeping track of freight cars is a problem that has plagued the railroad industry for a long time. If the location of freight cars were known at all times, the efficiency and profitability of the railroad companies could be increased by making better use of these cars. Such utilization is admittedly low at present. Automatic Car Identification (ACI) is intended to provide to management an up-to-the minute record of the location of its freight cars. By doing this automatically, ACI will be an integral part of the effort to bring more automation to the railroad industry.

The ACI system presently being used by the railroad industry is an optical one and consists of three parts: a color coded retroflective label mounted on the side of each car; a scanner mounted on a pole at trackside; and a decoder, located a short distance from the scanner, which converts analog signals to a digital format. The digital output of the decoder is transmitted to a control center for processing by a computer.

To date, about 97% of the freight cars in the U.S. have been labeled, but only a small number of scanner systems have been installed. There is an overall reluctance on the part of the railroad industry to participate actively in the ACI program, perhaps because they are not convinced that the benefit/cost ratio is to their advantage. One problem encountered with the optical system is the high number of errors that occur in reading the labels and identifying the cars. The main reason for this is label deterioration, one factor being the dirt, snow, or ice that collects on the label. For this reason, it has been suggested that radio transmission techniques be used instead. An obvious technique that comes to mind is to use a microwave system analogous to the optical system, where a transponder would replace the label. One manufacturer has developed such a system. Some other TRD techniques might also be applicable.

The ACI project does not seem to have a clear direction at this time, but the idea of keeping track of all freight cars is sound and hence ACI could be a potential user of a TRD system.

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